Design and Consulting Services Group

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ILVK Upper Colorado River Irrigation and Restoration Assessment Phase 1: K.B. Ditch to Blue River.

ILVK Upper Colorado River

Irrigation and Restoration Assessment Phase 1:

K.B. Ditch to Blue River.

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1 Introduction

AECOM contracted with Bruchez and Sons, LLC to perform an assessment of the irrigation and river issues along a 10 mile reach of the Colorado River outside Kremmling. The work is being performed for and partially funded by a group of neighboring ranch owners: Reeder Creek Ranch, Shepardsbend Ranch, the Peterson Ranch, Riverside Ranch, and the McElroy Ranch. Additional funding was provided by a Colorado Water Conservation Board, Colorado Basin Roundtable grant for $50,000. This report presents the research, data and findings of this study.

1.1 Project Purpose

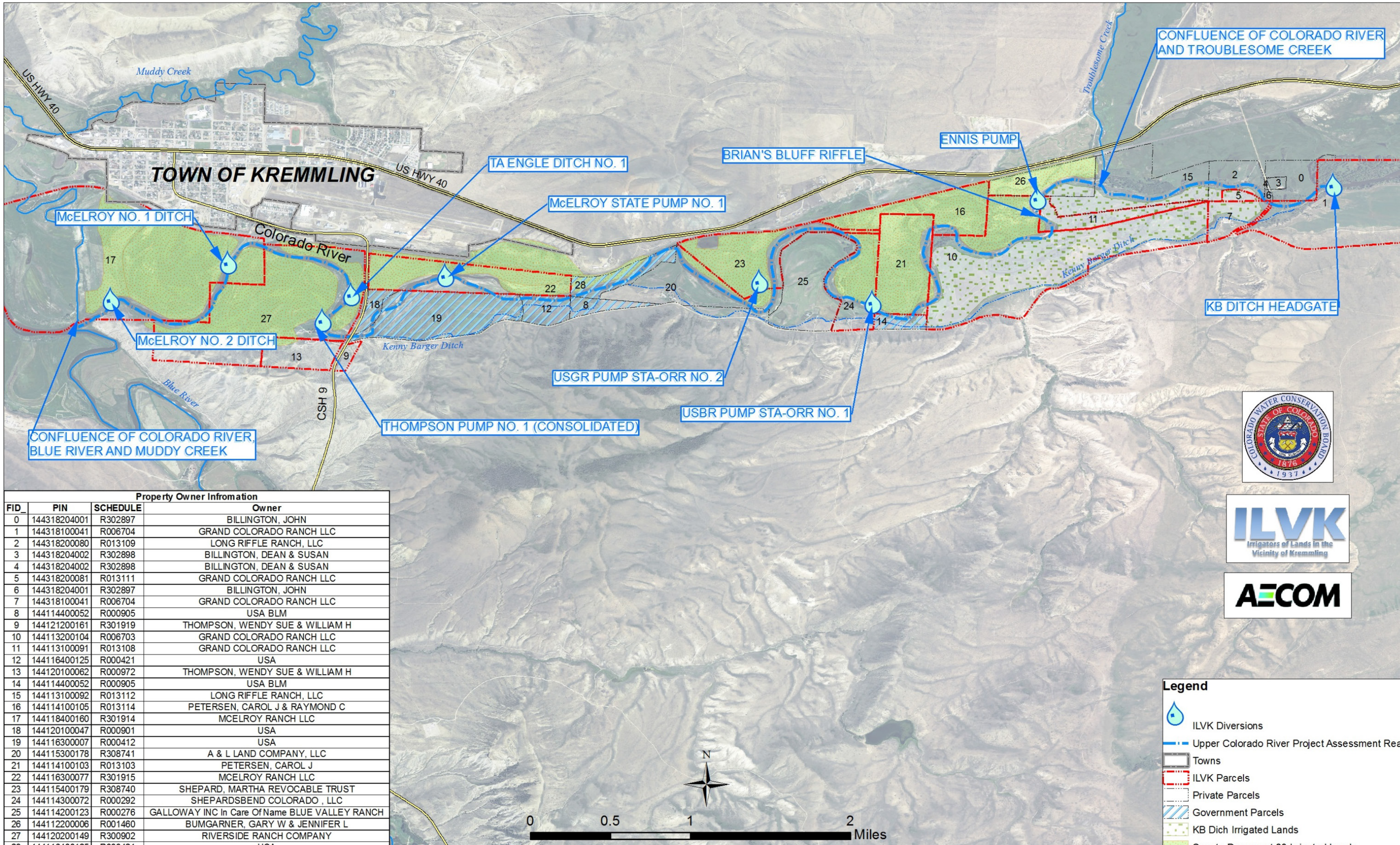
This project investigates the driving forces behind a number of issues related to the Colorado River outside of Kremmling, CO. These issues include failing diversion structures, loss of agricultural infrastructure and lands due to stream bank erosion, and loss of aquatic habitat. The goal of the project is to develop a better understanding of the Colorado River through this reach and the causes behind the issues observed and provide conceptual plans and costs for solutions.

1.2 History

Transbasin diversions have impacted the Colorado River for over 100 years. Senate Document 80, which authorized the Colorado-Big Thompson (CBT) project in 1937, included a requirement that an "adequate system…shall be provided for the irrigation of lands in the vicinity of Kremmling...and the installation…shall be a part of this project." This was done in response to concerns voiced by Grand County irrigators that low water flows, which are caused by trans-mountain water diversions, create a lack of positive pressure in ditch heads and reduced natural flood irrigation and sub-irrigation making the irrigation systems harder and more labor intensive to operate. Pump stations were authorised and construrcted as part of Senate Document 80. The ranches and farms subsequently filed for water rights on these sturtcures. These rights have have become crucial to the success of ranching along this reach of the Colorado River despite continued operational issues with the pumps. After negotiation with Northern Colorado Water Conservancy District (Northern), the Ranchers reached a settlement regarding the continued operation and maintenance of the Senate Document 80 irrigation pumps in which the Ranchers have agreed to own and maintain the pumps.

These Senate Document 80 Ranches are located along the Colorado River between the headgate of the Kenny-Barger Ditch (Kinney Barriger Ditch or KB Ditch), and the entrance to Gore Canyon, downstream of the Blue River Confluence. Five of the Senate Document 80 pumpers have continued to work together to develop sustainable solutions to a variety of issues related to their irrigation systems and the Colorado River. This group, called the ILVK (Irrigators of Land in the Vicinity of Kremmling), has begun to address significant long term issues with their irrigation infrastructure. Additionally, they have commited a portion of the settlemet to fund this study along with the support of the Colorado Water Conservation District, Colorado Basin Roundtable Grant Program. The ILVK consists of the owners of The McElroy, Riverside, Shepardsbend, Peterson and Reeder Creek Ranches.

ILVK Project Location Map



Property Owner Infromation

FID_	PIN	SCHEDULE	Owner
0	144318204001	R302897	BILLINGTON, JOHN
1	144318100041	R006704	GRAND COLORADO RANCH LLC
2	144318200080	R013109	LONG RIFFLE RANCH, LLC
3	144318204002	R302898	BILLINGTON, DEAN & SUSAN
4	144318204002	R302898	BILLINGTON, DEAN & SUSAN
5	144318200081	R013111	GRAND COLORADO RANCH LLC
6	144318204001	R302897	BILLINGTON, JOHN
7	144318100041	R006704	GRAND COLORADO RANCH LLC
8	144114400052	R000905	USA BLM
9	144121200161	R301919	THOMPSON, WENDY SUE & WILLIAM H
10	144113200104	R006703	GRAND COLORADO RANCH LLC
11	144113100091	R013108	GRAND COLORADO RANCH LLC
12	144116400125	R000421	USA
13	144120100062	R000972	THOMPSON, WENDY SUE & WILLIAM H
14	144114400052	R000905	USA BLM
15	144113100092	R013112	LONG RIFFLE RANCH, LLC
16	144114100105	R013114	PETERSEN, CAROL J & RAYMOND C
17	144118400160	R301914	MCELROY RANCH LLC
18	144120100047	R000901	USA
19	144116300007	R000412	USA
20	144115300178	R308741	A & L LAND COMPANY, LLC
21	144114100103	R013103	PETERSEN, CAROL J
22	144116300077	R301915	MCELROY RANCH LLC
23	144115400179	R308740	SHEPARD, MARTHA REVOCABLE TRUST
24	144114300072	R000292	SHEPARDSBEND COLORADO , LLC
25	144114200123	R000276	GALLOWAY INC In Care Of Name BLUE VALLEY RANCH
26	144112200006	R001460	BUMGARNER, GARY W & JENNIFER L
27	144120200149	R300902	RIVERSIDE RANCH COMPANY
28	144116400125	R000421	USA

Figure 1-1. Project Location Map

1.3 Project Description

The ILVK Irrigation and Restoration project's goal is to identify the driving forces behind the issues observed in this reach of the Colorado River and present conceptual plans and costs for engineering solutions. The following sections describe the lands involved in the ILVK, the water rights impacted, descriptions of the issues involved, and suggested causes.

1.3.1 Project Reach Location

The project is located in Grand County, Colorado, just outside the Town of Kremmling and upstream of Gore Canyon. The reach of the Colorado River examined in this study extends from the KB Ditch headgate to the confluence of the Colorado River, Blue River and Muddy Creek. The primary focus of this study is the reach between Troublesome Creek and the Blue River. Figure 1-1 shows the general project area, the study reach, the property ownership information, and the ILVK irrigated lands under the Senate Document 80 (S.D. 80) Pumps and the KB Ditch. The drainage basin areas for the reach are listed in Table 1-1.

Location	Area [mi]
Above Troublesome Confluence	1190
Above Blue River/Muddy Creek Confluence	1380

Table 1-1. Colorado River Basin Area

1.3.2 Water Rights Involved

The ILVK own ten S.D. 80 Pump Rights as well as partial ownership of the KB Ditch. The ILVK diversions (S.D. 80 Pumps and KB Ditch) irrigate a total of ~1300 acres of pasture based on the Colorado Decision Support System (CDSS) data dated 2000 (Figure 1-1). These lands are irrigated with a combined decreed diversion rate of 134.84 cfs. Table 1-2 presents the ILVK water rights impacted by this study.

Water Right Name	DIV	WD	ID	Admin No	Priority	Decreed Ammount [cfs]
McElroy No 1 Ditch	5	50	612	32335.11971	167	12
McElroy No 2 Ditch	5	50	613	32335.11677	165	11
					166	1
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	927	34241.18263	449C	4
Thompson Pump No 1	5	51	1148	34241.18263	449D	13.84
McElroy State Pump No. 1	5	50	755	39095.18414		8
Ennis Pump Ditch System	5	50	566	34762.18414		8
Holdcroft Pump No. 1 (A.K.A. Orr No. 1)	5	51	1274	33063.12023	430	24
	5	51	1274	34241.18263	449E	4
Holdcroft Pump No. 2 (A.K.A. Orr No. 2)	5	51	1275	33063.12023	430	24
	5	51	1275	34241.18263	449E	4
Kinney Barriger Ditch (Partially owned by ILVK Members)	5	51	763	20676.13818	171	11
	5	51	763	33063.12023	430	24
	5	51	763	33433.33151	438	10
	5	51	763	34241.18263	449D	2
	5	51	763	34241.18263	449E	18
Total (Priority 430 limited to 24cfs total and Priority 449E limited to 18cfs total)						134.84

Table 1-2. ILVK Colorado River Water Rights

Three additional water rights within this reach, that are not owner by the ILVK, could potentially benefit from this project as presented in Table 1-3.

Water Right Name	DIV	WD	ID	Admin No	Priority	Decreed Ammount [cfs]
Thompson Pump No 2	5	51	1149	34241.18263	449D	13.84
River Ranch Village PMP1	5	53	1112	38753.17319	409	2
TA Engle Ditch No 1	5	50	651	34762.18414		4
Total Flow						19.84

Table 1-3. Additional Colorado River Water Rights

1.4 Identification of Irrigation and River Issues

A number of issues surrounding the stability and health of the irrigation systems and the Colorado River have been identified. These issues differ depending on the location within the project reach. The following sections describe the type and general extent of issues identified. This study focuses on issues related directly to the river, such as bank instability and diversion structure issues. The ILVK Ranchers have additional issues with their irrigation infrastructure (e.g. pumps, distribution systems, etc.) that were not investigated in this study.

1.4.1 Irrigation Diversions

The S.D. 80 Pumps have undergone numerous repairs and upgrades over the years. The original pump stations consisted of a concrete wet well and wooden framed building on top, which housed the pump. Figure 1-2 shows a typical, original S.D. 80 Pump Station. A number of these pump stations are still in use and a few even have the original pumps. Of the eight S.D. 80 diversion structures owned by the ILVK (serving the McElroy No. 1 Ditch, McElroy No. 2 Ditch, T.A. Engle No. 1 Ditch, Thompson Pump No. 1, McElroy State Pump, Orr Pump No. 1, Orr Pump No. 2 and the Ennis Ditch Pump) two have been replaced due to changes in the river. The T.A. Engle No. 1 Ditch and the Thompson Pump No. 1 (a.k.a. Thompson Consolidated or Thompson ABC) pump stations were replaced in 1981 because channel incision (downcutting) and migration had left the intakes high and dry at normal flows. The remaining S.D. 80 Pumps largely use their original intakes.

Figure 1-2. Typical Senate Document 80 Pump Station.

During the drought of 2002-2003 a number of the S.D. 80 Pumps had difficulty diverting because of low flow (low river surface elevation). Under their previous obligation to maintain these structures Northern Colorado Water Conservation District installed several boulder drop structures to check the water surface up enough to maintain minimal operations. Drop structures were built at the McElroy No. 2 Ditch, the T.A. Engle, the Thompson Consolidated, and the Orr No. 1. Several additional structures (training vanes or weirs) were built upstream of the Thompson Consolidated in an effort to steer the river current towards the intake,.

Figure 1-3. Diversion Drop Structure installed by Northern Colorado Water Conservancy District in 2004.

While the Northern check structures did provide sufficient hydraulic control to help low flow operations for several years following installation, they did not did not completely fix the low flow diversion issues and they had several unintended consequences:

- These structures were installed with a curved planform with the centerline point the furthest downstream (Figure 1-3). This configuration forces water to flow against the bank and exacerbates bank erosion;
- The structures were installed without scour protection downstream which has allowed significant scour holes to form downstream of the structures leading to collapse of the structure;
- The structures were installed with limited preparation of the subgrade which has allowed for settling in certain locations, leading to collapse;
- The structures were constructed with only large boulder, leaving voids in the structure for water to flow through. The voids concentrate and accelerate flow with causes additional scour.

Figure 1-4. Automobile body used for bank protection.

During the course of this study two of these structures, The Thompson Consolidated and the Orr No. 1, were removed to address some of the above described issues. These structures were replaced with new structures to demonstrate and test design criteria developed during this investigation.

1.4.2 Bank Erosion

There is significant bank erosion evident throughout the entire 10 mile reach. While aerial photographs show that the overall planform of the Colorado River has been relatively consistent over the last 70 years certain locations have been experiencing increasing rates of bank erosion. Throughout the reach there are numerous locations were automobile bodies have been placed along the bank to protect against bank erosion (Figure 1-4). Many of these cars appear to be from the early to mid

Figure 1-5. Sever Bank Erosion on Reeder Creek Ranch.

1900's, indicating that efforts to stabilize banks have been ongoing for decades. Throughout the study reach there are miles of eroded banks. Over the last few years the rate of loss has been as high as 30 ft per year at some locations, resulting in the loss of irrigation infrastructure and irrigated lands (Figure 1-5 and Figure 1-6).

1.4.3 Loss of Aquatic Habitat

In 2011 the State of Colorado published the Colorado River Aquatic Resources Investigations Federal Aid Project F-237R-18 (Nehring *et al.*, 2011). During the 1980s, two studies developed baseline information on the fish and aquatic invertebrate fauna of the upper Colorado River from Windy Gap Dam (WGD) downstream to the confluence with the Blue River near Kremmling, Colorado (Nehring *et al.*, 2011). The goal of the 2011 study was to go back to the same riffles examined in the 1980-1981 study using the same sampling protocol to assess how the ecosystem has changed over the intervening decades. In 2010 the researchers were only able to successfully sample at 5 of the 7 riffle locations sampled in the 1980-1981. One of the sites was destroyed by WGD. The other site that was not sampled in 2010 is located just upstream of the Highway 9 bridge crossing the Colorado River. In the decades between the two studies this riffle had become completely buried in sediment (Nehring *et al.,* 2011).

Figure 1-6. Severe Bank Erosion on Reeder Creek Ranch.

The 2011 study found that throughout the study area there had been a 38% loss of total benthic macroinvertebrate diversity from 1980-1981 to 2010. Since 1980-1981 percentages of stoneflies have declined by up to 40%. A particularly important food sources for trout is a species of macroinvertebrate salmonfly or giant stonefly, *Pteronarcys californica* (*Pc*). Nehring *et al.* (2011) found that *Pc* larvae were completely eliminated at two of the sampling locations and that there was a reduction in number of *Pc* larvae at all other stations since 1980-1981. Some observers have interpreted the results of Nehring's study to indicate that the Upper Colorado River is at the point of ecologic collapse (Redal, 2011).

1.4.4 Channel Degradation

There is evidence of channel incision throughout the lower section of the project reach. The vertical, eroded river banks on the McElroy and Riverside Ranches are over 16 ft high in places (Figure 1-7). In places vegetation is beginning to take hold on the vertical banks, indicating that much of this bank erosion has been present for a significant period of time.

Figure 1-7. Evidence of Channel Incision on Riverside Ranch.

1.4.5 High Water Temperatures

Many factors including reduced flows have resulted in a channel that is overly wide at low flows. The CWCB in-stream flow for the Colorado River between the KB Ditch and the confluence with the Blue/Muddy is 150 cfs. At this flow the average hydraulic depth (cross-sectional area/top width) is 1.6 ft. Water surface width at these flows is as high as 200 ft. The wide, shallow flow is more easily heated by air temperature and solar radiation. This condition is exacerbated by the degraded condition of much of the riparian vegetation, which provides little shade.

Trout are cold water fish and a temperature in excess of 25°C (77°F) is considered the upper lethal limit for trout (Matthews and Berg, 1996). They prefer water temperatures generally less than 20°C (68°F) (Jobling, M., 1981). Fishing guides at Reeder Creek Ranch have been informally monitoring river water temperature over the past several years and on numerous occasions have recorded temperatures in excess of 68°F (20°C), as early in the year as June.

1.4.6 Hydromodification

The ILVK reach is downstream of a number of trans-basin diversions that divert on average in excess of 300,000 acre-feet a year of water from the Colorado River Basin across the Continental Divide to serve the Front Range. At full buildout these facilities will divert up to 80% of the native flow of the Colorado River above the ILVK reach. The situation is compounded by the fact that the ILVK reach is above the three compensatory storage reservoirs: Green Mountain, Wolford Mountain, and Ruedi Reservoirs that replace depletions downstream from this reach while the depletions occur upstream. These diversions have a significant impact on the hydrology, and therefor hydraulics, that shape the form of the Colorado River.

1.4.7 Channel Aggradation

At the Ennis Pump, located just downstream from the confluence with Troublesome Creek, the diversion intake pipe is frequently buried by gravel. Excavation of 5 to 10 yards of accumulated material is required nearly annually.

1.5 Geomorphic Theories

A number of theories have been proposed to explain the above described issues as follows:

- Troublesome Creek delivers more sediment to the Colorado River than the Colorado River is capable of moving which leads to aggradation. Channel aggradation may lead to bank erosion as flow paths are changed by bar formation, and decrease channel capacity will increase flooding (Schumm, 2005).
- Meander cutoff upstream of the Blue River Confluence has resulted in channel downcutting (headcut) and subsequent bank failure and channel adjustment.
- Drop structures were improperly built in 2004 resulting in frequent maintenance and failure.
- Agricultural land use has degraded riparian vegetation resulting in increased rates of bank erosion.
- Reduced flow in the Colorado River have reduced the frequency and magnitude of the Effective Discharge (Bankfull flow). This has resulted in less sediment being transported through the reach. The geomorphic response to this is for the channel to narrow over time.

The goal of this study is to examine the validity of these theories and provide solutions through the collection of field data and geomorphic analysis.

2 Field Work/Data Collection

A significant quantity of field data was collected during the course of this study: 1) The project team floated the ILVK Reach to identify the nature and extent of river issues; 2) thalweg and cross-section surveys were completed; 3) piezometers were installed at several locations to record stream stage and temperature; 4) Bed material samples were collected at several locations; and 5) Bed Load samples were collected at several locations. The following sections describe the field work and data collection efforts completed for this study.

2.1 Float Trip

On September 30, 2013 the project team floated the entire 10 mile reach from the KB Ditch to the McElroy Pump No. 2. Paul Bruchez (Reeder Creek Ranch) guided Ned Andrews, Ph.D., Berry Nehring and Chris Romeyn, PE, CFM on the trip.

A total of 138 geo-referenced photos were taken to document the nature and extent of river instabilities/issues. The observations and photos were used to build a GIS database of the proposed restoration. Figure 2-1 shows the locations of the geo-referenced photos. Hundreds of additional, non-georeferenced photos were also used for the assessment.

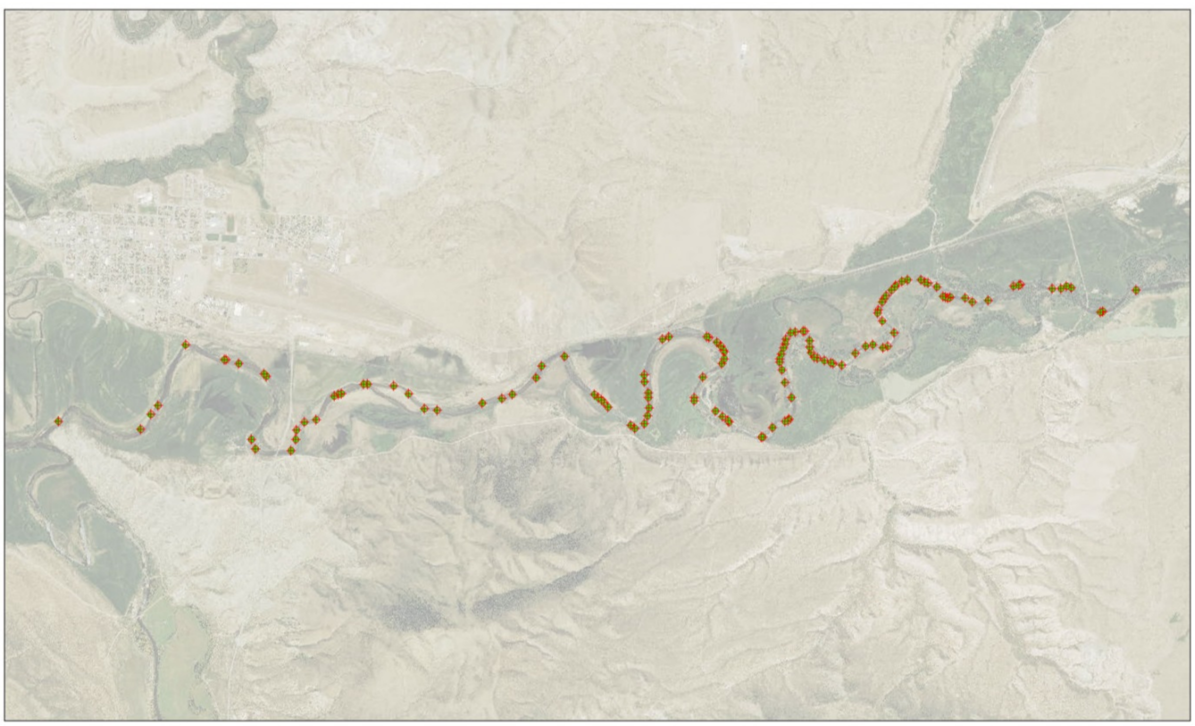


Figure 2-1. Geo-Referenced Photo Location Points from Float Trip.

2.2 Survey Data

Ayres Associates performed a bathymetric cross-section and profile (thalweg) survey in October of 2013. The channel thalweg was surveyed over the entire 10 mile reach. This data was used for geomorphic analysis and hydraulic modeling. The details of this survey are presented in the report titled Colorado River Near Kremmling, Colorado Transect and Profile Bathymetric Survey, dated January 2014. A total of 71 Cross-Sections (approximately 7 per mile) were surveyed from bank to bank. Survey data for the three bridges in the reach were obtained from Denver Water. These 11 additional cross-sections were surveyed for a dam break analysis of Williams Fork Dam. This survey data was supplemented by AECOM survey staff as necessary. Figure 2-2 shows the locations of the 82 cross-section used to develop the hydraulic model and perform the geomorphic analysis.

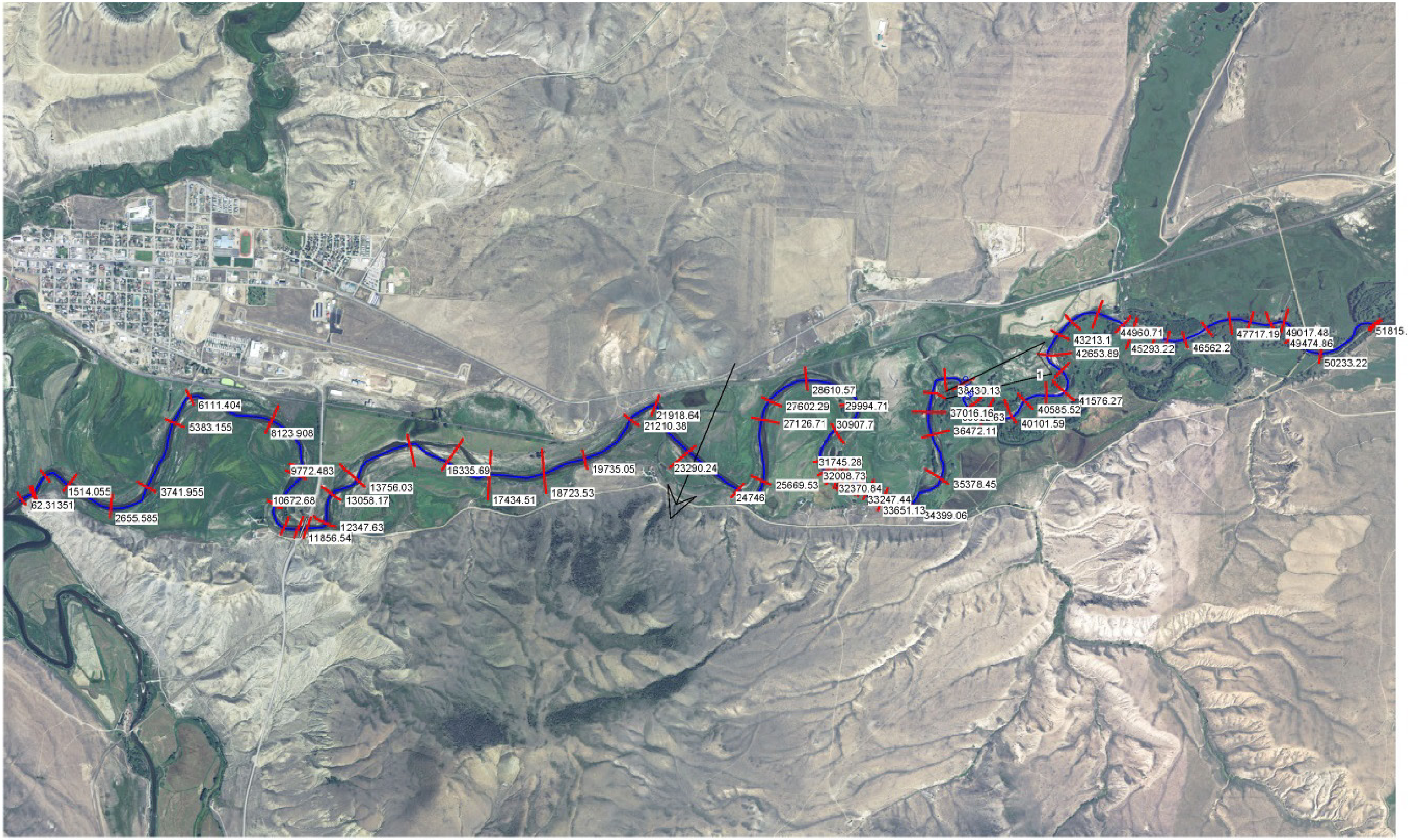


Figure 2-2. Cross-section Survey Locations.

2.3 Piezometer Installation

AECOM placed 7 sensors to measure river stage and temperature. Four of these were vibrating wire sensors owned by AECOM and three were Solinst Leveloggers provided by a team member. The location and type of sensor placed are listed in Table 2-1. The Leveloggers were removed from the field in early August. The vibrating wire sensors are still deployed but a budget has not been secured for ongoing maintenance and data collection. The surface water elevation data was used to calibrate the hydraulic model. Temperature data was used to establish a baseline condition.

Location	Instrument Type
Ennis Pump	Vibrating Wire
Orr No. 1 Pump	Vibrating Wire
Orr No. 2 Pump	Vibrating Wire
McElroy State Pump	Vibrating Wire
Thompson Consolidated Pumps	Solinst Levelogger
T.A. Engle Pump	Solinst Levelogger
McElroy No. 1 Pump	Solinst Levelogger

Table 2-1. Stage and Temperature Sensor Installation Data

Stage and temperature data were collected throughout the spring and summer of 2014. The period of record for each of the sensors is slightly different due to operational issues (e.g. installation issues, battery power, etc.). Each of the sensors recorded data from early April through the end of July. Loss of power limited late season recordings at several of the locations. Issues with the Solinst sensor data are still being investigated, as a result the Solinst data was not used. The period of record is sufficient for calibration of the hydraulic model.

In 2014 temperatures in excess of 65°F were recorded on 13 different days and temperatures in excess of 68 were recorded on one day. These temperatures were recorded during a period when the minimum flow of the river was 226 cfs and the average flow was in excess of 350 cfs, more than the in-stream right of 150 cfs. It's likely that the sensor's high temperature recordings may be representative of near surface conditions at the sensor and not deep pools where fish may find refuge. However, these high temperature readings point to the river's susceptibility to heat during periods of lower flow and higher air temperatures.

2.4 Bed Material Samples

Channel bed surface material samples were taken from six locations throughout the project reach (Table 2-2). CTL Thompson performed the sieve analyses according to ASTM D 422.

Location	Sample Type
Troublesome Creek USGS Gage Station	Surface Sample Sieve Analysis
Brian’s Bluff Riffle (just downstream of Ennis Pump)	Surface Sample Sieve Analysis
Brian’s Bluff Point Bar (just downstream of Ennis Pump on River Right)	Surface Sample Sieve Analysis
Shepardsbend Reach (just downstream of Orr No. 1 Pump)	Surface Sample Sieve Analysis
Thompson Ranch Reach (Riverside Ranch, upstream of TA Engle Pump)	Surface Sample Sieve Analysis
Point bar upstream of Rt. 9 Bridge	Surface Sample Sieve Analysis

Table 2-2. ILVK Bed Sample Locations

These sieve analysis were compared with the bed material gradation for Kemp Breeze from the Moffatt Collection System Project Final Environmental Impact Statement (Moffat EIS) data. The results presented in Figure 2-3 show a general trend of downstream fining of bed material from Kemp Breeze to the McElroy Ranch which corresponds well with the observation of decreasing channel slope in the downstream direction.

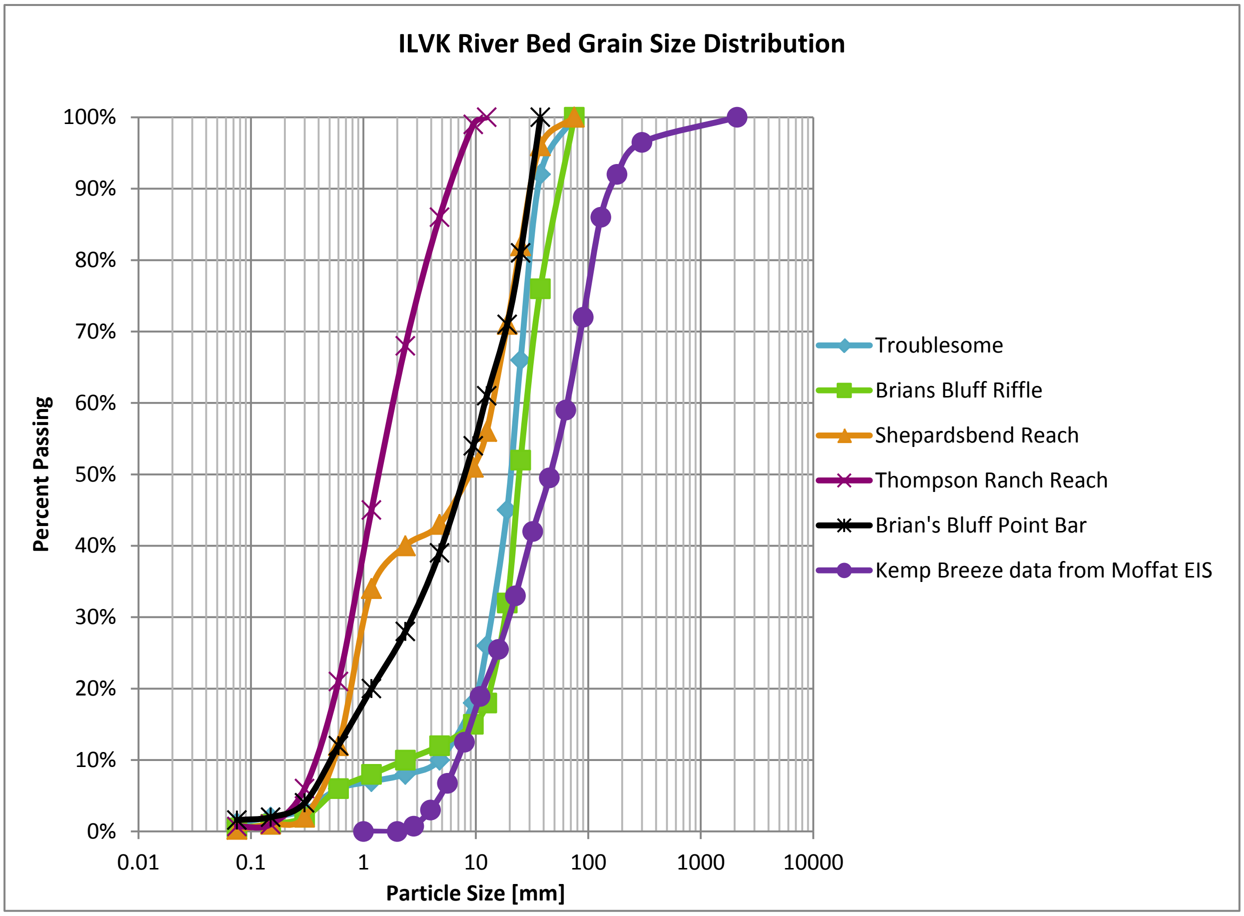


Figure 2-3. Bed Surface Material Gradation Results.

2.5 Bed Load Samples

Bedload Transport sampling was performed using a Helley-Smith 3” x 3” bedload sampler according to methods outlined in Edwards and Glysson (1999). Bedload sampling was performed at four different locations, and four different flows as shown in Table 2-3. The original project scope included an additional bedload sample to be taken in the lower reach. However, the first bedload sample taken upstream of the T.A. Engle diversion, as well as the bed material samples collected in this section, consisted of sand dominated material. Edwards and Glysson (1999) noted that sand-bed streams characteristically shift radically, at single locations and across segments of the channel cross-section over weeks to even hours. This makes accurate bedload estimates in sand bed channels extremely difficult. A second bed-load sample was not taken in the lower reach for this reason.

Bed Load Sampling Locaion	Date	Estimated Discharge	Bedload Transport Estimate [tons/day]
Brian’s Bluff Riffle	9/26/2013	450	2
Upstream of Shepardsbend	5/7/2014	2270	147
Brian’s Bluff Riffle	5/6/2014	2150	147
Upstream of TA Engle	8/5/2014	510	163 (Bad Data)

Table 2-3. Bedload Sampling Locations

:

3 Geomorphic Assessment

A geomorphic assessment was performed to test the hypotheses presented in Section 1.5 and develop engineering recommendations.

3.1 Hydrologic Assessment

The historic and future hydrologic conditions were assessed using two methods: 1) future flows were based on the Platte and Colorado Simulation Model (PACSM) results provided by Denver Water and 2) historic flows were estimated using regression analysis of historic gage records. The following sections present the estimates for the historic and future hydrologic conditions through the ILVK reach.

3.1.1 Future Hydrology

The Moffatt EIS PACSM analysis looked at baseline conditions and future conditions. The baseline conditions modeled the Colorado River system for the period of 1946 through 1991. The future conditions modeled future demands and diversions with the baseline hydrology from the period 1946 to 1991. Significant time and effort has been spent developing the PACSM results. They are the best available estimate of future conditions therefore this information was for this anlaysis.

3.1.2 Troublesome Creek Flow

One of the challenges with developing the hydrology for the ILVK reach of the Colorado River is that the USGS no longer operates a gage at the mouth of Troublesome Creek. The flow that Troublesome Creek contributes to the Colorado River is unknown and must be estimated which lends a level of uncertainty with any analysis. The flow in Troublesome Creek was measured on one occasion (August 5, 2014) in order to assess the magnitude of late season flows. The USGS maintained a gage on Troublesome Creek at Highway 40 off and on from 1904 to 1956 but there is insufficient overlap with other gage records to establish historic flows through the ILVK reach. The following sections describe the methods used to estimate historic flows.

3.1.3 Historic Hydrology

Since 1990 Northern has maintained a gage downstream of the KB Ditch headgate from early spring through mid-fall. The location of this gage upstream of the Troublesome Creek confluence and its short period of record make it poorly suited for establishing historic flows along the reach of the Colorado below Troublesome Creek. The USGS maintained gages at the mouth of Gore Canyon (USGS Gage No. 09058000-Colorado River Near Kremmling, CO) and at Hot Sulphur Springs (USGS Gage No. 09034500-Colorado River at Hot Sulphur Springs, CO) for various periods of time since 1904. These two gages have a common period of record from 1904 to 1916. These gage records were used to estimate flows through the ILVK reach as outlined below.

Vaill (2000) presents methods for estimating flood flows in Colorado at ungagged locations based on flows at gaged locations. While this method is intended for more rare flood events (e.g. 2-year, 100-year, etc.), it provides a reasonable method of approximating average flows through the project reach. It should be noted that the regression equations presented in Vaill (2000) can have significant errors. An effort was made to limit these errors by performing a site specific application of this method to estimate historic flows through the ILVK reach. The general form of the equation is presented in Equation 3-1 were Q_u is the unknown discharge, Q_g is the gaged (known) discharge, A_u is the ungagged basin area, A_g is the gaged basin area, and n is the average exponent for drainage area for specific regions across Colorado. The exponents for Colorado range from 0.40 on the plains to 0.88 in the Rio Grande basin.

Equation 3-1

$$Q_u = Q_g \left(\frac{A_u}{A_g}\right)^n$$

The gage record at Hot Sulphur Springs was used to refine the exponent value specifically for this reach of the Colorado River. A regression analysis was performed using the Hot Sulphur and Colorado Near Kremmling gage data for the period of 1904 to 1916. The exponent in Equation 3-1 was adjusted to minimize the error between the known discharge at Hot Sulphur and the discharge estimated from the Colorado Near Kremmling gage. The best fit was achieved with an exponent of 0.79. This exponent value is within the range established by Vaill, but provides a slightly more conservative estimate (i.e. ~6% lower flows). The calibrated equation was then applied to the basin below Troublesome Creek as follows:

Equation 3-2

$$Q_{below\ Troublesome} = Q_{Colorado\ near\ Kremmling} \left(\frac{1360}{2379}\right)^{0.79}$$

Equation 3-2 was applied to the average daily flow record for the period 1904-1916 from the Colorado River near Kremmling to estimate daily flows in the Colorado River below Troublesome Creek. Statistical analysis was performed on the results to estimate average daily flow for the period 1904-1916. While research has shown that this period, from 1904 -1916, is a period of high flows on the Colorado River, it is the best available information and provides an adequate approximation of the historic conditions. The results of this analysis are presented in Figure 3-1.

The above described analysis provides a reasonable assessment of the hydrologic conditions that shaped the Colorado River at this location through recent geomorphic history. The resulting estimated (synthetic) hydrology for the Colorado River below Troublesome was used in the geomorphic assessment presented in this report to provide geomorphic context to the issues identified in Section 1.4. The proposed river and/or irrigation system improvements presented in this report are based on the existing and future hydrology provided by Denver Water's PACSM analysis results.

The PACSM results show that through the ILVK reach the differences in hydrology from existing conditions to future conditions is small. This is particularly true when these flows are compared to the estimated historic flows calculated above. Figure 3-2 shows the estimated historic and future average daily flows for the Colorado River below Troublesome Creek. The reduction in annual peak discharges is clearly evident. Figure 3-3 presents the flow duration for the estimated historic, existing and future conditions for the Colorado River Below Troublesome Creek. Under future conditions the flow that is exceeded 10% of the time will be 750 cfs, reduced from a historic flow of 3500 cfs. The reduction in flows is even greater when typical annual high flows are considered (e.g. 5% Exceedance, 1% Exceedance). It's clear from this analysis that in the last 100 years there has been a significant decrease in peak flows and average flows through the ILVK reach of the Colorado River.

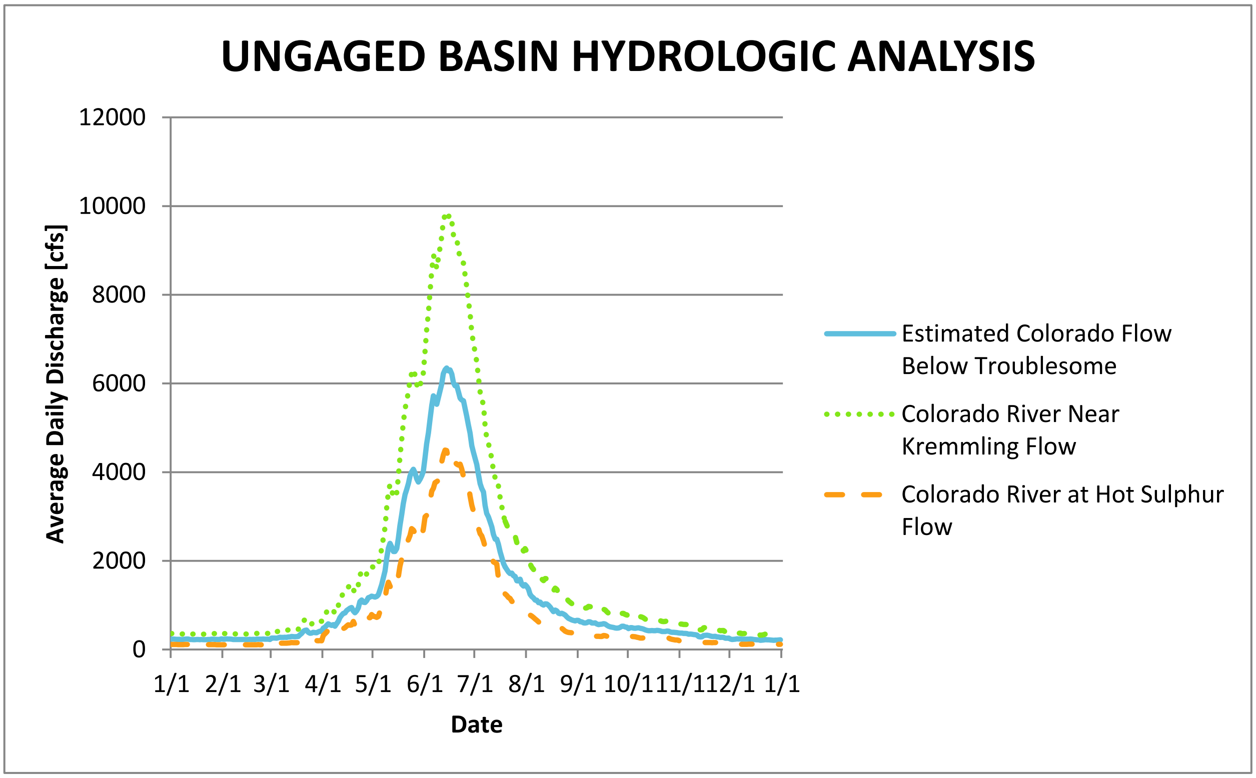


Figure 3-1. Estimated Historic Flow for Colorado River Below Troublesome Creek 1904-1916.

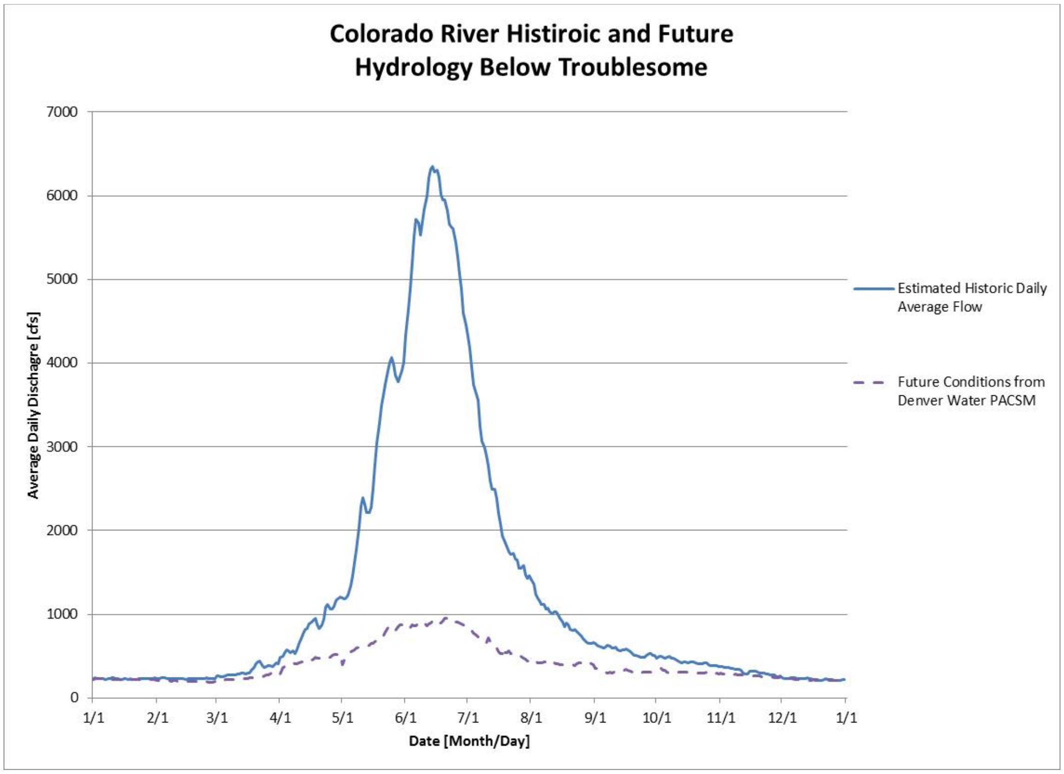


Figure 3-2. Estimated Historic and Future Flows for Colorado River Below Troublesome Creek.

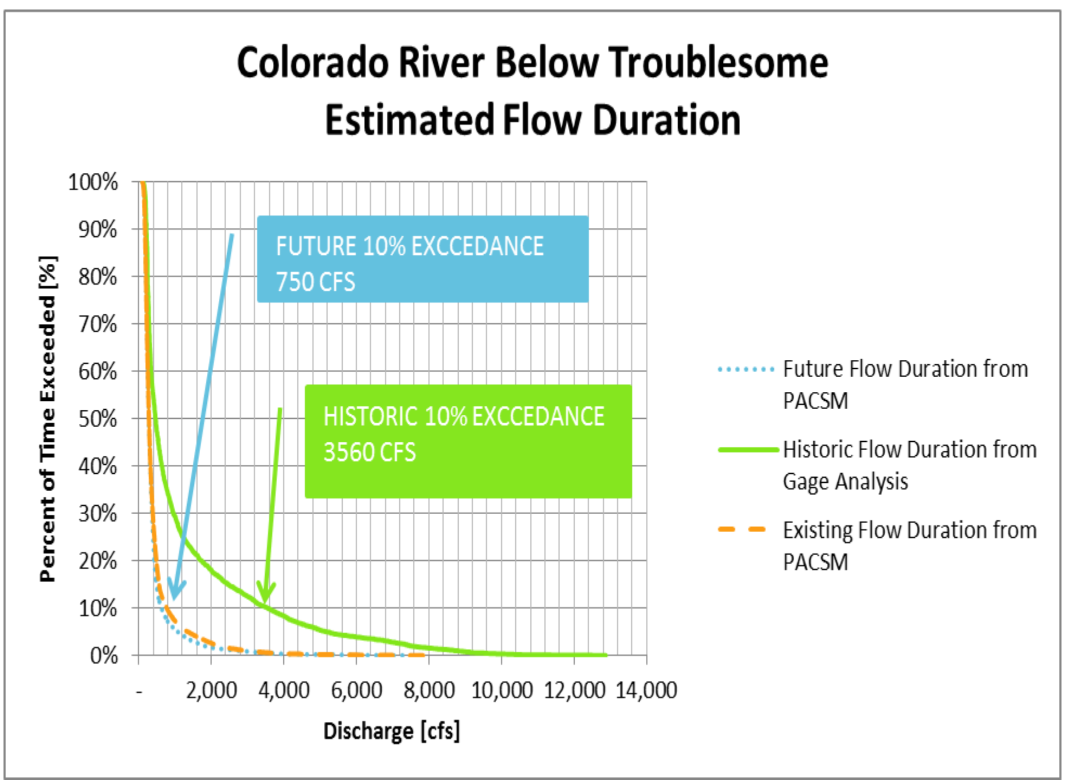


Figure 3-3. Estimated Historic, Existing and Future Flow Duration for Colorado River Below Troublesome Creek.

3.2 Hydraulic Model

Certain characteristics of a river channel can be easily quantified such as flow depth, width, and velocity. These quantities vary with discharge in predictable relationships across drainage basins (Leopold and Maddock, 1953). Referred to as Hydraulic Geometry Relationships, these physical characteristics are expressions of a river's geomorphic tendency. Sound understanding of the river's hydraulics is essential to understanding these geomorphic characteristics. River flows are highly turbulent, unsteady, three-dimensional flows. While modern computing power and programming have made multi-dimensional hydraulic modeling increasingly accessible, these methods are not warranted for planning level studies.

3.2.1 Model Development

For this assessment a 1-Dimensional hydraulic model of the ILVK reach was developed using HEC-RAS (v. 4.1.0 ACOE, 2010). A total of 82 cross-sections were used to develop the model; an average spacing of 8 cross-sections per mile. The original intent had been to combine the surveyed cross-section data with the USGS 10 meter DEM data to develop a hydraulic model suitable for floodplain modeling. However, the USGS data proved to be too inaccurate for hydraulic modeling, with estimated errors in excess of 100 ft. Therefore, the HEC-RAS model only modeled the main channel and banks. Additional topographic data is likely required to assess the restoration plans for flood conveyance capacity.

3.2.2 Model Calibration

For the analysis the model was run in steady state for a range of flows from 150 cfs to 4750 cfs. The model calibration was performed for three different flows at locations throughout the project (Table 3-1). Variables adjusted during the calibration process include downstream normal energy slope, Manning's n, bridge contraction and expansion coefficients, ineffective flow areas and lateral structures which were used to mimic overbank flows.

Station	Location	Discharge [cfs]		
		850	**2150**	**4750**
43213	Ennis Pump	Calibration Point	Calibration Point	Calibration Point
32752	Orr No. 1	Calibration Point	Calibration Point	Calibration Point
27126	Orr No. 2	Calibration Point	Calibration Point	Calibration Point
15326	McElroy State Pump	Calibration Point	Calibration Point	Calibration Point
11316	Thompson Consolidated (upstream)	Calibration Point	N/A	N/A
9542	TA Engle Pump	Calibration Point	N/A	N/A
5383	McElroy No. 1 Pump	Calibration Point	N/A	N/A

Table 3-1. Hydraulic Model Calibration Locations and Flows.

Calibrating a single model over such a wide range of flows is difficult. Many factors can impact the results of the hydraulic model. The specific challenges faced with this model include the following:

- Overbank flows at higher discharges in the upper section;
- Backwater impacts from Blue River, Muddy Creek, and Entrance to Gore Canyon in the lower section;
- Sand bed channel roughness varies with stage in lower section;
- At higher flows additional roughness on banks.

Model variables were adjusted to minimize the error in water surface prediction. For simplicity the model was calibrated with a single set of Manning's n; Manning's n does not very with stage. The final calibrated Manning's n values range from 0.024 in the lower, sand-bed section to 0.036 in the upper cobble and gravel sections. Overbank Manning's n ranged from 0.08 to 0.09.

The downstream normal depth boundary slope was set at 0.00025 for 850 cfs flows, 0.00015 for 2150 cfs and 0.00005 for 4750 cfs. Given the uncertainty of the higher flow rates below troublesome, the model is sufficiently accurate for planning level analysis.

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Obs WS	Difference
		(cfs)	(ft)	(ft)	(ft)	(ft)
43213.1	850	850	7337.43	7345.71	7345.62	0.09
43213.1	2150	2150	7337.43	7346.67	7346.54	0.13
43213.1	4750	4750	7337.43	7347.89	7347.6	0.29
32752.25	850	850	7330.83	7334.67	7334.62	0.05
32752.25	2150	2150	7330.83	7337.13	7336.64	0.49
32752.25	4750	4750	7330.83	7340.23	7340.16	0.07
27126.71	850	850	7326.27	7332.25	7332.06	0.19
27126.71	2150	2150	7326.27	7334.76	7334.33	0.43
27126.71	4750	4750	7326.27	7338.1	7338.21	-0.11
15326.95	850	850	7321.02	7329.7	7329.31	0.39
15326.95	2150	2150	7321.02	7332.09	7331.82	0.27
15326.95	4750	4750	7321.02	7335.97	7336	-0.03
11316.33	850	850	7321.32	7329.16	7328.72	0.44
11316.33	2150	2150	7321.32	7331.36		
11316.33	4750	4750	7321.32	7335.32		
9542.435	850	850	7313.93	7328.37	7328.4	-0.03
9542.435	2150	2150	7313.93	7330.52		
9542.435	4750	4750	7313.93	7335.02		
5383.155	850	850	7322.73	7327.39	7327.3	0.09
5383.155	2150	2150	7322.73	7329.33		
5383.155	4750	4750	7322.73	7334.6		

Table 3-2. Hydraulic Model Calibration Results.

For 850 cfs the average departure from the known water surface is +/- 2.2 inches, or 6% of the average hydraulic depth. The average departure at 2150 cfs is +/- 4.0 inches, or 7% of the average hydraulic depth. And the average departure for 4750 cfs is +/- 1.5 inches, or 6% of the average hydraulic depth. The results of the calibrated hydraulic model were used for the critical shear stress calculations, the preliminary conceptual design and cost estimates. Figure 3-4 shows the calibrated water surface profiles for the three calibration flows along with the known water surface elevations.

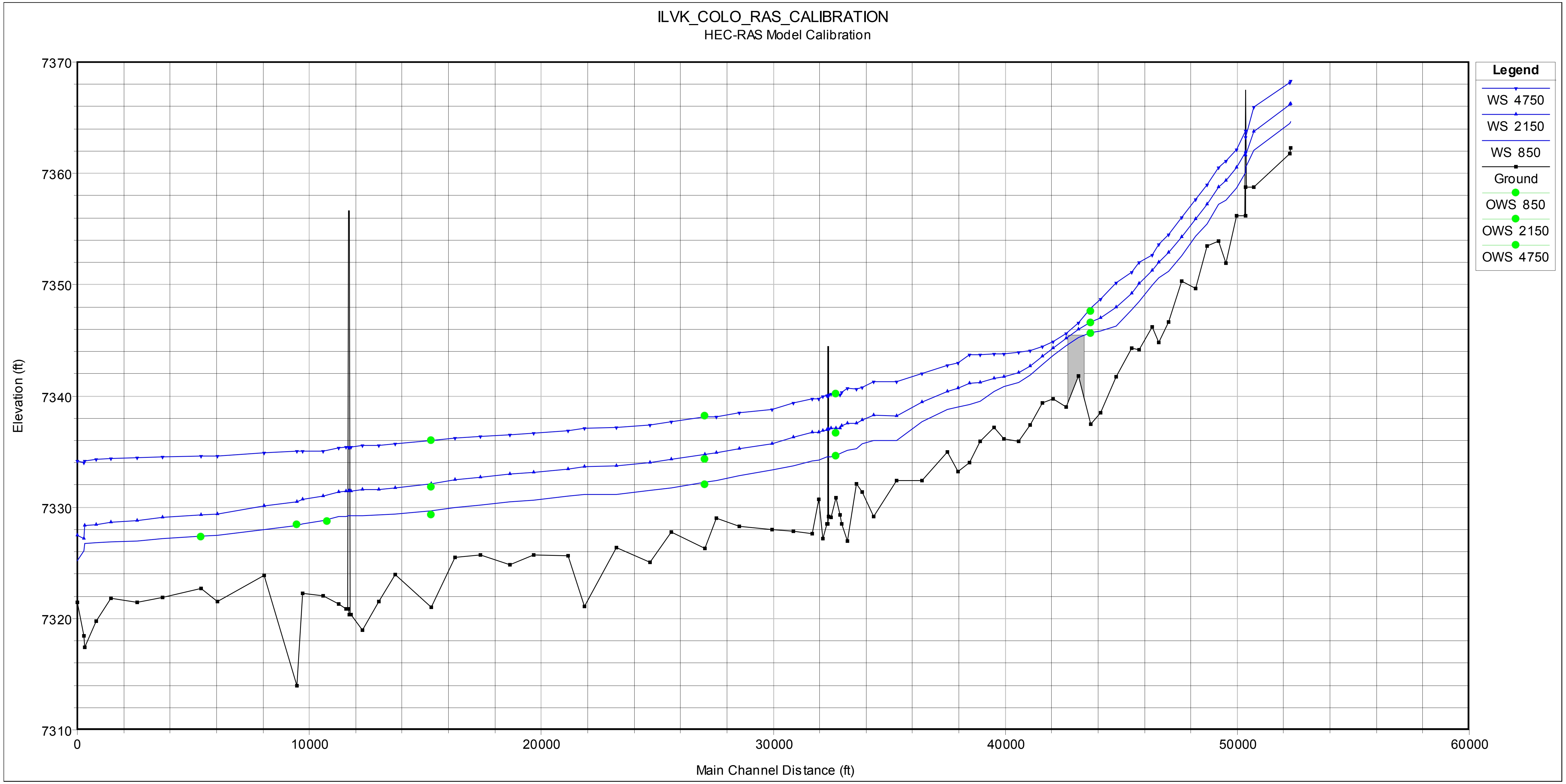


Figure 3-4. HEC-RAS Calibration Profile with Known Water Surface Elevations.

3.3 Sediment Transport Modeling

Sediment transport modeling was performed to support the geomorphic analysis, specifically the effective discharge analysis (Section 3.7). Sediment transport analysis was performed using the USDA BAGS (Bedload Assessment for Gravel-Bed Rivers) Software (Pitlik *et al.,* 2009). The Parker (1990), Wilcock (2001), and Wilcock and Crowe (2003) transport equations were used in conjunction with the bed material particle size analysis (Section 2.4) and surveyed cross-sections (Section 2.2). The bedload measurements (Section 2.5) were used to validate the results of the bedload analysis. The goal of the sediment transport modeling was to develop a sediment transport curve for the upper section of the ILVK Reach, in the vicinity of Troublesome Creek so several cross-section locations were investigated.

Figure 3-5 shows the results of the various sediment transport runs. The model was run for three cross-sections, Sta. 42653, Sta. 40585, and Sta. 36472 resulting in nine separate sediment transport rating curves. The effective discharge calculations (Section 3.7.2) were performed with each of the sediment rating curves. Effective discharge calculations are a function of the slope of the sediment discharge rating curve: the effective discharge calculation is independent of which equation is used. It can be seen in Figure 3-5 that there is generally good agreement in slope between the various runs and the measured bedload data. If required for future studies the Parker (1990) equation could be calibrated to the measured bedload data to more accurately estimate discharge rate.

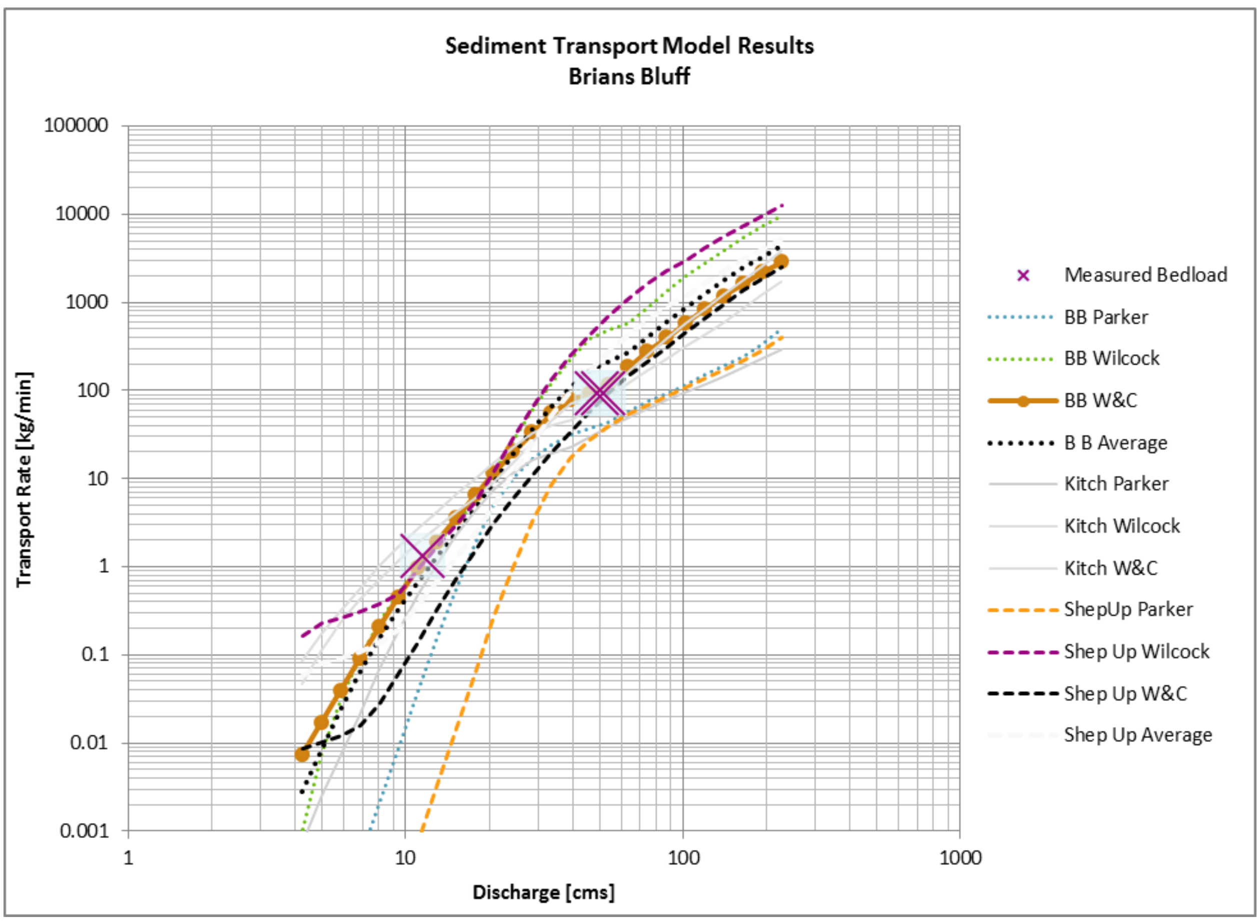


Figure 3-5. Sediment Transport Analysis Results.

3.4 Geomorphic Stream Type

Stream classification systems can facilitate communication, describe river conditions, and help explain restoration goals. There are several classification systems used in river restoration work, but Dave Rosgen's system has experienced the broadest acceptance. The following Rosgen Level II assessment is presented for completeness and communication only; the conceptual restoration plans in no way attempt to change the Colorado River from one type of stream to another.

The entrenchment ratio (W_{FPA}/W_{BKF}), Width to Depth Ratio ($W_{BKF}/\overline{d}_{BKF}$), and Sinuosity ($l_S/l_V$), were estimated for the upper reach (just below Ennis Pump) and the lower reach, downstream of the Highway 9 Bridge. Water surface slope was estimated from the hydraulic model. See Section 2.4 for details on bed material analysis. Table 3-3 presents details of the assessment.

Location	Attributes								
	Rosgen Stream Type	Reach Length [ft]	Reach W.S. Slope [ft/ft]	Sinuosity	Bankfull Width [ft]	Average Bankfull Depth [ft]	Maximum Bankfull Depth [ft]	Entrenchment Ratio	Median Grain Size [mm]
Downstream of Troublesome	C4	6278	0.0014	1.82	237	3.6	9.67	12.24	24.4
Downstream of Rt. 9 Bridge	C5	9180	0.0008	1.80	266	12.5	12.46	12.32	1.43

Table 3-3. Rosgen Level II Stream Type Analysis

The upstream portion of the ILVK Reach is a Rosgen Type C4 channel. A C4 Channel is a meandering, gravel-dominated, riffle-pool channel with a well-developed floodplain (Rosgen, 1996). The lower portion of the ILVK Reach is a Rosgen Type C5 channel. The C5 stream type is a meandering, sand-dominated, riffle/pool channel with a well-developed floodplain.

Between the upstream C4 and downstream C5 channel types there is a continuum of channel form; there is no abrupt change from C4 to C5. During field work it was noticed that gravel was present at certain locations in the downstream reach, perhaps a hint to the channel's former morphology. The transition to a sand dominated channel happens somewhere between the Elktrout Lodge (Cross-Section 21210.38 in Figure 2-2) and the T.A. Engle Pump (Cross-Section 9772.463 in Figure 2-2).

3.5 Upper Reach Analysis

Troublesome Creek is a significant source of sediment for the Colorado River through the ILVK reach. As previously noted the river bed material of the Colorado River upstream of Troublesome Creek has a median particle size of 45 mm (cobble) while below its confluence with Troublesome Creek the bed is dominated by gravel size material (24.4 mm). This decrease in median particle size is due to the sediment inputs from Troublesome Creek. The Troublesome and Rabbit Ears formations are widespread in the Troublesome Basin and are particularly erodible. These formations contain areas of soft tuffaceous rocks which are high in clays. When these layers are saturated with groundwater they become plastic and creep, flow, or slide to form landslides and related features (Izett, 1968). This leads to high sediment loading in Troublesome Creek.

Historic aerial photos of the upper section of the ILVK reach show evidence of multiple channels. There have been issues with aggradation at the Ennis Pump diversion structure requiring annual excavation of the intake pipe. This evidence suggests that the river may tend towards a braided or anastomosing form. It is hypothesized that Troublesome Creek has a greater capacity to deliver sediment to the Colorado River than the Colorado River has the capacity to move.

To assess this hypothesis AECOM performed two different analyses. First, AECOM investigated the Colorado River's tendency toward being braided using relationships developed by Lane (1957) and Leopold and Woolman (1957). Second, AECOM estimated the relative frequency with which Troublesome Creek and the Colorado River are capable of moving sediment. The following sections describe these analyses and results.

3.5.1 Meandering versus Braided

To test the theory that the Colorado River tends towards a braided channel near its confluence with Troublesome Creek AECOM used empirical relationships developed by Lane (1957) and Leopold and Wolman (1957) that relate discharge and channel slope to a rivers tendency to be braided or meandering. Figure 3-6 below shows the results of this analysis.

Leopold and Wolman's relationship categorizes rivers into braided or meandering categories based on were the river's slope versus discharge plots with respect to the trend line. If the point is above this line the river tends towards being braided, and if it is below the line the river tends towards meandering. Lane's relationship uses an upper threshold for braided rivers and a lower threshold for meandering streams. When a river plots between these two lines it is considered to be in transition between braided and meandering.

The analysis was performed for the upper most and lower most sections of the ILVK reach. Figure 3-6 presents the results of this analysis. Two points were plotted for each section: historic conditions and future conditions. It can be seen in Figure 3-6 that the upper section of the river, in the vicinity of Troublesome Creek, tends towards braiding under both the historic and future conditions. Conversely the lower section tends towards meandering. The results of this analysis indicate that the upper section of the ILVK reach tends towards a braided planform.

The tendency toward braiding is influenced by numerous variables including sediment load, valley slope, bank vegetation, variability of discharges, and the banks resistance to erosion. There is debate on the nature of braided channels versus anastomosing channels and they are often confused (Makaske, 2001). Concerning the genesis of anastomosing rivers Makaske (2001) states, "Anastomosing rivers are formed by avulsions in two ways: 1) by formation of bypasses, while bypassed older channel-belt segments remain active for some period; and 2) by splitting of the diverted avulsive flow, leading to contemporaneous scour of multiple channels on the floodplain." Aerial photographs show clear evidence of historic channels crossing Reeder Creek Ranch lands that are clearly separated by floodplains, a characteristic of anastomosing rivers. Whether the geomorphic character of the upper section of the ILVK reach is a function of a system tending towards braiding or anastomosing is less important that the geomorphic characteristics themselves; most importantly aggradation and bank instability. The tendency towards braiding is an indication that the aggradation issue may be systemic and not the direct result of hydromodification.

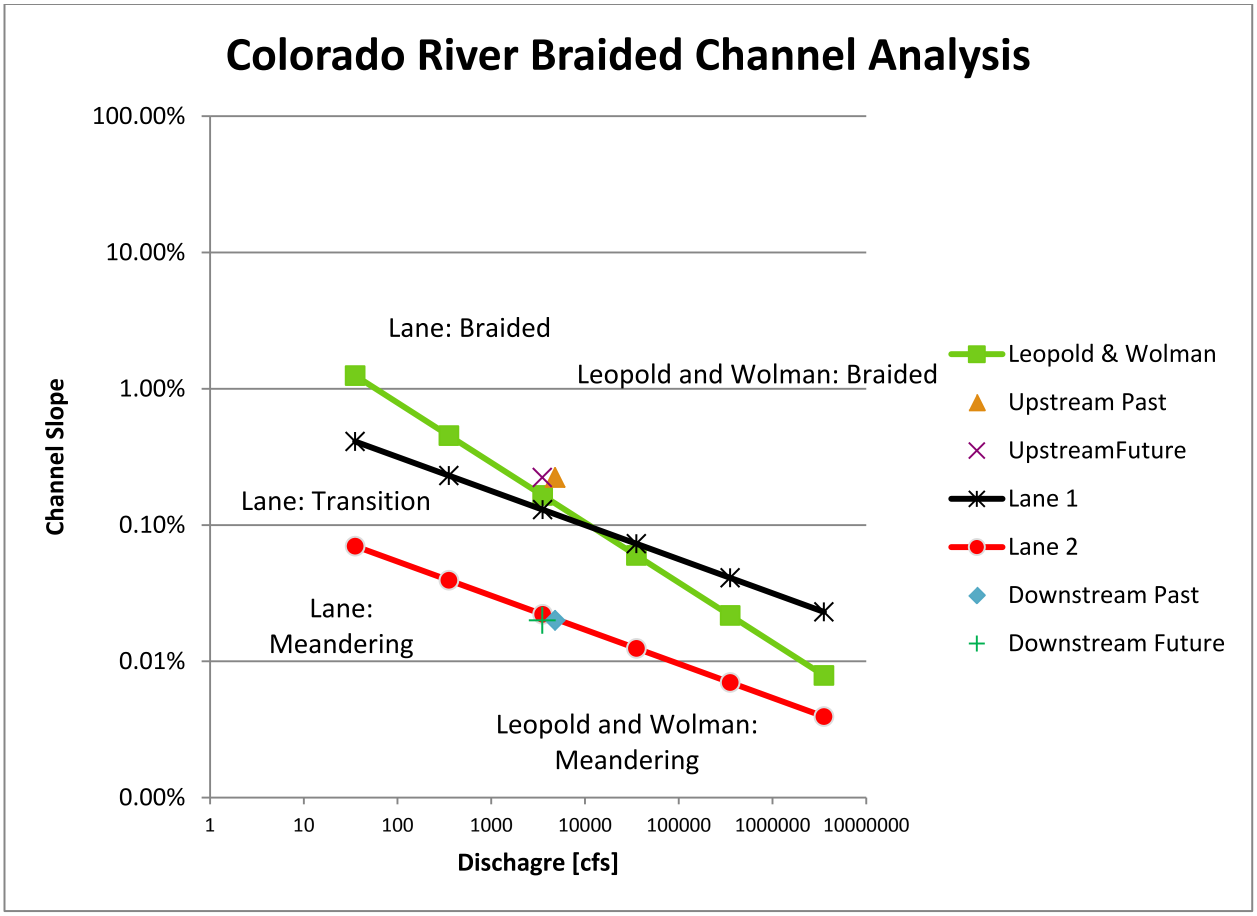


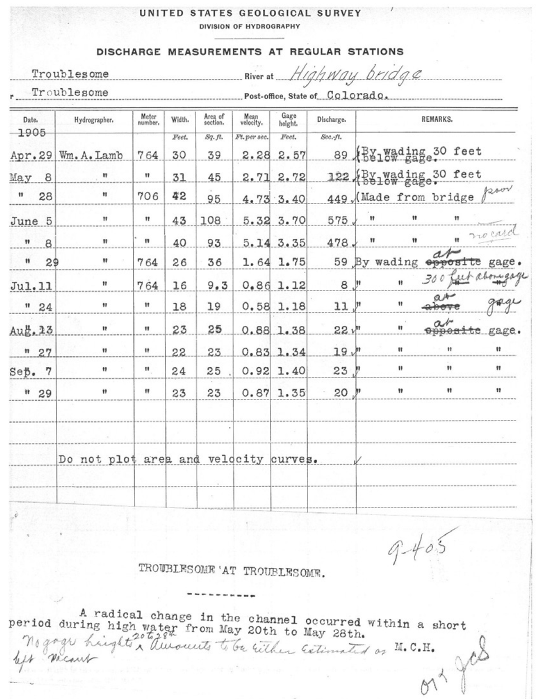
Figure 3-6. Braided and Meandering Analysis from Lane (1957) and Leopold and Wolman (1957).

Figure 3-7. Evidence of multiple channels at Colorado River's confluence with Troublesome Creek.

3.5.2 Troublesome versus Colorado

Research shows that sediment transport begins when the dimensionless shear stress for the median particle size (τ^*_{d50}) is greater than critical shear stress, or 0.03 (Meyer-Peter & Müller, 1948). Bed material gradations for Troublesome Creek and the Colorado River below the Ennis Pump have similar bed material gradations with a d_{50} of 20.4 mm and 24.4 mm respectively (Figure 2-3). Aggradation of the Colorado River would be expected if Troublesome Creek exceeds a d_{50} critical shear stress of 0.03 with greater frequency than the Colorado. To test the hypothesis a preliminary assessment of the frequency with which Troublesome Creek and the Colorado River was performed as described below.

The USGS measures stream discharge on a regular basis to maintain an accurate rating curve for stream gage stations. These field measurements are recorded on USGS Form 9-207 and frequently include measurements of discharge, cross-sectional area, flow width and velocity. The field records from the periods 1904-1905, 1922-1924, and 1937-1956 for the USGS Gage 09040500 (Troublesome Creek near Troublesome, CO) were obtained to estimate shear stress as described below. Since Troublesome Creek has not experienced significant development and there are no reservoirs or trans-mountain diversions in the basin it is assumed that the current hydrology of Troublesome Creek can be approximated with the historic record. On the other hand the Colorado River has experienced significant hydromodification.



UNITED STATES GEOLOGICAL SURVEY
DIVISION OF HYDROGRAPHY

DISCHARGE MEASUREMENTS AT REGULAR STATIONS

Troublesome River at Highway bridge
Troublesome Post-office, State of Colorado.

Date.	Hydrographer.	Meter number.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.	REMARKS.
1905			Feet.	Sq. ft.	Ft. per sec.	Feet.	Sec.-ft.	
Apr. 29	Wm. A. Lamb	764	30	39	2.28	2.57	89	(By wading 30 feet (below gage.
May 8	"	"	31	45	2.71	2.72	122	(By wading 30 feet (below gage.
" 28	"	706	42	95	4.73	3.40	449	(Made from bridge poor
June 5	"	"	43	108	5.32	3.70	575	" " "
" 8	"	"	40	93	5.14	3.35	478	" " " no card
" 29	"	764	26	36	1.64	1.75	59	By wading ~~opposite~~ at gage.
Jul. 11	"	764	16	9.3	0.86	1.12	8	" " 300 feet above gage
" 24	"	"	18	19	0.58	1.18	11	" " ~~above~~ at gage
Aug. 13	"	"	23	25	0.88	1.38	22	" " ~~opposite~~ at gage.
" 27	"	"	22	23	0.83	1.34	19	" " " "
Sep. 7	"	"	24	25	0.92	1.40	23	" " " "
" 29	"	"	23	23	0.87	1.35	20	" " " "
	Do not plot area and velocity curves.							

9-405

TROUBLESOME AT TROUBLESOME.

A radical change in the channel occurred within a short period during high water from May 20th to May 28th.
No gage heights 20 to 28th Amounts to be either estimated or left vacant M.C.H.

Figure 3-8. Typical USGS Form 9-207 for Troublesome Creek.

The dimensionless stress is defined by (Vanoni, 1975)

Equation 3-3

$$\tau^* = \left(\frac{R' \cdot S_o}{1.65 \cdot d_{50}}\right)$$

Where R' is the effective hydraulic radius, S_o is the channel slope, and d_{50} is the median bed material size. In streams with a high width to depth ratio the hydraulic radius (R) may be approximated by the hydraulic depth (H), which is defined as the cross-sectional flow area (A) divided by the surface width (W). Here, the effective hydraulic radius is noted as H'. Thus Equation 3-3 can be rewritten as follows:

Equation 3-4

$$\tau^* = \left(\frac{H' \cdot S_o}{1.65 \cdot d_{50}}\right)$$

In natural channels resistance to flow comes from a variety of sources such as riparian vegetation and large obstructions like boulders in addition to the bed material. At a particular discharge the stage and hydraulic radius of a channel adjust to overcome the total resistance to flow. Only a portion of the shear stress is exerted on the river bed. Some portion of the shear stress is dissipated on those other sources of resistance like riparian vegetation and boulders. Thus, the hydraulic radius in Equation 3-3 and Equation 3-4 is less than actual hydraulic radius (R) and is referred to as the effective hydraulic radius (R').
The challenge is to estimate R' (or H') to solve for the dimensionless stress.

The shear velocity (u*) is defined by:

Equation 3-5

$$u^* = (g \cdot H' \cdot S_o)^{1/2}$$

Where, g is gravitational acceleration, H' is the effective Hydraulic Depth (A/W), and S_o is the channel slope (Dingman, S.L., 2009). Research has shown that the ratio of the mean channel velocity to shear velocity has the following relationship (Engelund and Hansen, 1967):

Equation 3-6

$$\frac{U}{u^*} = 2.5 \cdot ln\left(\frac{C \cdot H'}{2 \cdot d_{65}}\right)$$

Where, U is the mean velocity, u* is the shear velocity as defined in above, H' is the effective hydraulic depth, d_{50} is the median bed particle size and C is a constant the ranges from 4 to 12. Equation 3-5 and Equation 3-6 are solved simultaneously to calculate H'. Dimensionless shear stress for d_{50} is then calculated using H' in Equation 3-4. Sediment transport occurs when the dimensionless shear stress calculated with Equation 3-4 is greater than 0.03. The data from the USGS field forms for Troublesome Creek was used to estimate critical shear stress for the median bed material particle size for various flows. Critical shear stress for the Colorado River was calculated using the HEC-RAS model results.

Flow duration statistics for Troublesome Creek were calculated from Flow Records for the period of record (1904-1953). Flow duration statistics for the Colorado River were calculated from the results of Denver Water's PACSM model for the existing condition (1946 through 1991). The estimated historic daily discharge (Figure 3-1) was used to examine the historic conditions. The flow duration statistics were combined with the shear stress calculations described above to estimate the frequency with which each stream exceeds the critical shear stress. Figure 3-9 shows the results of this analysis.

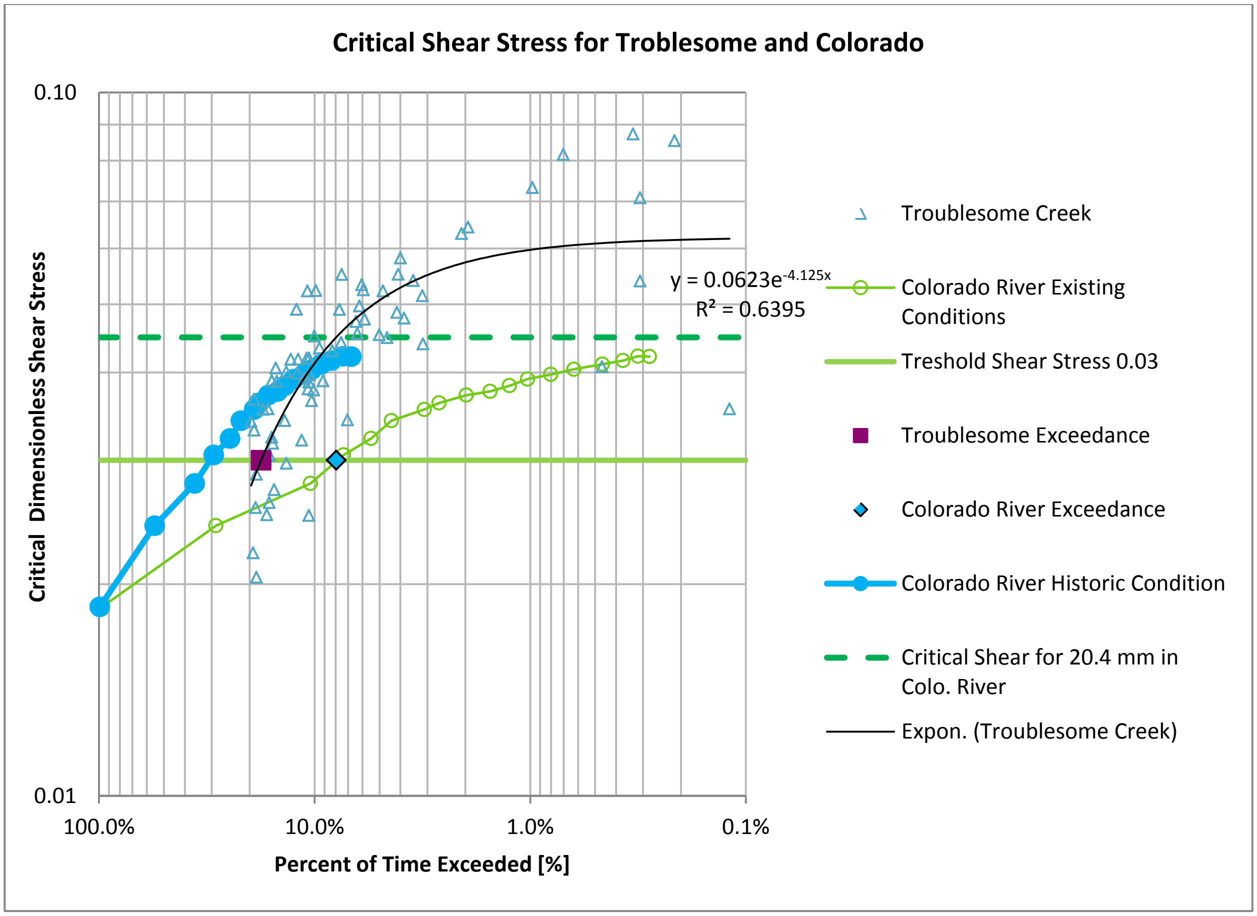


Figure 3-9. Shield's Stress Exceedance for Troublesome Creek and Colorado River.

Figure 3-9 shows the estimated dimensionless shear stress for Troublesome Creek and the Colorado River (existing and historic). An exponential line of regression shows the general trend of the Troublesome Creek data. The thresholds shear stress of 0.03 is displayed. When the median diameter particle's dimensionless shear stress is above 0.03 significant sediment transport is occurring. Andrews (1983) determined that for particle sizes between 0.3 to 4.2 times the median diameter the average critical dimensionless shear stress is defined by Equation 3-7. The ratio of median particle size for Troublesome Creek and the Colorado River ($d_{50Troublesome}/d_{50Colorado}$) is 0.8372. Thus, in the Colorado River, the median Troublesome particle size of 20.4 mm has a critical dimensionless shear stress of 0.045, which is also marked on Figure 3-9.

Equation 3-7

$$\tau^* = 0.0834\left(\frac{d_i}{d_{50}}\right)^{-0.872}$$

This analysis indicates that Troublesome Creek exceeds the critical dimensionless shear stress (0.03) for the median particle diameter (20.4 mm) approximately 17% of the time. In contrast the Colorado exceeds the critical dimensionless shear stress for the median particle diameter (24.4) approximately 8% of the time. Additionally, the threshold for Troublesome Creek's median diameter particle size in the Colorado River is greater than 0.04, which is achieved less than 1% of the time.

3.5.3 Conclusions

The reach of the river from Troublesome to Shepardsbend has excellent aquatic habitat. The primary issues are aggradation at the Ennis Pump irrigation intake and severe bank loss which threatens agricultural infrastructure. Based on the above described assessment these conditions are caused in large part by the fact that Troublesome Creek delivers more sediment to the Colorado River than the Colorado River can move. This aggradation places more stress on the banks. In places where riparian vegetation is limited this condition leads to bank erosion. The aggradation and bank erosion are inherent to this reach of the Colorado River and have resulted in frequent overbanks flows, multiple channels, and frequent channel movements over geologic history. The reduced hydrology of the Colorado River will have even less capacity to move sediment. Trying to engineer a solution to aggradation is very difficult. While the Colorado River channel could be modified to transport the sediment load coming from Troublesome Creek, the result would be more of a sediment flume and less of a natural river and it would simply pass the aggradation downstream to an adjacent land owner. The preferred approach to addressing these issues is as follows:

1) Allow river to flow overbank and move where it can;
2) Use flexible bank (bio-engineering) stabilization to limit bank loss were necessary;
3) Use hard stabilization only at critical locations;
4) Maintain sediment transport capacity by limiting in-channel modifications;
5) Consider in-channel infiltration for irrigation intake.

One approach to addressing the aggradation issue at the Ennis Pump is to replace the intake structure with a riverbed infiltration system. One way to accomplish this would be through the use of self-cleaning Coanda screens. These tilted wedgewire screens can be installed in a concrete wet well located within the riverbed. These screens are self-cleaning down to 1 mm. These types of facilities are typically unaffected by aggradation and can save significant maintenance costs over time.

3.6 Lower Reach Assessment

In the lower section of the ILVK reach there is evidence of historic headcuts. The following sections investigate the impacts of these events.

3.6.1 Meanders and Headcuts

In meandering systems the river may erode the bank on the outside of a bend to such a degree the channel cuts off a meander loop as shown in Figure 3-10. When this happens the channel slope increases in the vicinity of the meander cutoff which can lead to a headcut. A head cut occurs when the base elevation of a channel is lowered, which increases the local channel slope. The steeper channel slope results in increased velocities, shear stress and subsequent erosion of the channel as the river adjusts to the new base elevation (Figure 3-11). A river's response to a headcut can follow a typical pattern of adjustment (Figure 3-12).

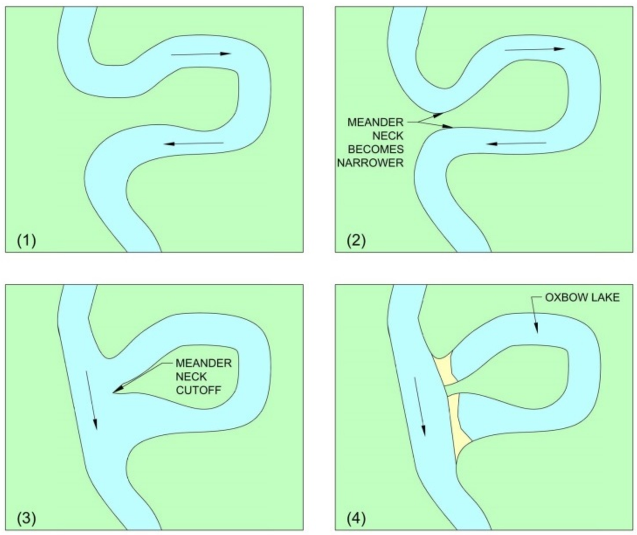


Figure 3-10. Explanation of meander cutoff.

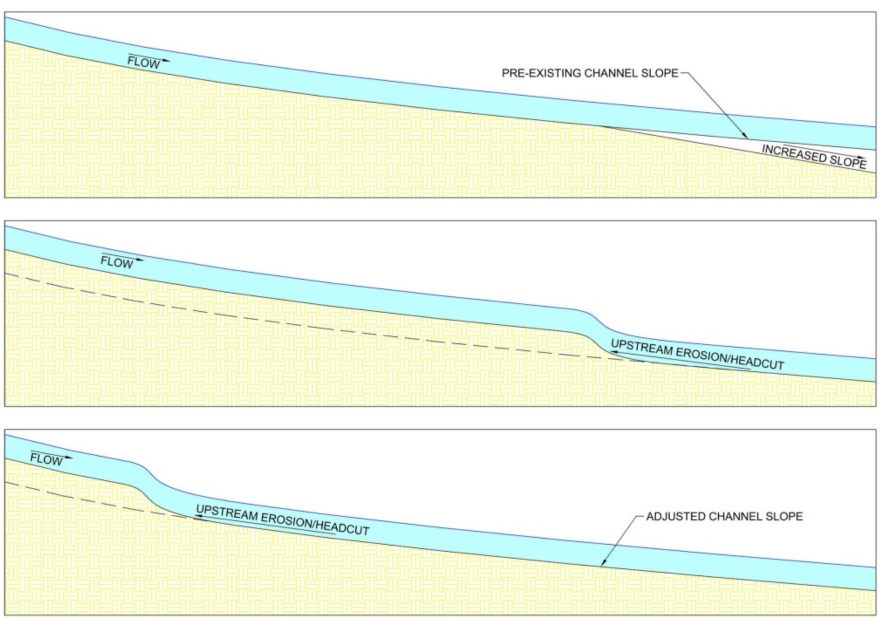


Figure 3-11. Explanation of channel headcut.

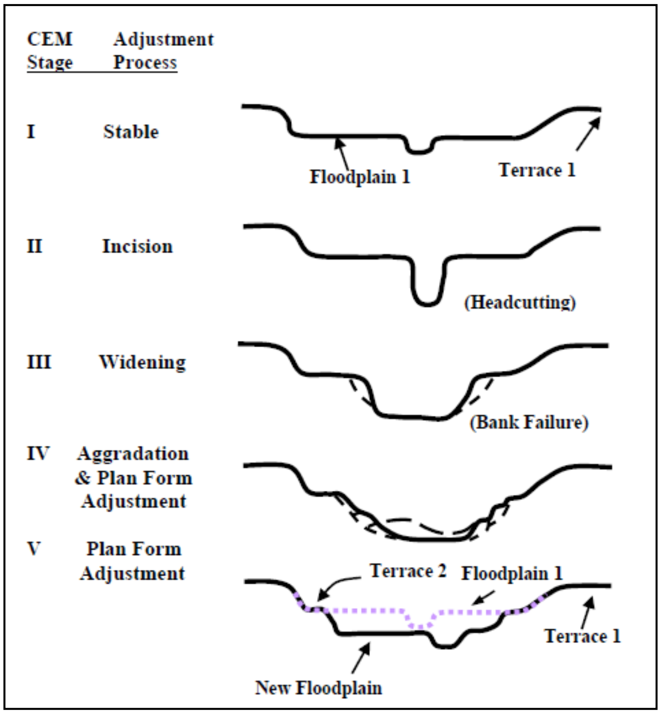


Figure 3-12. Channel adjustment to headcut.

3.6.2 Historic Assessment

Headcuts can be caused by a variety of factors, both natural and human caused. Inspection of aerial photographs shows that there were two meanders downstream of the ILVK reach that have been cutoff from the main channel in recent geologic history. These are easily identified in the 2014 Google Earth photo in Figure 3-13.

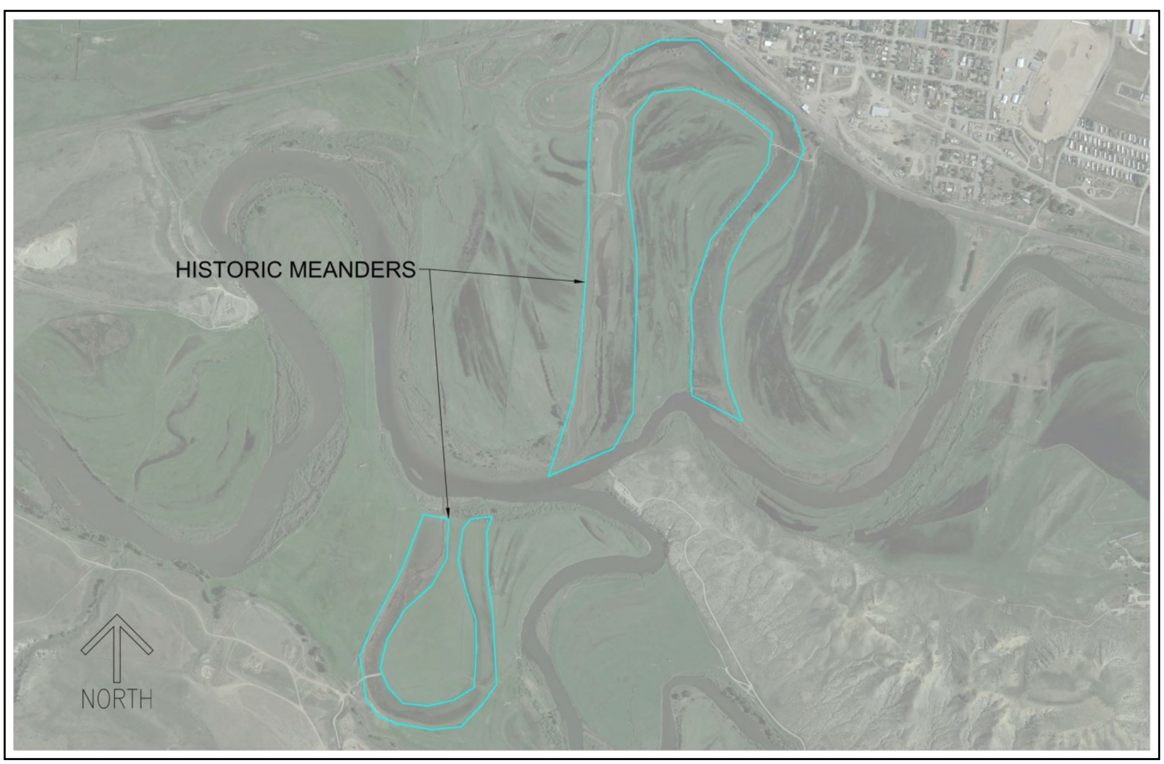


Figure 3-13. Historic meanders evident in 2014 Google Earth Photo.

No information about the cutoff of the southwest meander was found, and it may be a historic Blue River channel. However, research discovered that early in the 20th century a channel was excavated that cutoff the northeast meander. Research of historic photographs indicates that this likely occurred between 1907 and 1914. The photos in Figure 3-14 show this meander on the McElroy Ranch. They were both taken from the ridgeline due north of the Town of Kremmling looking south towards the Eagle's Nest Range. The upper photo was taken between 1900 and 1907 and shows large meander close to Town. The scar of the historic meander is clearly evident in the lower photo, taken in 2010.

Regardless of their origin, these meander cutoffs would have had an impact on the upstream channel morphology as the river adjusted. Research indicates that headcut migration rates can vary widely, over orders of magnitude (Loget and Van Den Driessche, 2009). Reported headcut migration rates range from as high as 2600 meters per year (Robbins and Andrew, 1984) and as low as 0.67 meters per year. Sometimes these headcuts can rotate (incline) and become a riffle when energy is dissipated over a longer reach over time (Stein *et al.*, 1998). Given the complexity and uncertainty of the river system response to this type of disturbance it’s difficult to precisely determine the height of the vertical adjustment or how far upstream in propagated. At moderate rates of headcut migration this disturbance could have easily impacted miles of channel in the lower portion of the study reach over the last 100 years.

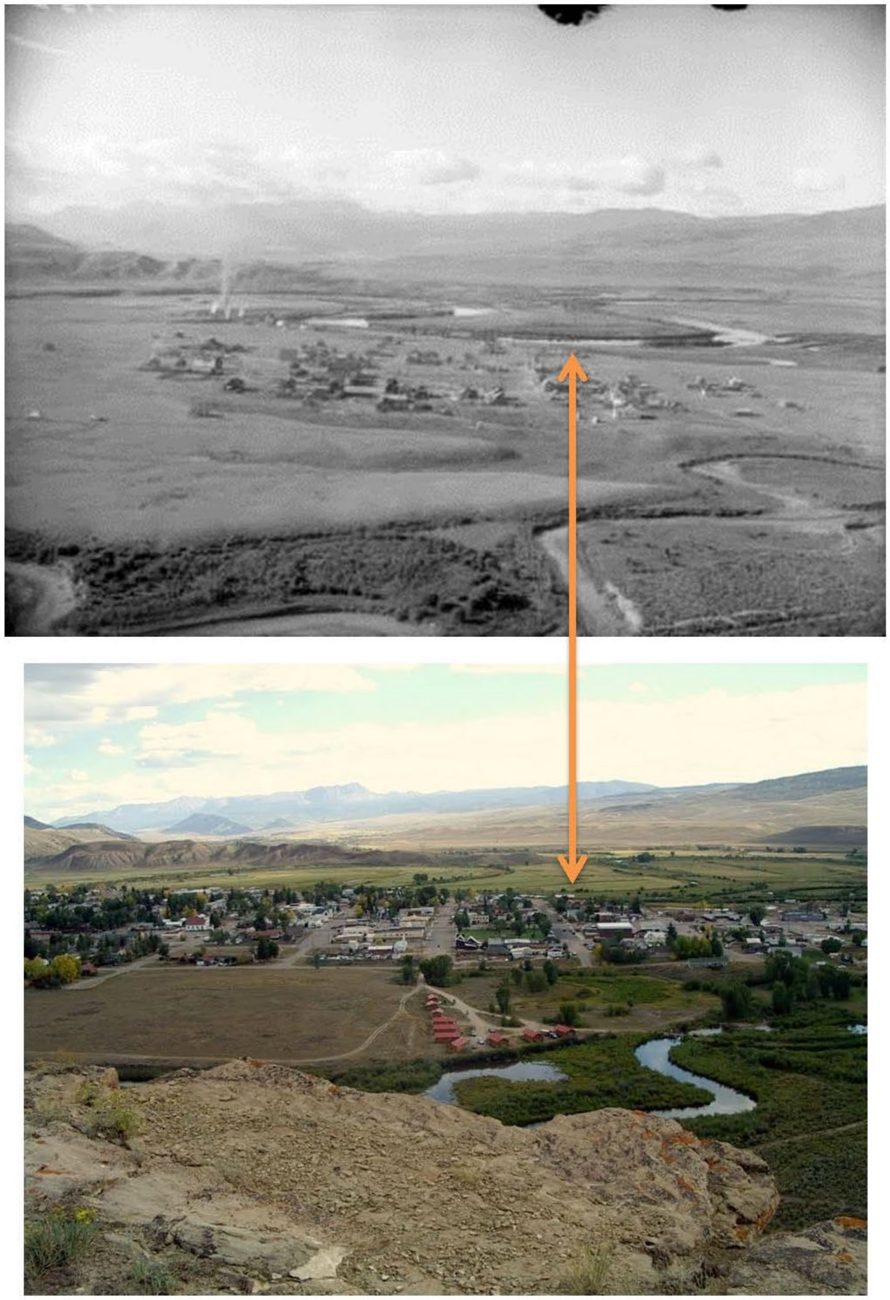


Figure 3-14. Photos of Historic Meander Location.

The reach from Highway 9 to the Blue River has a slope of approximately 0.0002 ft/ft. The meander that was cutoff was approximately 7250 ft long. It is assumed that the River has had adequate time to adjust to the meander cut off, and the existing channel slope is similar to the historic (pre-cutoff) channel slope. This would indicate that the channel degraded approximately 1.5 ft as a result of the meander cut (7250*0.0002=1.45) .

3.6.3 T.A. Engle Intake

The original T.A. Engle pump station was abandoned because of difficulty getting water into the intake. A new T.A. Engle intake was constructed at the present location, approximately 150 ft west of the old location. The difference in elevation of these two intakes provides a second estimate of the degree of channel downcutting experienced through this reach as a result of the meander cutoff and headcut. The surveyed elevation difference is 2.05 ft.

3.6.4 Conclusions

The lower section of the ILVK reach was impacted by a meander cutoff in the early part of the 20th Century. These types of cutoffs can occur naturally in meandering river systems such as the Colorado, however this one was manmade. Over the last 100-years the Colorado River has responded by downcutting its channel to establish a new equilibrium slope. Based on the above described assessment AECOM estimates that the lower section of the ILVK Reach downcut approximately 2 ft due to downstream meander cutoffs. This downcutting has led to bank instabilities throughout the lower ILVK Reach as the channel adjusted. Given the range of headcut advancement rates noted in the literature, it’s likely that the slope of the channel has adjusted to the impacts of the hedacut whereas the banks have not had time to stabilize.

3.7 Bankfull/Effective Discharge

There are a number of terms frequently used in stream restoration that merit definition. The terms Effective Discharge, Bankfull Discharge, and Dominant Discharge all address the same concept, but from a slightly different point of reference. Dave Rosgen (1996) considers bankfull discharge "…the single most important parameter in Level II classifications," or paraphrased: If you don't know bankfull, you don't know anything.

Bankfull discharge is the flow that fills the channel to the point where water spills out of the active channel and onto the floodplain. Bankfull flow is a somewhat objective classification, although research suggests that bankfull flow may transport the greatest amount of material over many years. Effective discharge is the discharge that transports the largest percentage of sediment load over a period of many years. It is the peak of a curve obtained by multiplying the flood frequency curve and the sediment discharge rating curve as shown in Figure 3-15 (Andrews, 1995). Dominant discharge is a theoretical discharge. If maintained constantly over time the dominant discharge would produce the same channel geometry that is produce by the long-term, variable hydrology of the stream.

Bankfull discharge is a physical condition that differs from location to location over short distances. It is determined in the field and different people will frequently delineate different bankfull elevations/discharges. In stable systems bankfull discharge is a physical representation of the central tendency of a stream system. Using field determined bankfull flow only works if this central tendency is not changing. In modified systems the central tendency may not be expressed because the system is still in response because geomorphic change takes time.

Andrews (1995) found that effective discharge for streams in the upper Colorado Basin ranged from 0.8 to 1.6 times the bankfull discharge. Effective discharge is a physical phenomenon. While it takes effort to calculate accurately, effective discharge may be the most appropriate surrogate for hydromodified systems. For this study it is assumed that bankfull discharge and effective discharge are equivalent; a representation of the central tendency of the river.

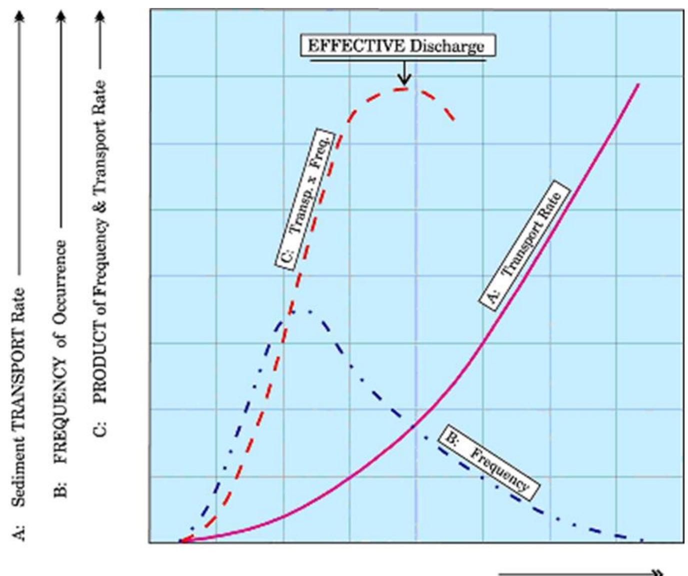


Figure 3-15. Effective Discharge.

The change in effective discharge over time was investigated using two methods. Historic effective discharge was evaluated using bankfull flow data for Colorado Basin streams collected by Andrews (1984). Future effective discharge was calculated using a combination of sediment transport modeling and the PACSM future hydrology. The following sections describe the procedures and results.

3.7.1 Historic Bankfull Estimate

Andrews (1984) investigated 24 gavel-bed rivers in the Upper Colorado basin in a detailed analysis of bed-material mobility and hydraulic geometry. For this study Andrews' data was used to relate basin area (mi^2) to bankfull discharge. A power function was fit to the data with a resulting R^2 of 0.92. The regression was used to estimate bankfull flow for the historic Colorado River through the ILVK reach. Figure 3-16 shows the results of this analysis. The estimated historic bankfull discharge for the ILVK reach is approximately 4800 cfs.

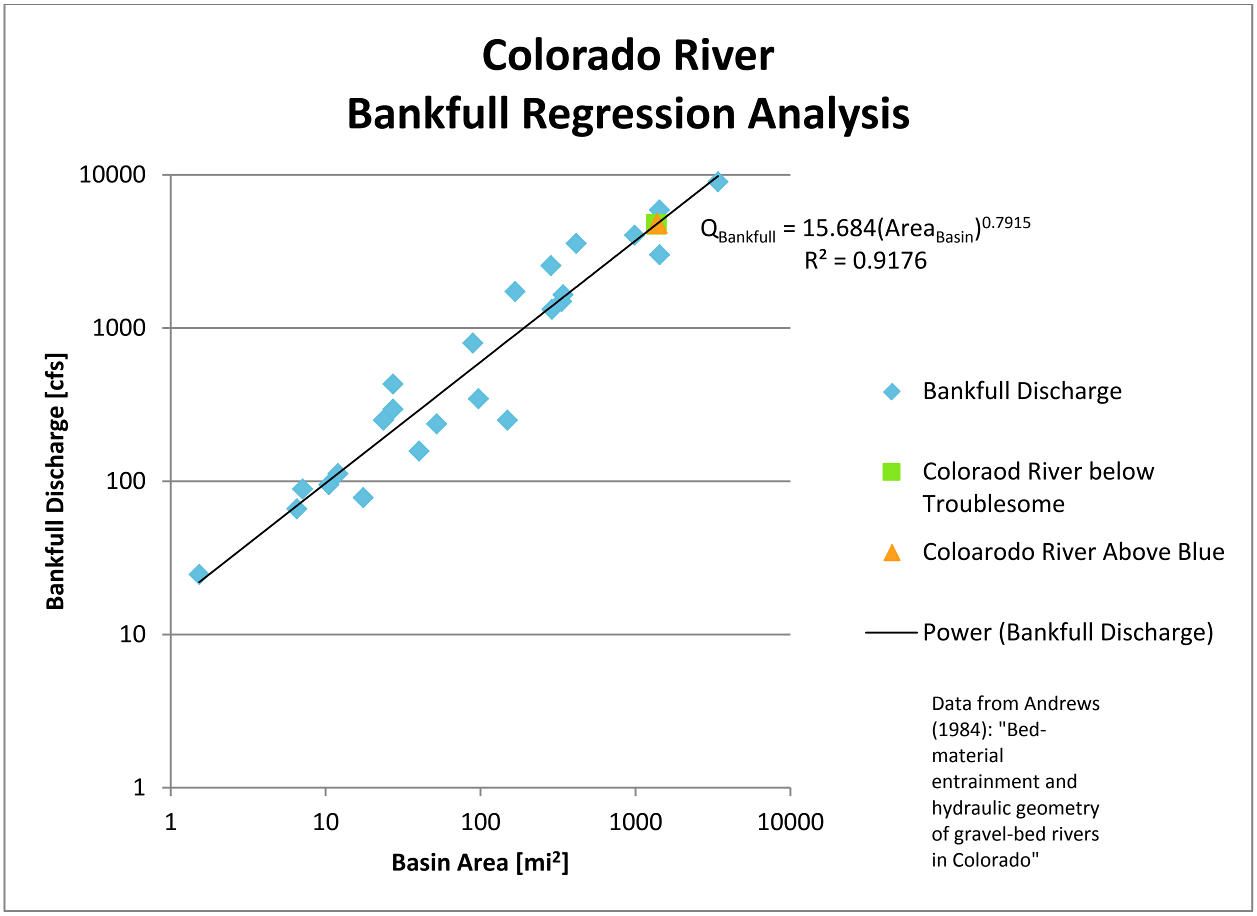


Figure 3-16. Historic Bankfull Discharge Estimate.

3.7.2 Future Effective Discharge Estimate

The sediment transport modeling resulted in nine different sediment rating curves (Section 3.3). These sediment transport relationships were used with the PACSM hydrologic data to develop an estimate of the future effective discharge for the Colorado River below its confluence with Troublesome Creek.

Logarithmic binning was used to separate the Colorado River flow frequency data into 26 different bins. The product of the flow frequency and the sediment discharge produces an effective discharge rating curve. Each of the nine different sediment rating curves resulted in an effective discharge estimate of 3500 cfs. Figure 3-17 shows the results of this analysis for the Brian's Bluff cross-section using average results from the Parker, WIlcock and Wilcock and Crow sediment transport analyses.

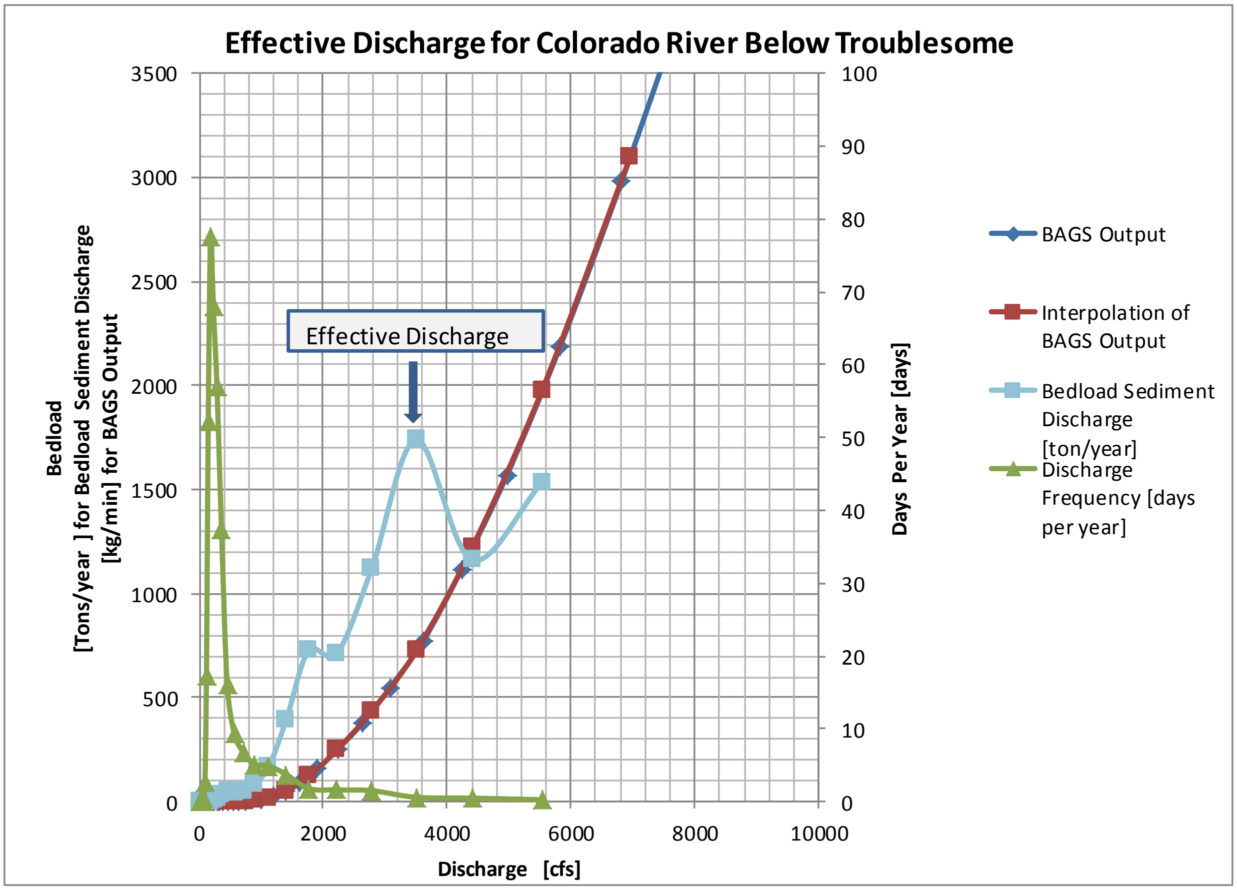


Figure 3-17. Future Effective Discharge Estimate.

3.7.3 Conclusions

Bankfull discharge and effective discharge are both used as surrogates to describe the central geomorphic tendency of a river system. For this analysis it is assumed that these values are equivalent for a reach of river over a period of time. Using a power regression of data relating bankfull flow to basin area the historic bankfull flow was estimated to be 4800 cfs. Calibrated sediment transport modeling was used to develop sediment rating curves for three different cross-sections downstream of Troublesome Creek. This data was combined with projections of future hydrology from Denver Water's PACSM model output. The estimated future effective discharge is 3500 cfs. Future channel and irrigation system improvements should be designed for a bankfull flow of 3500 cfs.

The reduction of channel forming discharge under the future conditions is in excess of 25%. A Log Pearson Type III analysis was performed on the hydrologic data to approximate the return period for the historic bankfull discharge and the future effective discharge. This analysis shows that the historic bankfull flow of 4800 cfs is approximately a 2-year event, whereas the future effective discharge of 3500 cfs is closer to a 10-year event.

3.8 Channel Width

The hydraulic geometry of a stream is the geomorphic expression of the river's central tendency. The hydraulic geometry of a river is described by the variables of bankfull mean depth, bankfull width, and channel slope. Without ground survey data spanning the time period of channel evolution there are limited ways to estimate historic channel hydraulic geometry. Historic bankfull width can be estimated from aerial photographs. The following sections describe an analysis of channel width evolution over the past 70 years.

3.8.1 Analysis

Relationships established by Andrews (1984) were used to estimate historic and future expected bankfull channel widths for the historic bankfull flow of 4800 cfs and the future flow of 3500 cfs. Table 3-4 shows the results of this analysis. The results indicate that the historic bankfull width of the Colorado River would be expected to be between 187 ft and 224 ft, whereas the bankfull width under future conditions would be 161 ft to 193 ft, a reduction in width of approximately 14%.

Veg Type	Condition	Q [cms]	D50 [m]	Qbar	W*	W [m]	W [ft]
Thin	Colroado River Historic	134.7	0.0244	573786	2795	68	224
Thick	Colroado River Historic	134.7	0.0244	573786	2333	57	187
Thin	Colroado River Future	99.1	0.0244	422249	2414	59	193
Thick	Colroado River Future	99.1	0.0244	422249	2013	49	161

Table 3-4. Bankfull Channel Width from Andrews (1984).

As the hydrology of the Colorado River has changed over time the river has responded. The reduced flows have allowed vegetation to become established on point bars. This vegetation has promoted the additional deposition of sediment which narrows the active channel. Analysis of historic photos provides evidence of this adjustment. Figure 3-18 shows a bend of the Colorado River just upstream of Elktrout Lodge. It is evident from the vegetation in this photo that the active channel of the Colorado River has narrowed in the 75 years between when photos were taken. This process of narrowing continues, albeit at a slow rate.

Examination of the HEC-RAS results show that 3500 cfs is contained within the active channel at some of the cross-sections, but that for many of the cross-section 3500 cfs spills out of the active channel and onto deposition features such as point bars. Figure 3-19 shows a typical HEC-RAS cross-section at a discharge of 3500 cfs. The active channel is located between the two bank stations (red dots). On the right side of the right bank station there is the point bar (Station 280 to Station 500). This is the same point bar shown in Figure 3-18. Over the last 75 years this point bar has become vegetated. This vegetation causes deposition on the point bar during high flows. This deposition is slowly narrowing the channel over time.

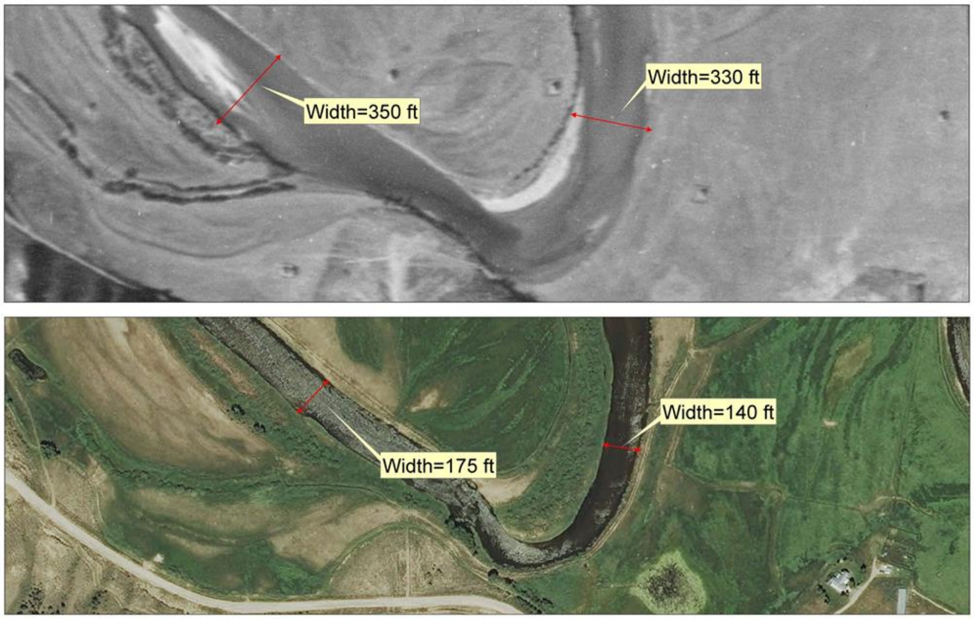


Figure 3-18. Channel Width Evolution.

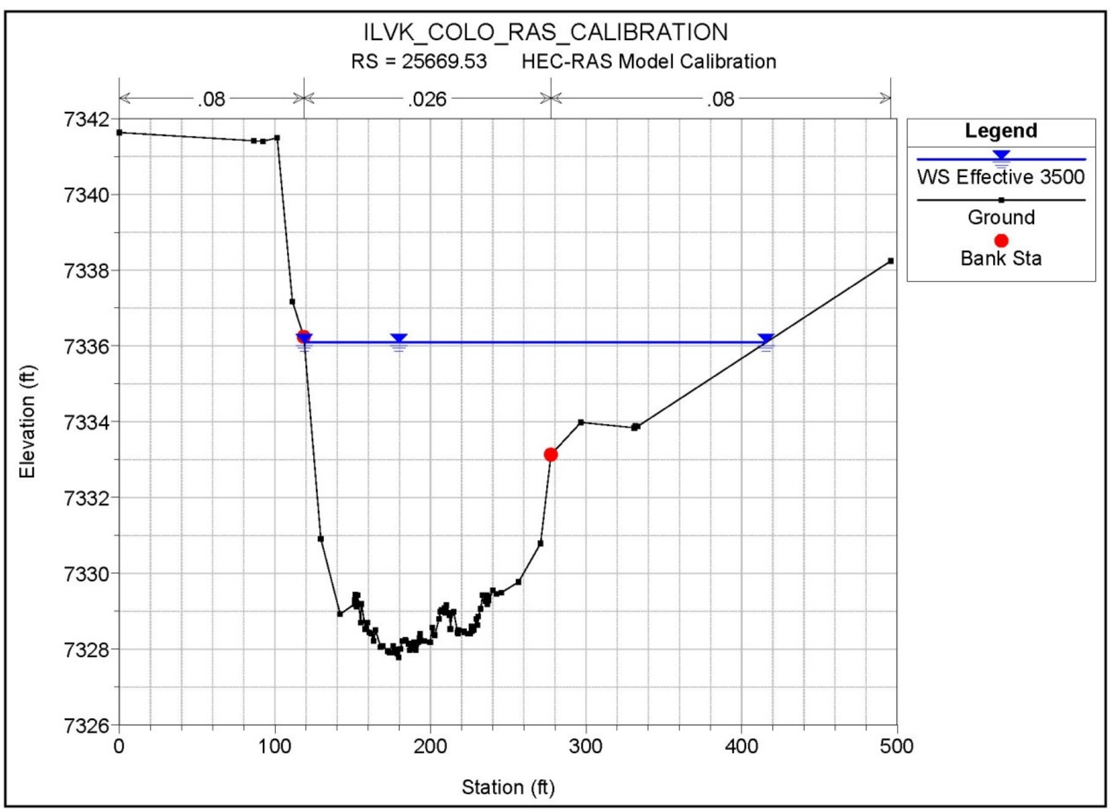


Figure 3-19. Typical Cross-section at bankfull flow.

3.8.2 Conclusions

Regression analysis of Bankfull Flow Widths for the Colorado River Basin indicates that a 14% reduction in bankfull channel width would be expected given the changes to the basin hydrology. Analysis of aerial photos from 1938 show that historically the active channel of the Colorado River was much wider than it is now. The historic channel is wider than predicted by the regression analysis, indicating that the historic bankfull (effective) discharge may be even larger than the 4800 cfs determined in Section 3.7. The Colorado River through the ILVK reach has appeared to narrow substantially over the last 75 years in response to the decrease in hydrology, a process that will continue. While narrowing the channel for these flows may make sense at specific locations, a wholesale narrowing of the 10 mile reach is impractical and unwarranted. With respect to channel width the critical issue is controlling temperatures at low flows. So, the restoration plan should focus on narrowing the low flow channel, and facilitating the natural narrowing of the high flow channel where feasible.

3.9 Historic Photos

Historic aerial photographs dating as far back as 1938 were reviewed to assess the historic changes throughout this reach. Figure 3-20 presents aerial photos from 1938 and 2013 for comparison. The 1938 aerial photographs have been geo-rectified using objects that are common to both photos, of which there are few. The resulting georeferenced photos are suitable for a planning level analysis but they should not be used for detailed analysis.

It is evident from this photo comparison that the Colorado River has maintained a relatively stable planform over the past 75 years. While the planform is similar, it is clear from the photos that the historic Colorado River had significantly more structure (point bars, mid-channel bars, and riffles). The channel has also narrowed significantly during this time period.

Figure 3-20. Aerial Photographs from 1938 and 2013.

3.10 Geomorphic Analysis Summary

The preceding sections present the geomorphic assessment of the Colorado River between the KB Ditch Headgate and its confluence with the Blue River and Muddy Creek. This analysis looked at geomorphic issues relating to bank instability, channel degradation, channel incision and channel width. The following points summarize the results of the geomorphic analysis.

- The effective discharge (aka Bankfull Flow) of the Colorado River has decreased from a historic discharge of 4800 cfs to 3500 cfs.
- The return period for the bankfull flow events has reduced from a 2-year event to a 10-year event.
- The upper section of the ILVK Reach, in the Vicinity of Troublesome Creek, is prone to aggradation because Troublesome Creek delivers more sediment to the Colorado River than it can reliably move. This is an inherent issue with the Colorado River and engineering solutions are likely economically unfeasible.
- The lower section of the ILVK Reach, upstream from the confluence with the Blue River, has degraded approximately 2 ft. due to a meander cutoff in the early 20th Century.
- The overall width of the Colorado River appears to be adjusting to the modified hydrology. While the bankfull discharge (effective discharge) is contained within the active channel at some locations, it flows out of the active channel at other locations. Narrowing the entire channel so that the bankfull flow is contained within the active channel would require placing in excess of 300,000 cubic yards of material over the 53,300 linear feet of channel. This would require a significant engineering and construction effort with questionable return on investment. The recommended approach is to focus restoration activities on creating habitat diversity, narrowing the low flow channel to address high water temperatures, stabilize the banks, and establish riparian vegetation for cover.

4 Restoration Recommendations

Based on the geomorphic assessment AECOM has developed a number of recommendations. The first section outlines the general approach to restoring the healthy function of the ILVK Reach of the Colorado River. The next section presents the specific engineering recommendations including methods. A conceptual restoration plan is presented with a preliminary cost estimate.

4.1 Restoration Approach

A healthy river is capable of providing all of the multiple benefits expected from the Colorado River including agricultural irrigation, wildlife, and recreation. The approach to resolving the irrigation diversion problems for the ILVK ranches should also restore the other healthy functions of the river. During this project AECOM worked closely with the ILVK to develop an approach to restoring the Colorado River through the ILVK reach. The following outlines important parts of this approach.

- Projects should preserve and enhance agricultural operations. The irrigation and agricultural operations are the lifeblood of these ranches. Any attempts to resolve the issues outlined in this report should be done with an emphasis on developing sustainable ranching operations. The agricultural infrastructure should be protected from damage due to bank instabilities and channel migration. Irrigation diversions should require minimal maintenance and perform well.
- Projects should be designed with the goal of multiple benefits. Diversion structures should be designed within the geomorphic context of the channel to provide not only sustainable irrigation diversions, but also provide habitat. Bank protection and channel stabilization should also be design with habitat in mind.
- Projects should use local materials where possible. In particular, importing material such as riprap or boulders can be a significant source of cost. While engineering design will drive the material used for the construction of projects, finding/developing local sources of material that require minimal hauling could have significant costs savings. Additionally, using locally sourced material results in projects that blend into the natural environment. In the upper sections of the ILVK Reach there may be good sources of appropriately sized alluvium nearby the stream which could be used at great economy. Where material is suitable, it could be mined and then area turned into an oxbow pond. These ponds could connect to the river channel to provide refuge habitat for juvenile fish.
- Projects should limit the use of large boulders in the channel. Boulder drop structures are frequently used for diversion structures and grade control in stream restoration. Research indicates that the use of boulder drop structures has a negative impact on aquatic habitat suitability for trout (Salant et al., 2012; Kolden, 2013 and Fox, 2013). Boulders can provide habitat and scour protection, but should be limited in their use in drop structures.
- Projects should maintain flood conveyance. River modifications should safely pass the 100-year flood without negatively impacting critical infrastructure.
- Projects should be designed to an appropriate bankfull flow. AECOM estimates the effective discharge to be approximately 3500 cfs in the upper section of the ILVK Reach. Effective discharge can range anywhere from 0.8 to 1.6 times the bankfull discharge indicating that design bankfull discharges could range from 2200 cfs to 4300 cfs.
- Projects should allow overbank flow where acceptable. Flooding is a natural occurrence in healthy streams. Projects should continue to allow overbank flows where acceptable. Bankfull benches should be constructed were floodplain connection is limited to allow for overbank flows. These areas can also provide additional wetlands and riparian habitat.
- Projects should limit the use of hard revetment. While there are certain situations where solid protection is required and riprap blankets, concrete blocks, or boulder walls are necessary, but their use should be limited when possible. Bank protection should be performed with deformable banks where acceptable. Stream bank erosion is a characteristic of healthy stream systems and bank stabilization methods should allow for some future channel adjustment where acceptable. Using willow stake planting and other bio-engineering methods should be emphasized.
- Projects should improve the low flow channel. Low river flows make irrigation diversion difficult and result in high water temperatures that threaten trout and other aquatic organisms. Projects should be designed to reduce the width of the water surface at these low flows where possible. This can be accomplished using a combination of point bars, riffles, and expanded pools.

4.2 Engineering Approach

The proposed conceptual restoration plan utilizes a number of different features to achieve the restoration goals. The design of these features will be based on an analytical analysis. The following sections describe the various features proposed.

4.2.1 Grade Control Riffle

A number of the ILVK diversion structures need to be replaced or reconfigured to improve intake performance. Several of them will require new grade control structures to replace those installed by Northern. These grade control structures should be designed to mimic a natural riffle as much as possible: what is being termed a “Grade Control Riffle” (Figure 4-1). The healthy, productive riffle at Brian’s Bluff (see Figure 1-1) on Reeder Creek Ranch has a bed slope of approximately 0.25%. Constructing a slope as flat as 0.25% may not be achievable for these intake structures, but slopes should be minimized where possible.

Figure 4-1 Grade Control Riffle at Riverside Ranch

These proposed Grade Control Riffles will provide adequate water surfaces for pumping operations while at the same time providing critical habitat. A demonstration Grade Control Riffle was constructed at the Thompson Consolidated Pump diversion in the fall of 2014 as a pilot project (Figure 4-1). The riffle was completed in early November 2014. Within a few months benthic invertebrates were found using the riffle habitat (Figure 4-2). The design of these riffles can be easily modified to include in-channel infiltration and/or sediment by-pass sluices.

Figure 4-2 Benthic Invertebrates Found at Riffle Grade Control Pilot Project

A conceptual design for the Grade Control Riffle is presented on Sheet R- 1 in Appendix A. The conceptual design includes a core of riprap that is keyed into the banks to prevent outflanking. This core is laid out with wings that extend out from the bank in an upstream direction to a control section across the center of the river. The riprap core provides structural stability and resists against scour. The riprap core is then covered with locally sourced alluvium which is graded out to an appropriately flat slope. The size (d_{50}, gradation, etc.) of the alluvium will be determined during the final design process. While this approach takes more material than a boulder drop structure it provides the same function while providing habitat.

4.2.2 Sustainable Riffle

The purpose of the sustainable riffle is to provide habitat for aquatic organisms, provide diversity of flow, and to narrow the low flow channel. They are to be used in conjunction with point bars and pools. The Sustainable Riffle differs from the Grade Control Riffle in several ways: they do not have a riprap core, they are not intended to be used to provide a precise water surface elevation, they do not key into the bank, and they have limited impact on the profile of the river.

The concept behind these sustainable riffles was developed from research by Andrews and Nelson (1989) who investigated a mid-channel bar in the Green River, Utah that was stable over long periods of time. The concept is to use a depth integrated, 2-Dimensional hydraulic model with sediment transport modeling and a live bed to design a riffle structure that will be partially mobilized during high flow events but will remain relatively stationary, or “Sustainable”. The Sustainable Riffles will have a very small impact on the overall slope of the channel and may only raise the riverbed a few inches. The design should consider the potential effect of these structures on channel aggradation.

It may be possible to use this type of self-sustaining riffle for intake diversions where the expected bedload is sufficient to maintain them. This would be determined during final design. For the purposes of cost analysis it was assumed that these sustainable riffles would not be used for diversion structures.

4.2.3 Enhanced Pools

An important factor in moderating river water temperature is groundwater inflow. This inflow can be from either natural groundwater sources or irrigation return flows. Pools, or holes, can be enhanced by excavating their bottoms and when combined with properly design riffles and point bars these pools can be self-scouring. This method will work in locations were the river bottom is gravel. In sections were the river bottom is sand it’s likely that these enhanced pools will fill with sediment and be unsustainable, therefore they are only proposed upstream of the Highway 9 Bridge.

4.2.4 Bank Protection

The variety of different bank protection methods used in stream restoration is endless and there are numerous combinations of techniques that will work. For simplicity four types, or levels, of bank protection were considered in the concept plan with Level 1 being the simplest and Level 4 being the most robust. Possible substitutions for each level are mentioned.

4.2.4.1 Level 1

This is the simplest form of bank protection to be used in locations where the shear stresses are not significant. Drawing R- 2 in Appendix A presents the Level 1 bank protection design details. If a bankfull bench is constructed the excavated material may be used to shape the bank prior to installing the bank protection. Then locally sourced alluvium placed along the bank at a slope of 2(H):1(V) or flatter. The alluvium is keyed into the existing river bed as specified during design (typically 3ft). Where the alluvial fill meets the bankfull bench a series of soil wrapped lifts are used. The bank is then planted with live willow stakes or other appropriate vegetation. The bankfull bench is planted with Cottonwood stakes and other native grasses, forbs and shrubs.

The soil wrapped lifts consist of two layers of geotechnical fabric wrapped around a 12 inch lift of topsoil of alluvium. The outer fabric is a woven coir fabric designed to prevent abrasion, and the inner layer is a non-woven coir used to prevent the loss of fines. A 12 inch coir log is placed inside the wrap on the river side to protect against impacts from floating debris. Wooden stakes are then used to secure the fabric. The wrapped soil lifts will be used as needed.

4.2.4.2 Level 2

This is similar to Level 1 bank stabilization but utilizes rip-rap for toe scour protection. Drawing R- 3 in Appendix A presents the Level 2 bank protection design details. If a bankfull bench is constructed the excavated material may be used to shape the bank prior to installing the bank protection. Riprap is then placed along the toe of the proposed finished bank which is then backfilled with locally sourced alluvium at a slope of 2(H):1(V) or flatter. Were the alluvial fill meets the bankfull bench a series of soil wrapped lifts are used were necessary. The bank is then planted with live willow stakes or other appropriate vegetation. The bankfull bench is planted with Cottonwood stakes and other native grasses, forbs and shrubs.

Level 2 bank protection can be modified to include bioengineering alternatives such as incorporating woody debris (Figure 4-3) or a live crib wall for bank protection (Figure 4-4). For planning purposes it was assumed that these various methods would have similar costs. The type of bio-stabilization used at each location will be determined during final design based on land owner input, availability of materials and costs.

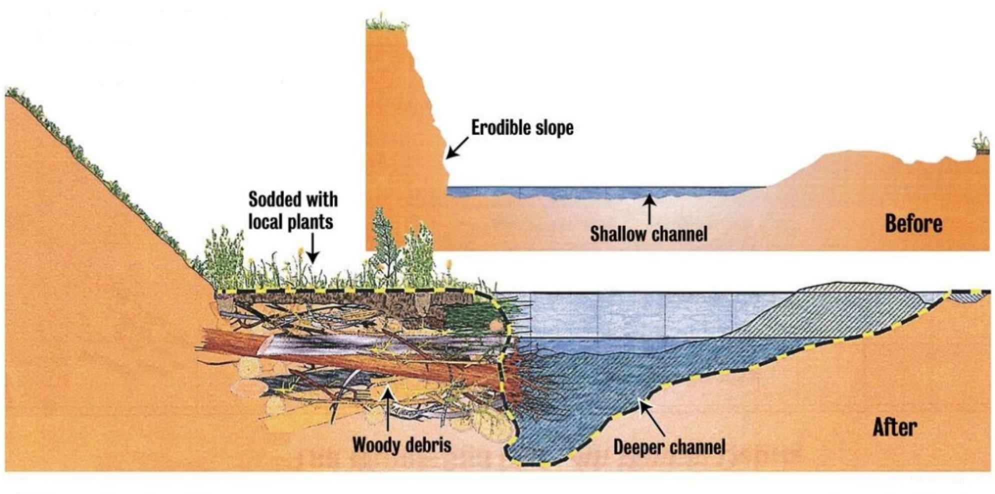


Figure 4-3 Example of Wood Bank Protection (image from http://www.mankatofreepress.com/).

4.2.4.3 Level 3

This is similar to Level 2 bank stabilization but utilizes large boulders for toe scour protection. This is used where shear stresses are significant, such as the outside of bends. Drawing R- 4 in Appendix A presents the Level 3 bank protection design details. If a bankfull bench is constructed the excavated material may be used to shape the bank prior to installing the bank protection. Boulders are then placed along the toe of the proposed finished bank which is then backfilled with locally sourced alluvium at a slope of 2(H):1(V) or flatter. Were the alluvial fill meets the bankfull bench a series of soil wrapped lifts are used were necessary. The bank is then planted with live willow stakes or other appropriate vegetation. The bankfull bench is planted with Cottonwood stakes and other native grasses, forbs and shrubs.

4.2.4.4 Level 4

Level 4 bank protection is an imbricated, vegetated boulder wall. This is used where shear stresses are significant and space is constrained, such as the outside of bends were irrigation infrastructure is located. Drawing R- 5 in Appendix A presents the Level 4 bank protection design details. If a bankfull bench is constructed the excavated material may be used to shape the bank prior to installing the bank protection. Boulders are then stacked along the proposed finished bank at a slope of 0.5(H):1(V). Were the boulder wall meets the bankfull bench a series of soil wrapped lifts are used were necessary. The wall is then planted with live willow stakes or other appropriate vegetation. The bankfull bench is planted with Cottonwood stakes and other native grasses, forbs and shrubs.

Figure 4-4 Example of Live Crib Wall Construction-Level 2 Alternative

4.2.5 Riffle Vanes

A riffle vane is a modification of a typical rock vane used in stream restoration. Instead of using boulders for the vane structure, the riffle vane is constructed in a similar fashion as the Grade Control Riffle described above: a riprap core is backfilled with locally sourced alluvium. The vane is angled upstream at an angle of less than 30° from parallel. The purpose of this structure is to redirect flow at critical locations while also providing habitat diversity. These can be thought of as being similar to the Grade Control Riffles but they only span a portion of the river. Drawing R- 6 in Appendix A presents Riffle Vane design details. A riffle vane was constructed at the Orr No. 2 Ditch intake in the fall of 2014 to pilot test the design.

4.2.6 Habitat Boulders or Logs

These habitat improvement structures provide flow diversity and refuge. Log structures are typically placed along the bank. Boulder structures can be placed along the bank or in the channel. The use of boulder clusters should be limited to the upstream reaches and not used in the lower sand bed channel sections. Drawing R- 7 in Appendix A presents the details of the habitat log design.

4.2.7 Automobile Bodies

Throughout the ILVK reach there are numerous automobile bodies that have been placed for bank protection. Many of these are from the early 20th century. In many cases the riverbanks have revegetated around the car bodies (Figure 4-5). While removal of these cars would be an excellent project goal, the costs could be significant, and the disturbance could outweigh the benefit. Therefore, the restoration plan was developed assuming that these car bodies would be left in place and backfilled.

Figure 4-5 Example of revegetation through Automobile Body

4.2.8 Riparian Fencing

Throughout the project reach there is evidence of livestock grazing in the riparian corridor. While riparian fencing has been installed to protect some sections of the river, much of the ILVK reach does not have riparian fencing. AECOM recommends installing riparian fencing throughout the project reach. It is particularly important for newly restored areas to be fenced to allow vegetation to be established. Once riparian vegetation is established grazing management plans can be developed that allow a sustainable level of grazing in the riparian corridor.

4.3 Restoration Plan

4.3.1 Maps

Appendix B contains 17 restoration plan maps that present a concept plan for restoration. These maps are conceptual and are intended for planning purposes only. Details, such as the type, location and extent of bank protection will be finalized during the design process.

4.3.2 Cost Estimate

Cost estimates were developed for the conceptual plan outlined in Maps 1 to 17. Costs were developed based on correspondence with local contractors and suppliers, previous projects, and professional judgment. Estimates for Permitting, Design and Administration were based on assumed percentages of the construction estimate.

A large portion of the estimated costs are for material (e.g. boulders, alluvium, etc.). Significant cost savings could be incurred if local sources of material are found. For example, throughout the upper section of the ILVK Reach the valley bottom consists of alluvial deposits of sands, gravels and cobbles. Were suitable material is located oxbow ponds or wetlands could be constructed and the excavated material used for the river construction. This may not be possible in the lower section of the river due to sand deposits. Additional savings could be also realized by collecting willow and cottonwood stake plantings locally.

The items considered in the cost estimate are as follows:

- Mobilization/Demobilization-cost includes contractor mobilization and bonding. Actual costs may differ and will be determined during design. Approximated as 10% of construction costs.
- Care of Water-cost covers dewatering, sediment/erosion control, and preparation of Stormwater Pollution Prevention Plans. Actual costs may differ and will be determined during design. Approximated as 10% of construction costs.
- Grade Control Riffle-cost includes labor, equipment and material to construct a Grade Control Riffle as outlined in Drawing R- 1. Cost per Grade Control Riffle is $85,000.
- Sustainable riffle-cost assumes average width=75 ft., height=1 ft., length=105 ft, and a total volume of fill=400 yd^3. Cost per riffle is $10,000.
- Point Bar-cost assumes average depth=1 ft, labor and materials. Cost per acre is $24,200.
- Level 1 Bank Protection-cost for conceptual design R- 2. Includes geotechnical fabric and plantings. Cost per linear foot is $75.00.
- Level 2 Bank Protection-cost for conceptual design R- 3. Includes geotechnical fabric and plantings. Cost per linear foot is $100.00.
- Level 3 Bank Protection-cost for conceptual design R- 4. Includes geotechnical fabric and plantings. Cost per linear foot is $200.00.
- Level 4 Bank Protection-cost for conceptual design R- 5. Includes geotechnical fabric and plantings. Cost per linear foot is $235.00.
- Riffle Vane-cost includes labor and material to construct vane as shown in Drawing R- 6. Cost per vane is $20,000.
- Habitat Structures- cost includes labor and material to construct habitat structures as shown in Drawing R- 7. Cost per structure is $5,000.’
- Island removal-cost to move island upstream of Shepardsbend Bridge. Total cost is $9,000.
- Land Reclamation-cost to reclaim land lost to erosion upstream of Shepardsbend Bridge and construct bankfull wetlands bench. Material from island removal will be used for fill. Does not include wetlands planting. Cost per acre is $51,000.
- Wetlands Planting-cost to plan wetlands. Cost per acre is $10,000.
- Oxbow creation-cost includes excavation and final grading. Average excavated depth six feet. Assumes excavated material will be used nearby. Cost per acre is $39,000.
- Pool enhancement-cost includes excavation and final grading. Average excavated depth is two feet. Assumes excavated material will be used nearby. Cost per acre is $16,000.
- Unlisted items-covers miscellaneous items. Approximated as 10% of total construction costs.

The breakdown of estimated costs is provided in Table 4-1. The total estimated cost for restoration of the ILVK reach is $15,894,000. This includes a 35% contingency, 3% for permitting, 15% for designs, plans and specifications, and 10% for administrative costs.

Item Description	Unit	Unit Price	Total	
			Quantity	Cost
Mob/Demob (10%)	LS	$700,000	1	$700,000
Care of Water (10%)	LS	$699,600	1	$700,000
Grade Control Riffle	EA	$85,000	9	$765,000
Sustainable Riffle	EA	$10,000	18	$180,000
Point Bar Creation	AC	$24,000	11	$253,000
Level 1 Bank Protection	LF	$75	17141	$1,286,000
Level 2 Bank Protection	LF	$100	22885	$2,288,000
Level 3 Bank Protection	LF	$200	6033	$1,207,000
Level 4 Bank Protection	LF	$235	1980	$465,000
Riffle Vane	AC	$20,000	7	$140,000
Habitat Structures	EA	$5,000	26	$130,000
Island Removal	AC	$23,000	0.4	$9,000
Shepardsbend Reclamation	AC	$51,000	0.3	$15,000
Wetland Planting	AC	$10,000	3	$26,000
Oxbow	AC	$39,000	4	$159,000
Pool Enhancement	AC	$16,000	5	$73,000
Unlisted Items	LS	$692,300	1	$692,000
Subtotal				**$9,088,000**
Contingency	35%			$3,181,000
Permitting	3%			$273,000
Design, Plans, Specs	15%			$1,363,000
Admin	10%			$909,000
Total				**$14,814,000**

Table 4-1 Engineer's Cost Estimate.

5 Recommendations for Future Work

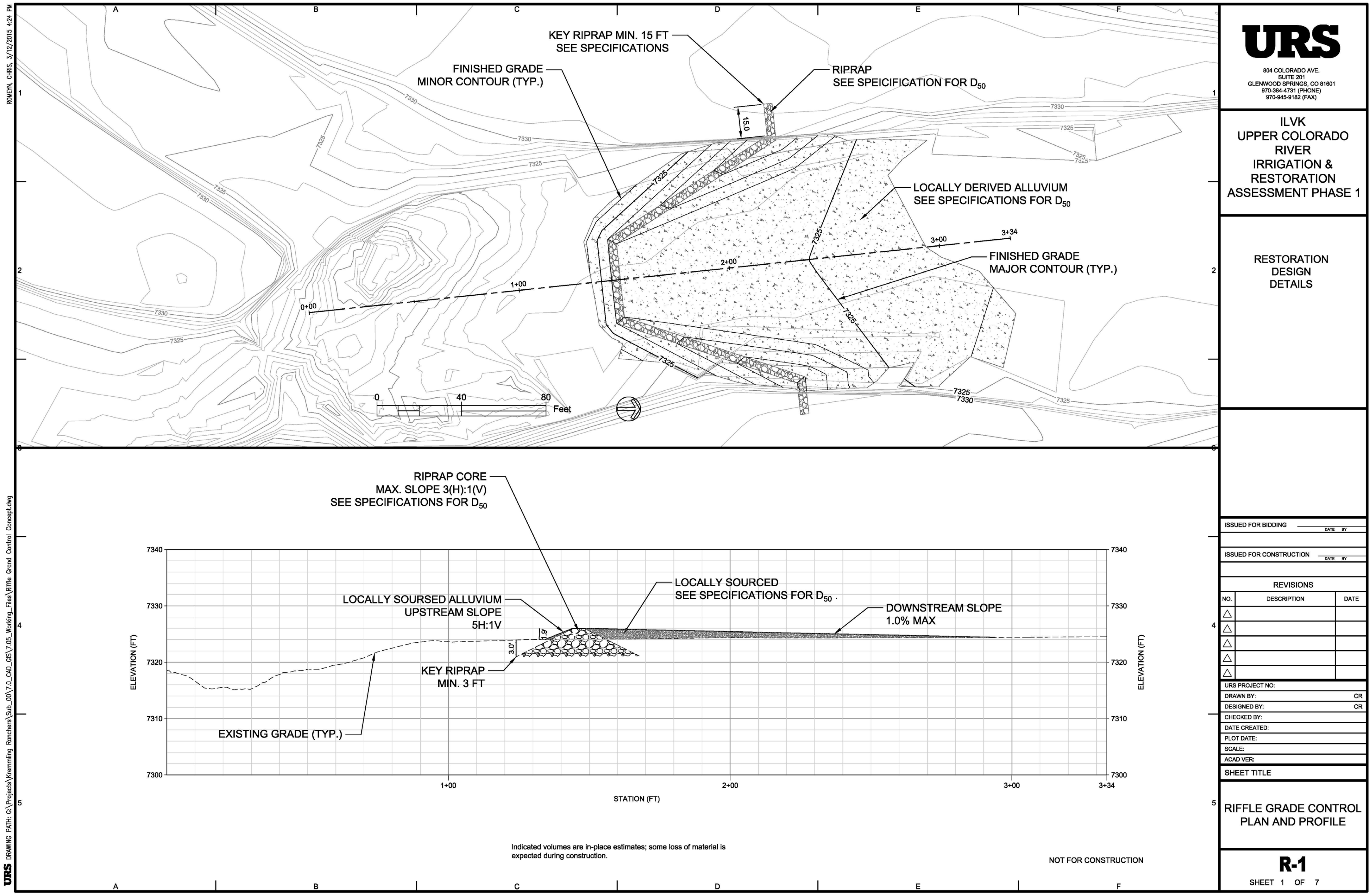
During the course of this assessment a number of topics were identified for future investigations as follows:

- The temporary stream and temperature data collected is adequate for this qualitative analysis. AECOM recommends that a permanent monitoring program be initiated across the restoration reach to establish long term temperature trends and toassess restoration success.
- Without ongoing gaging the flow below Troublesome Creek must be estimated. The Denver Water PACSM results for the base conditions were used to estimate flows through the reach by correlating known flows below the KB Ditch to modeled flows. Installation of a flow gaging station on Troublesome Creek would be invaluable to the future restoration design and monitoring efforts along the ILVK reach.
- The plan for this investigation was to use the USGS mapping for overbank cross-section and for construction plans. AECOM has identified the USGS mapping is inaccurate by as much as 100 ft when compared to the Ayers survey data in the ILVK Reach. To evaluate flood conditions AECOM recommends topographic mapping through the ILVK reach for both analysis and construction planning.
- Develop plans and specifications by individual ranch (Landowner) to incorporate individual recommendations and to refine construction cost estimates.
- Develop demonstration or adaptive management projects for the bank protection alternatives to refine design and construction techniques. This will ensure that sustainable, cost effective solutions are implemented. Monitoring of the projects should occur post-construction.
- Perform aquatic habitat baseline and periodic monitoring to document the performance of the stream restoration measures.
- Coordination with other stream restoration projects in the Upper Colorado River to coordinate activities and to share successful and unsuccessful stream restoration techniques.

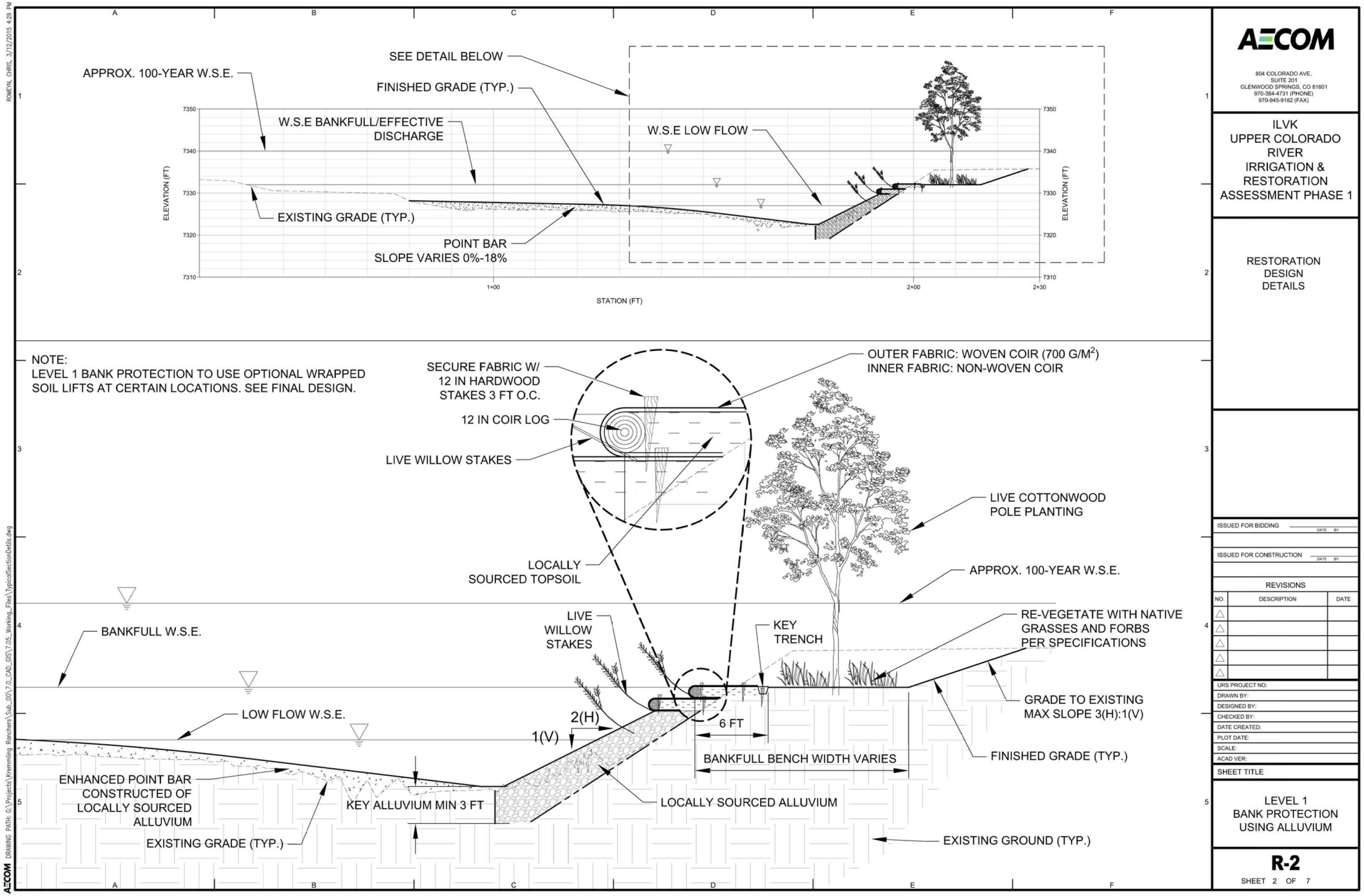
6 Appendices

Appendix A.
Restoration Details

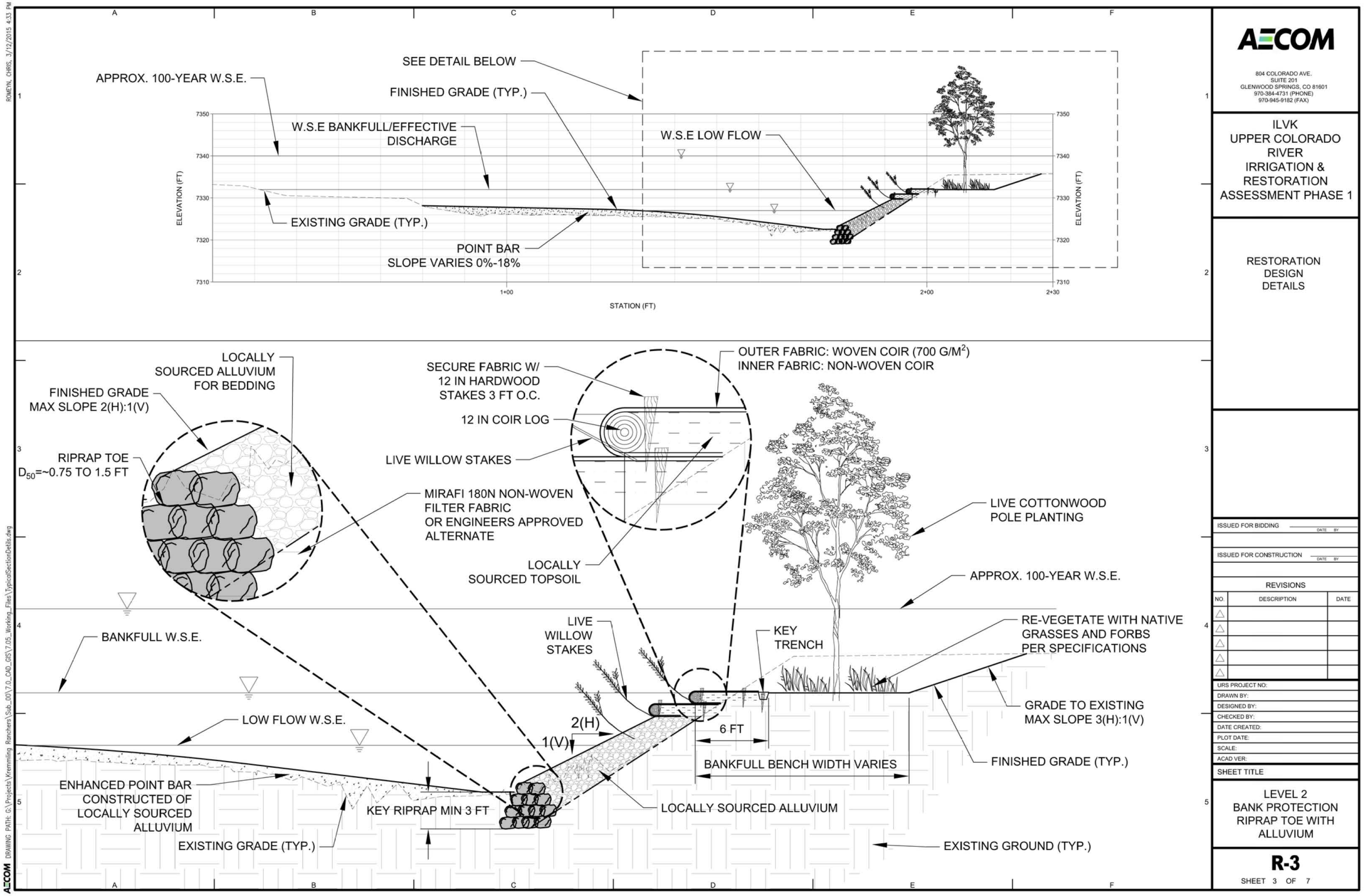
Appendix A.
Restoration Details



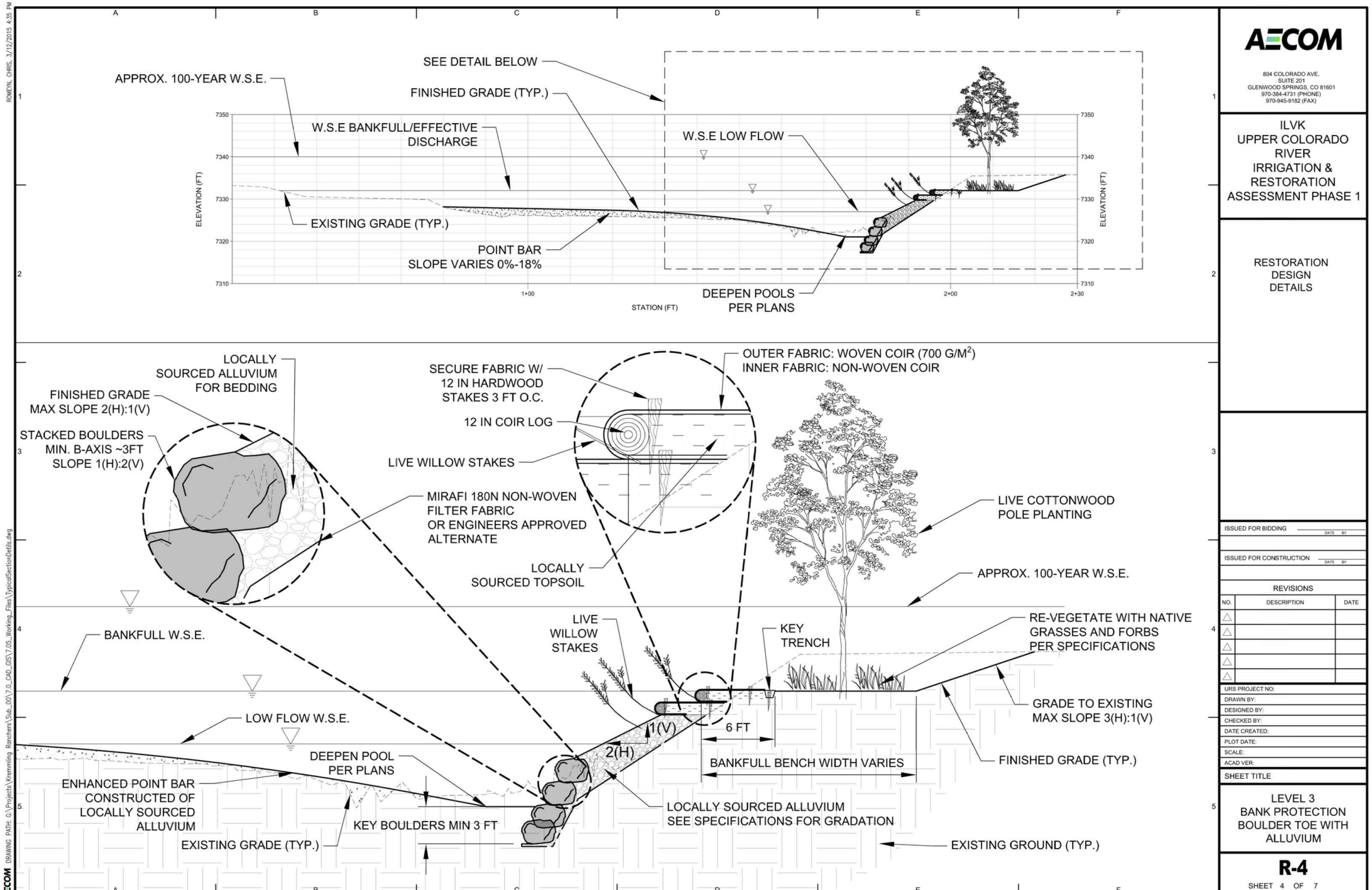
R- 1 Riffle Grade Control Structure



R- 2 Level 1 Bank Protection



R- 3 Level 2 Bank Protection



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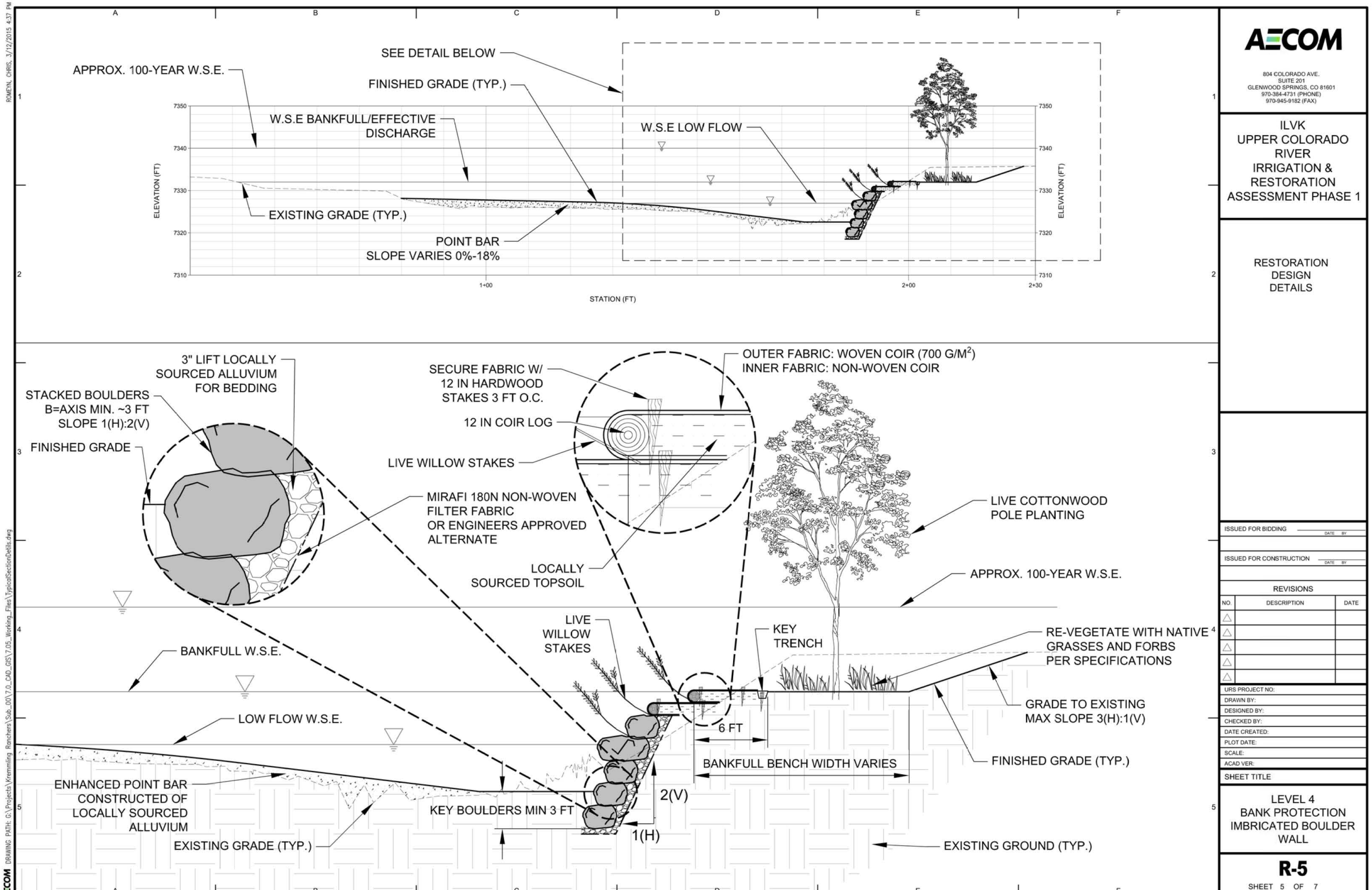
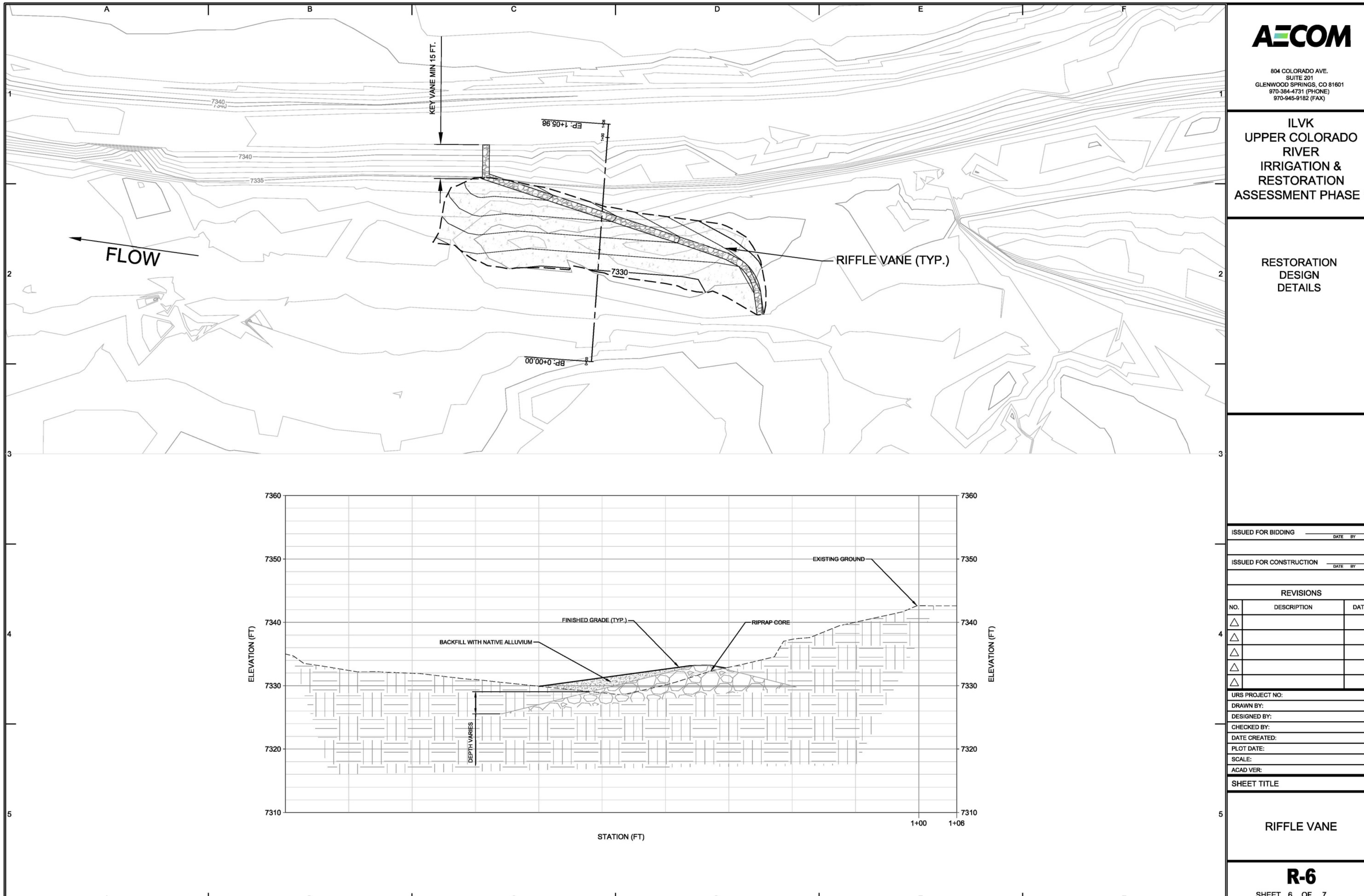
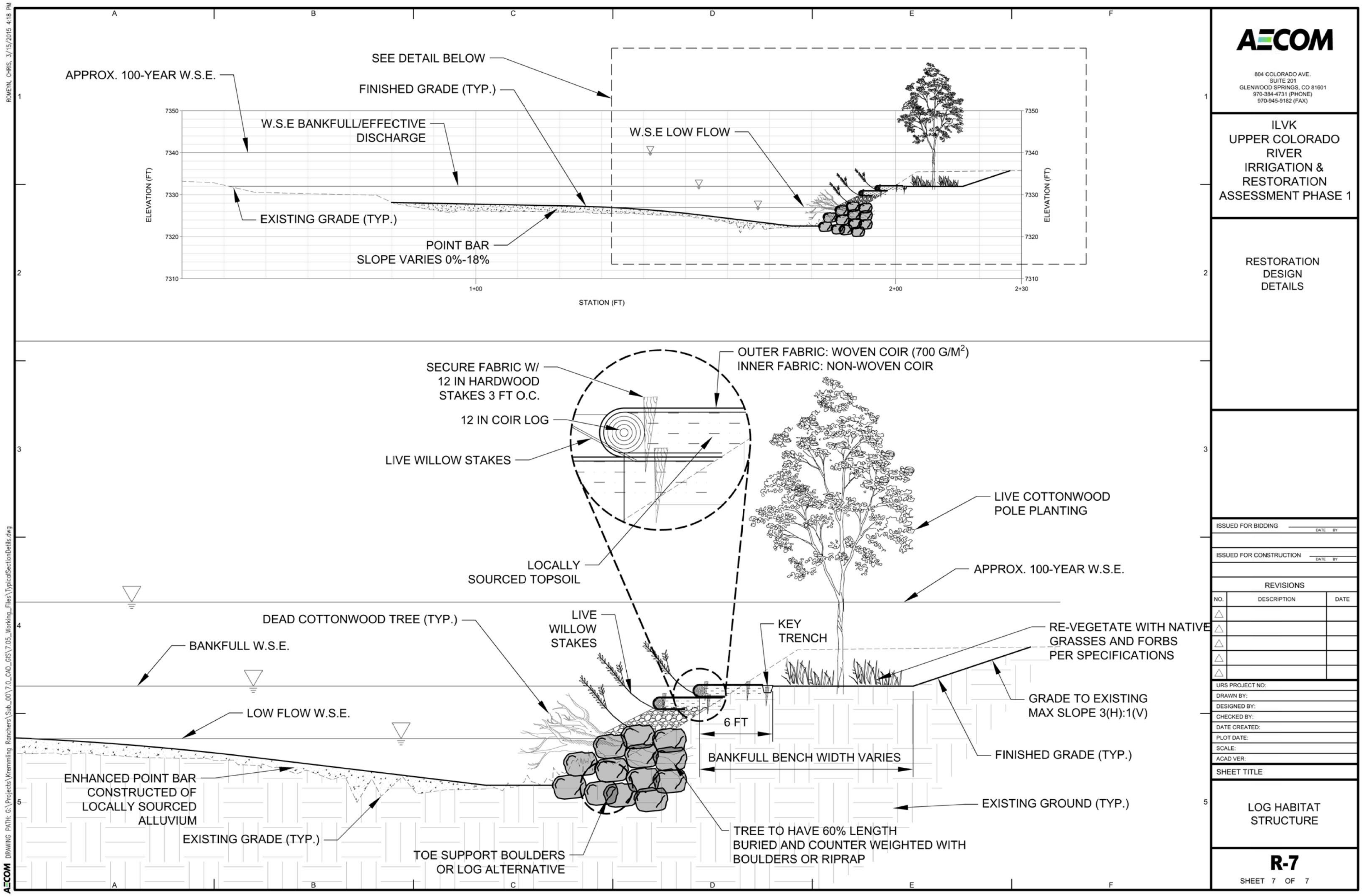


R- 5 Level 4 Bank Protection



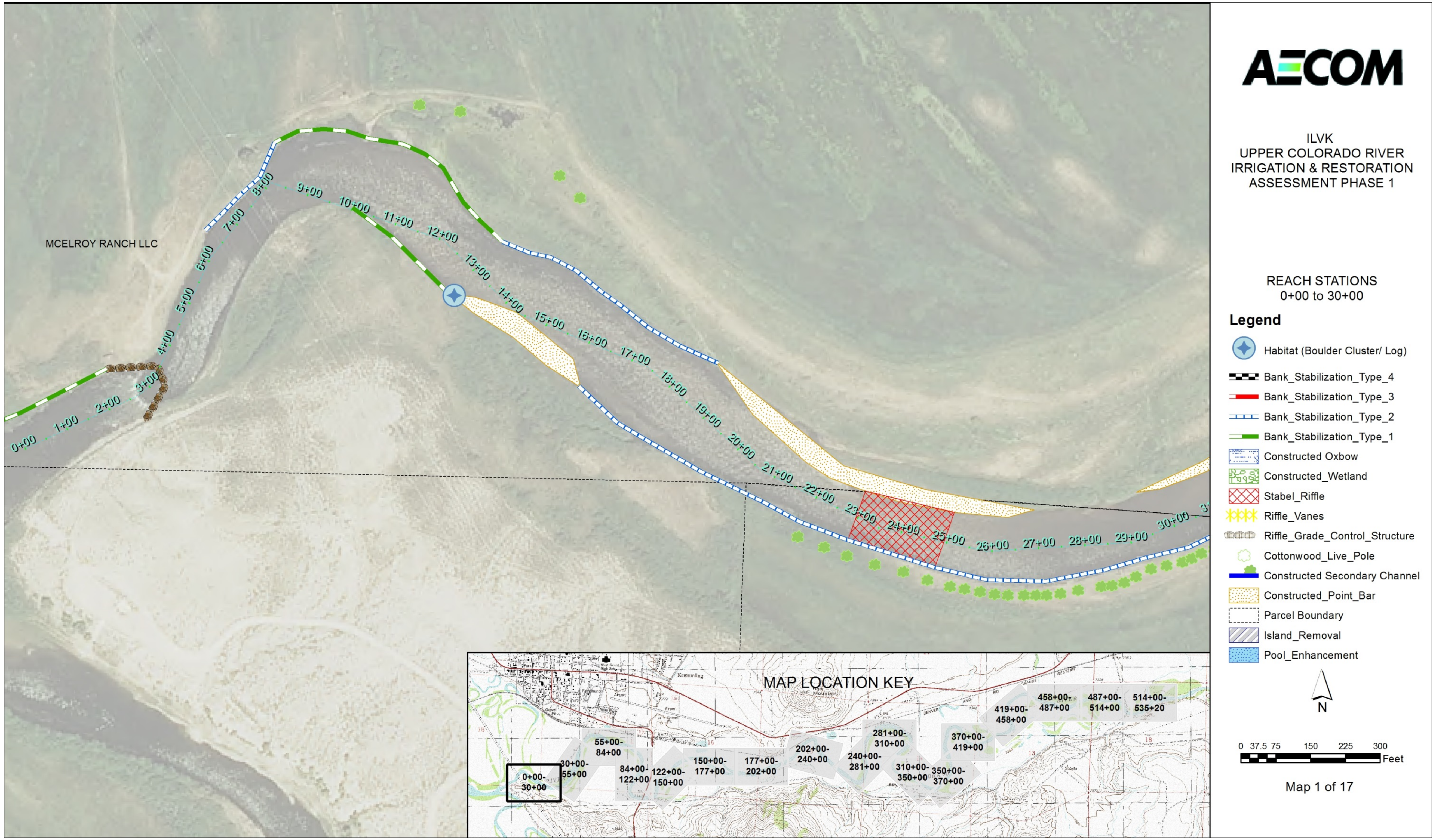
R- 6 Riffle Vane



R- 7 Habitat Log

Appendix B.
Restoration Planning Maps

Appendix B.
Restoration Planning Maps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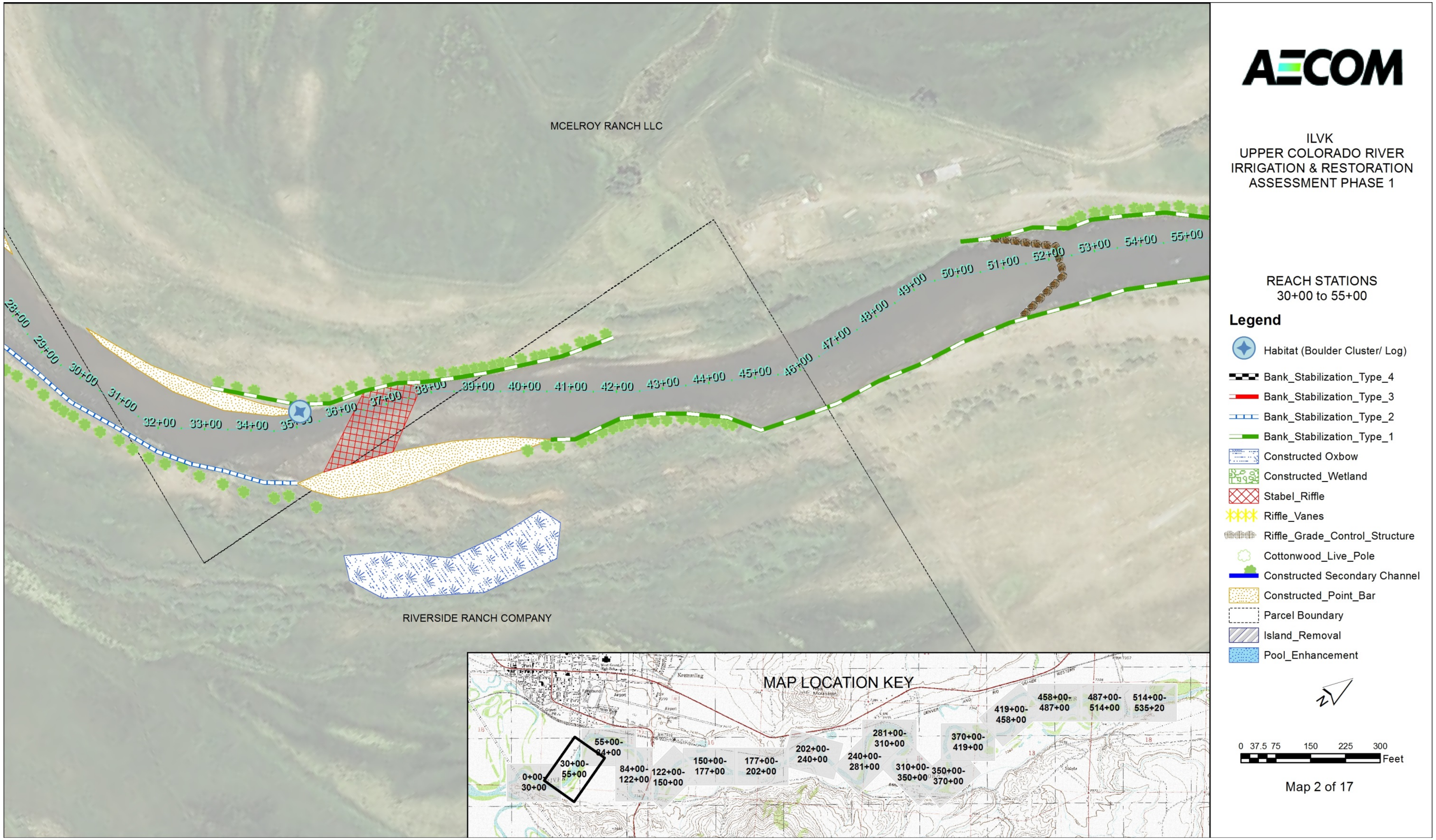
487+00-514+00
514+00-535+20
AECOM
ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
0+00 to 30+00
Legend
Habitat (Boulder Cluster/ Log)
Bank_Stabilization_Type_4
Bank_Stabilization_Type_3
Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
Constructed Oxbow
Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
N
0 37.5 75 150 225 300
Feet
Map 1 of 17

Map No. 1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458+00-487+00
487+00-514+00
514+00-535+20
AECOM
ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
30+00 to 55+00
Legend
Habitat (Boulder Cluster/ Log)
Bank_Stabilization_Type_4
Bank_Stabilization_Type_3
Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
Constructed Oxbow
Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
N
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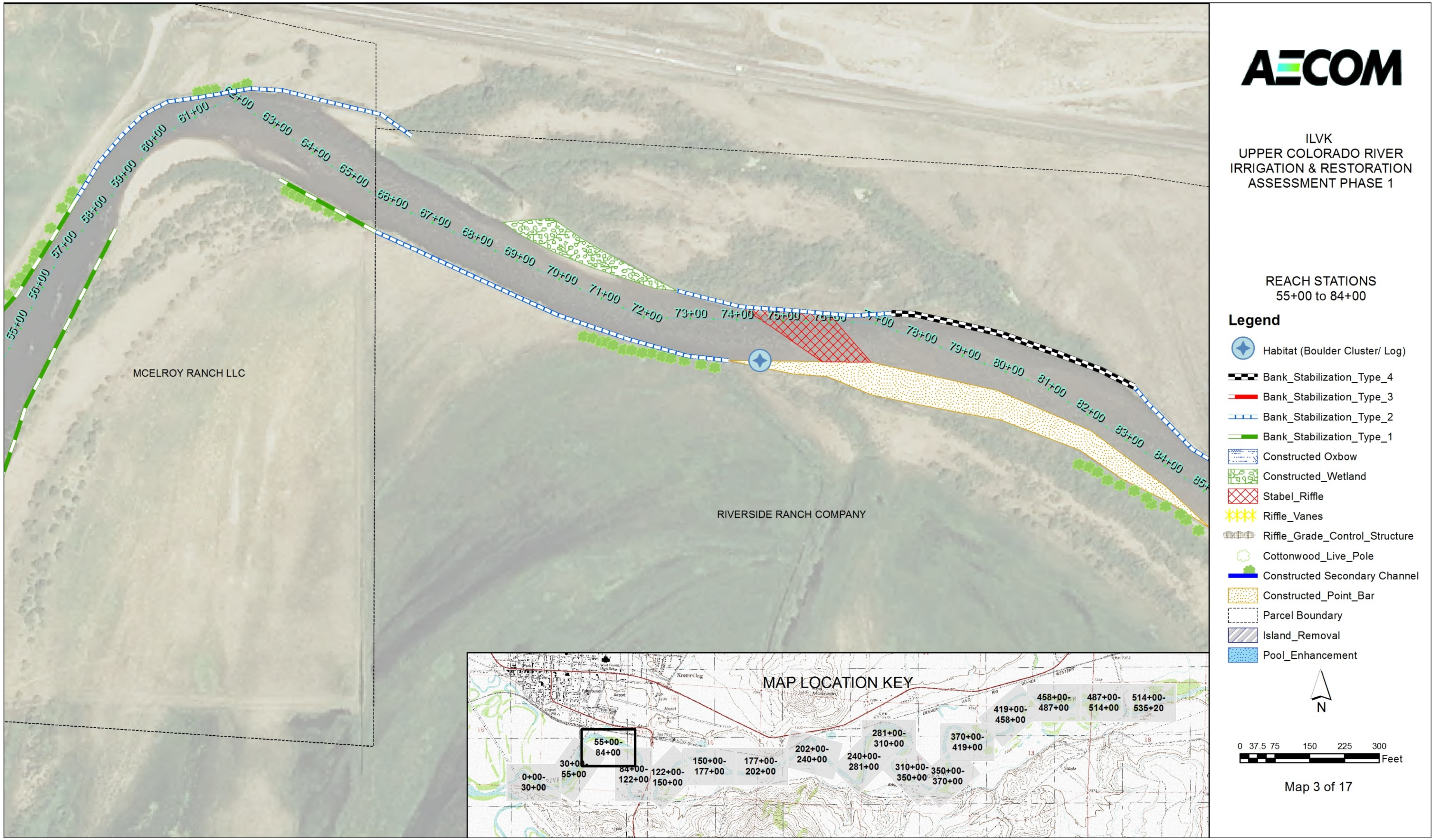
Feet
Map 2 of 17

Map No. 2


AECOM
ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
55+00 to 84+00
Legend
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Bank_Stabilization_Type_3
Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
Constructed Oxbow
Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
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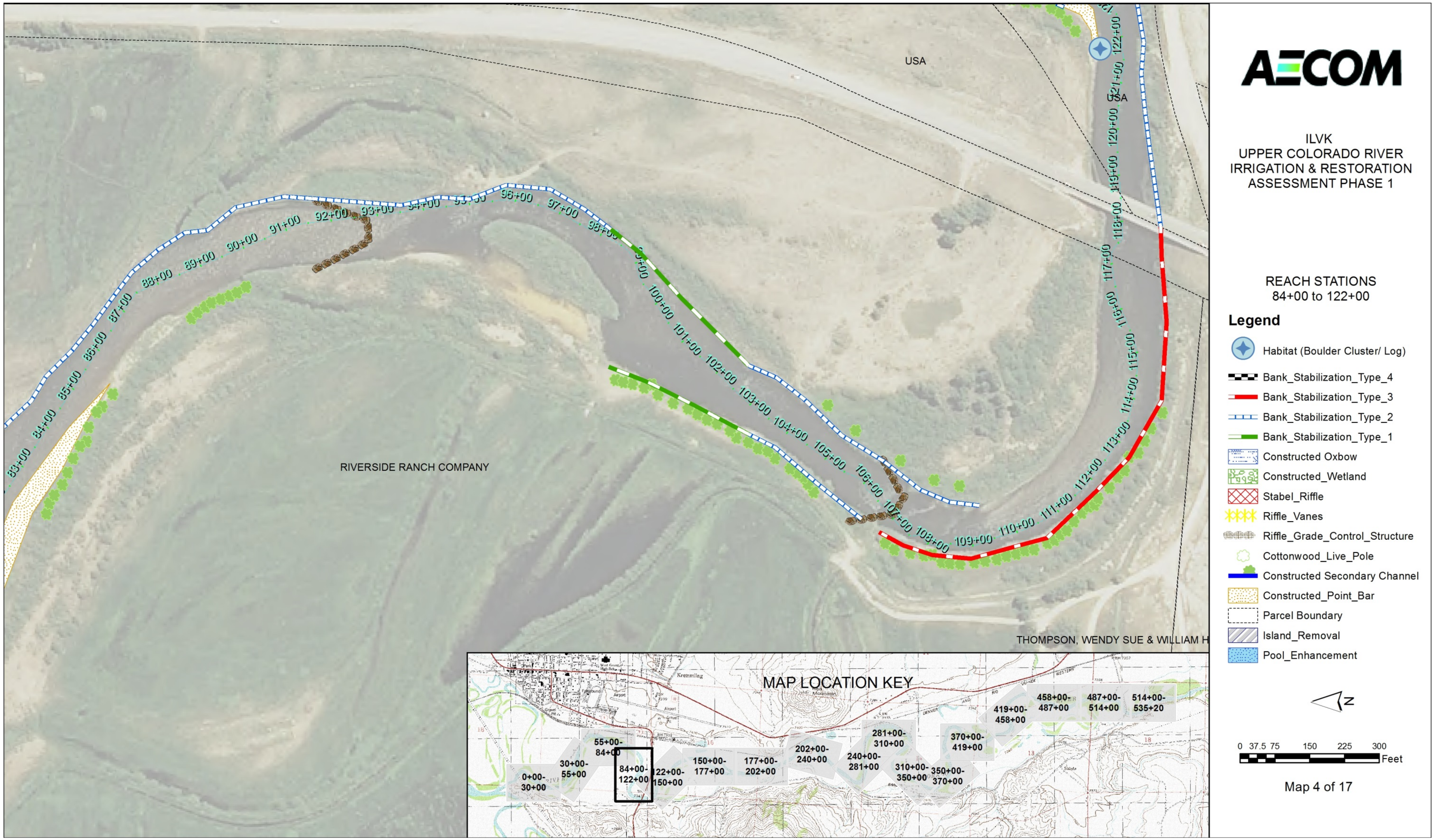
Feet
Map 3 of 17
MCELROY RANCH LLC
RIVERSIDE RANCH COMPANY
MAP LOCATION KEY

Map No. 3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RIVERSIDE RANCH COMPANY
THOMPSON, WENDY SUE & WILLIAM H
MAP LOCATION KEY
AECOM
ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
84+00 to 122+00
Legend
Habitat (Boulder Cluster/ Log)
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Bank_Stabilization_Type_3
Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
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Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
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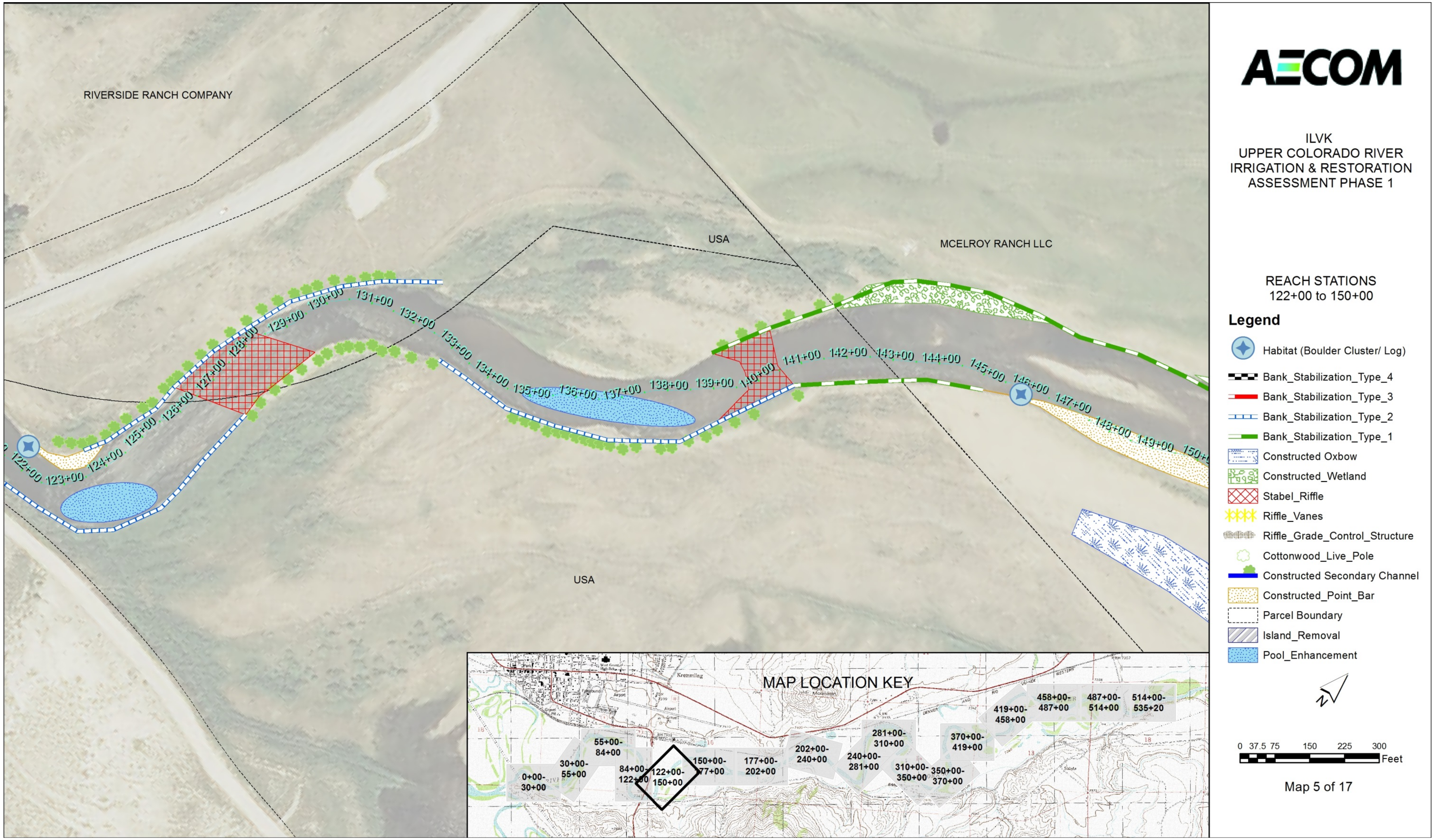
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
0 37.5 75 150 225 300 Feet
Map 4 of 17

Map No. 4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MCELROY RANCH LLC
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458+00-487+00
487+00-514+00
514+00-535+20
AECOM
ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
122+00 to 150+00
Legend
Habitat (Boulder Cluster/ Log)
Bank_Stabilization_Type_4
Bank_Stabilization_Type_3
Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
Constructed Oxbow
Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
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Feet
Map 5 of 17

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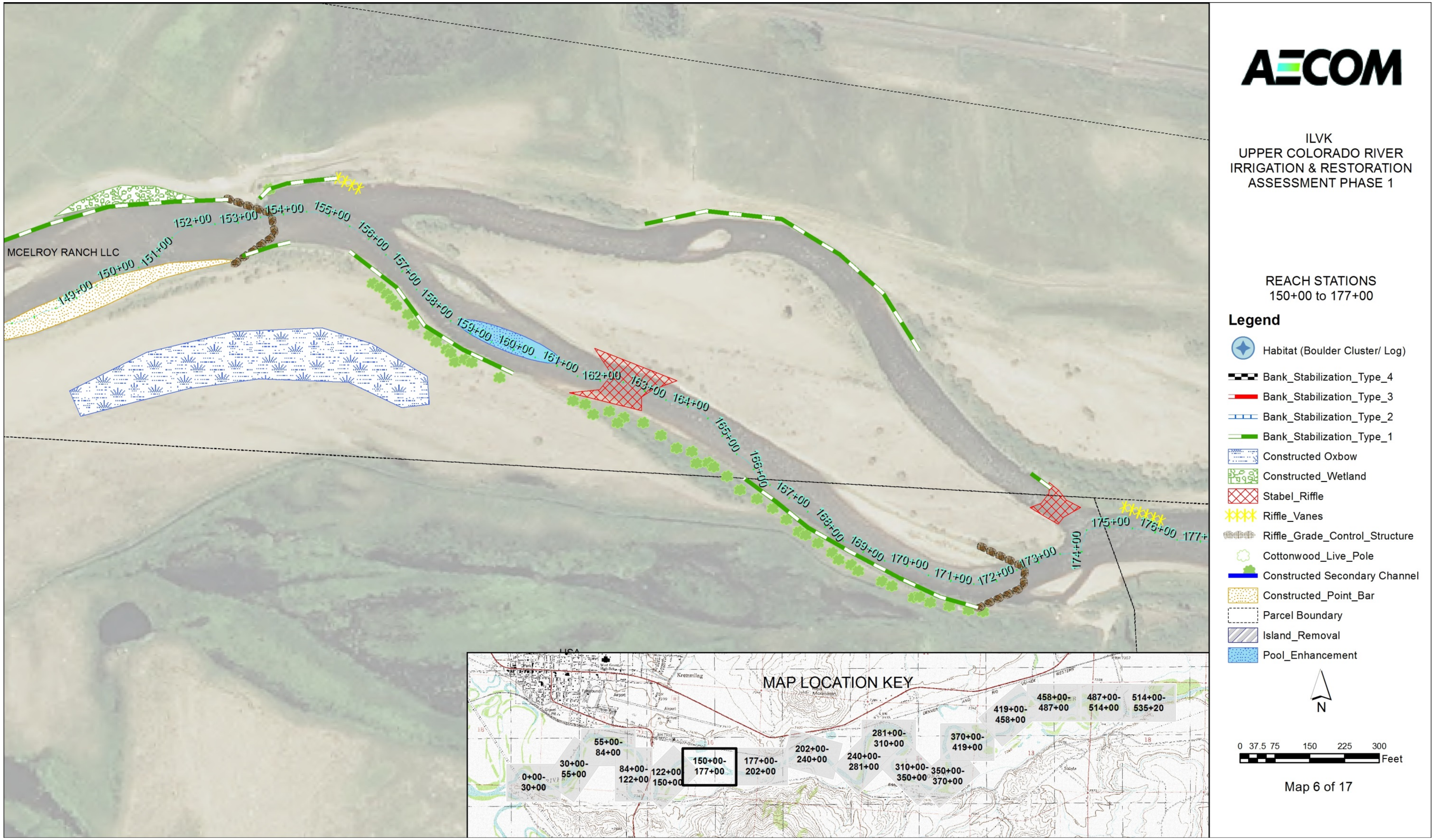
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IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
150+00 to 177+00
Legend
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Bank_Stabilization_Type_3
Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
Constructed Oxbow
Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
N
0 37.5 75 150 225 300
Feet
Map 6 of 17
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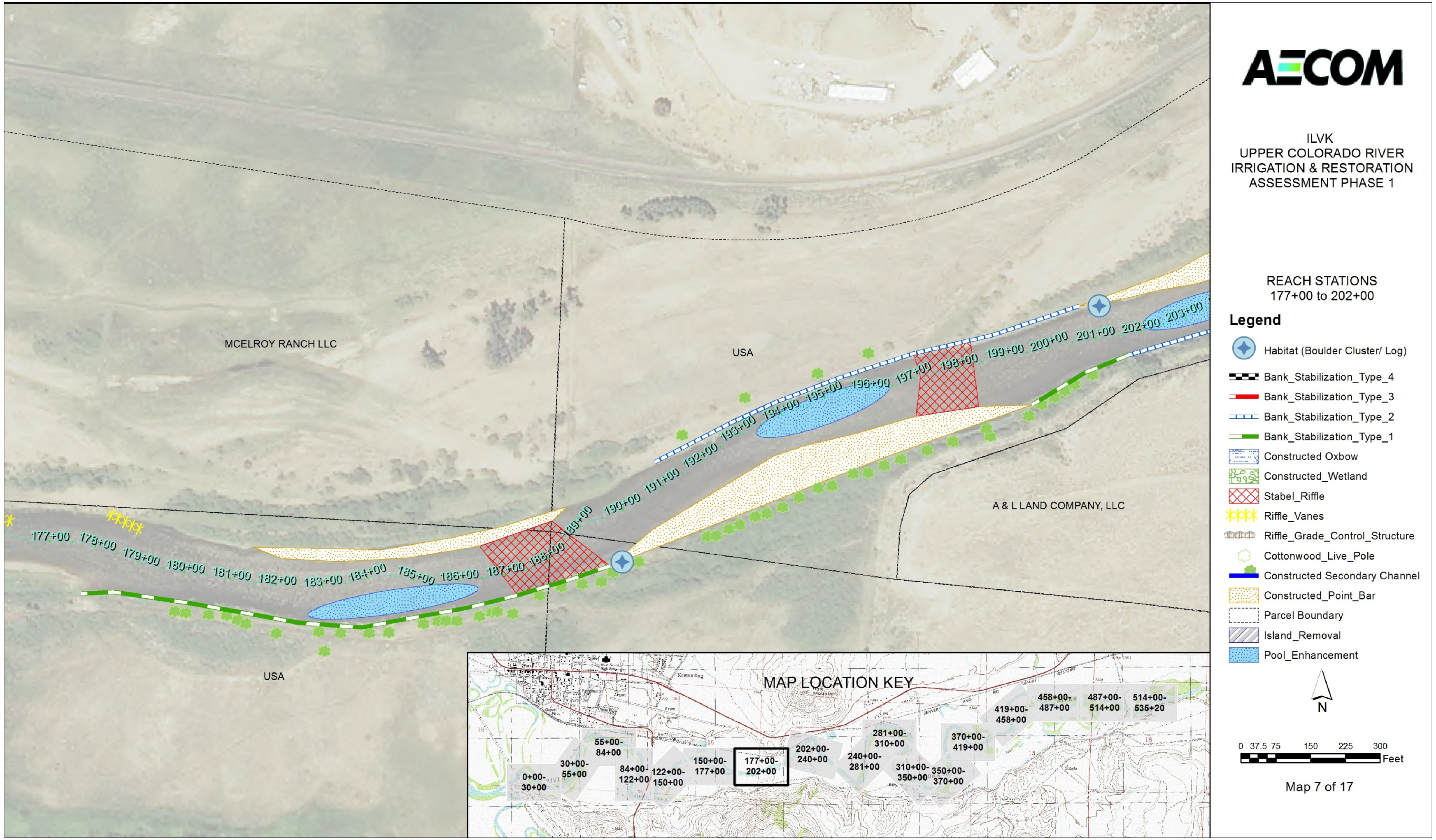

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USA
A & L LAND COMPANY, LLC
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AECOM
ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
177+00 to 202+00
Legend
Habitat (Boulder Cluster/ Log)
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Bank_Stabilization_Type_3
Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
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Constructed_Wetland
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Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
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Parcel Boundary
Island_Removal
Pool_Enhancement
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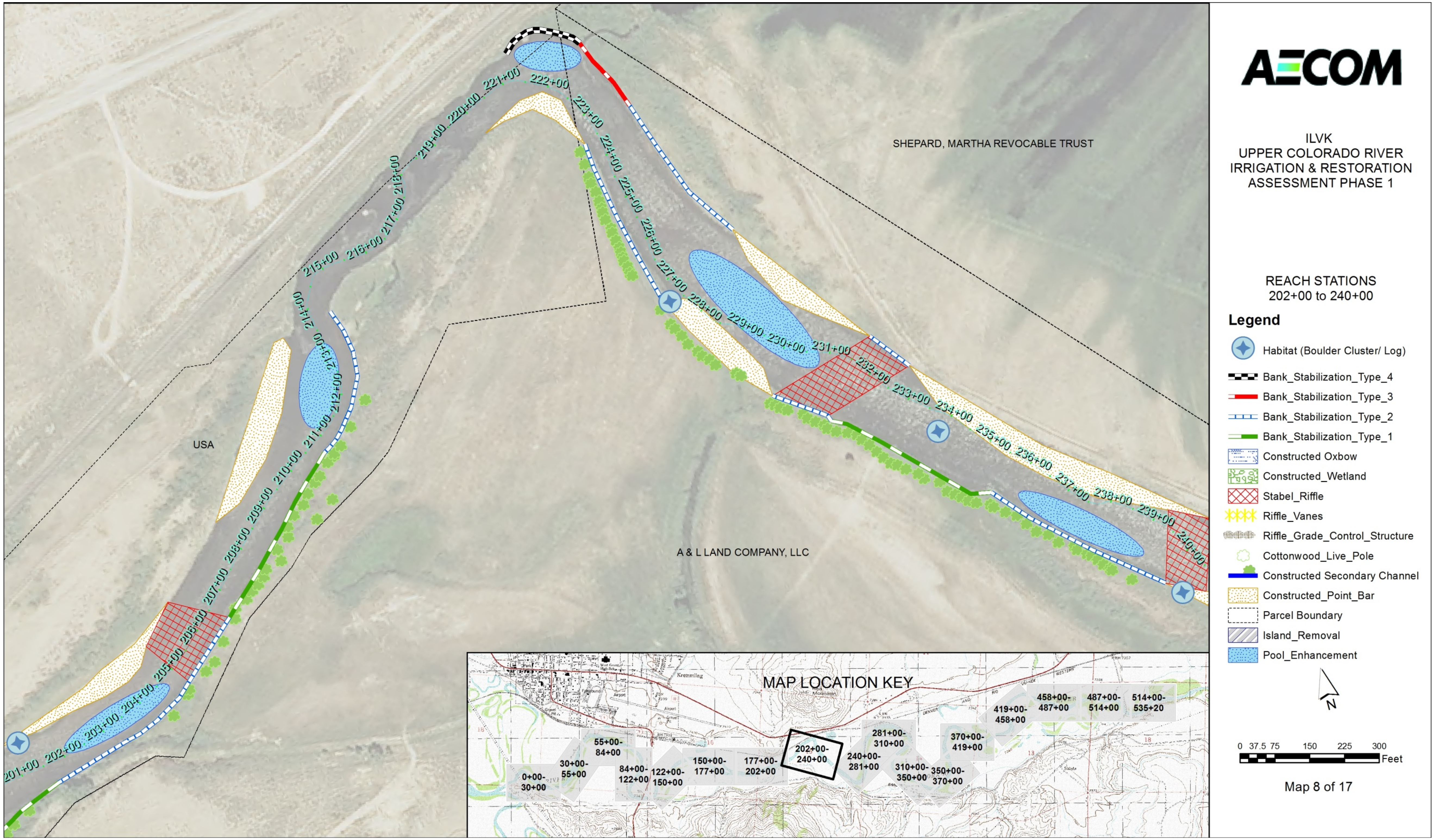
Feet
Map 7 of 17

Map No. 7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ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
202+00 to 240+00
Legend
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Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
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Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
N
0 37.5 75 150 225 300
Feet
Map 8 of 17
SHEPARD, MARTHA REVOCABLE TRUST
USA
A & L LAND COMPANY, LLC
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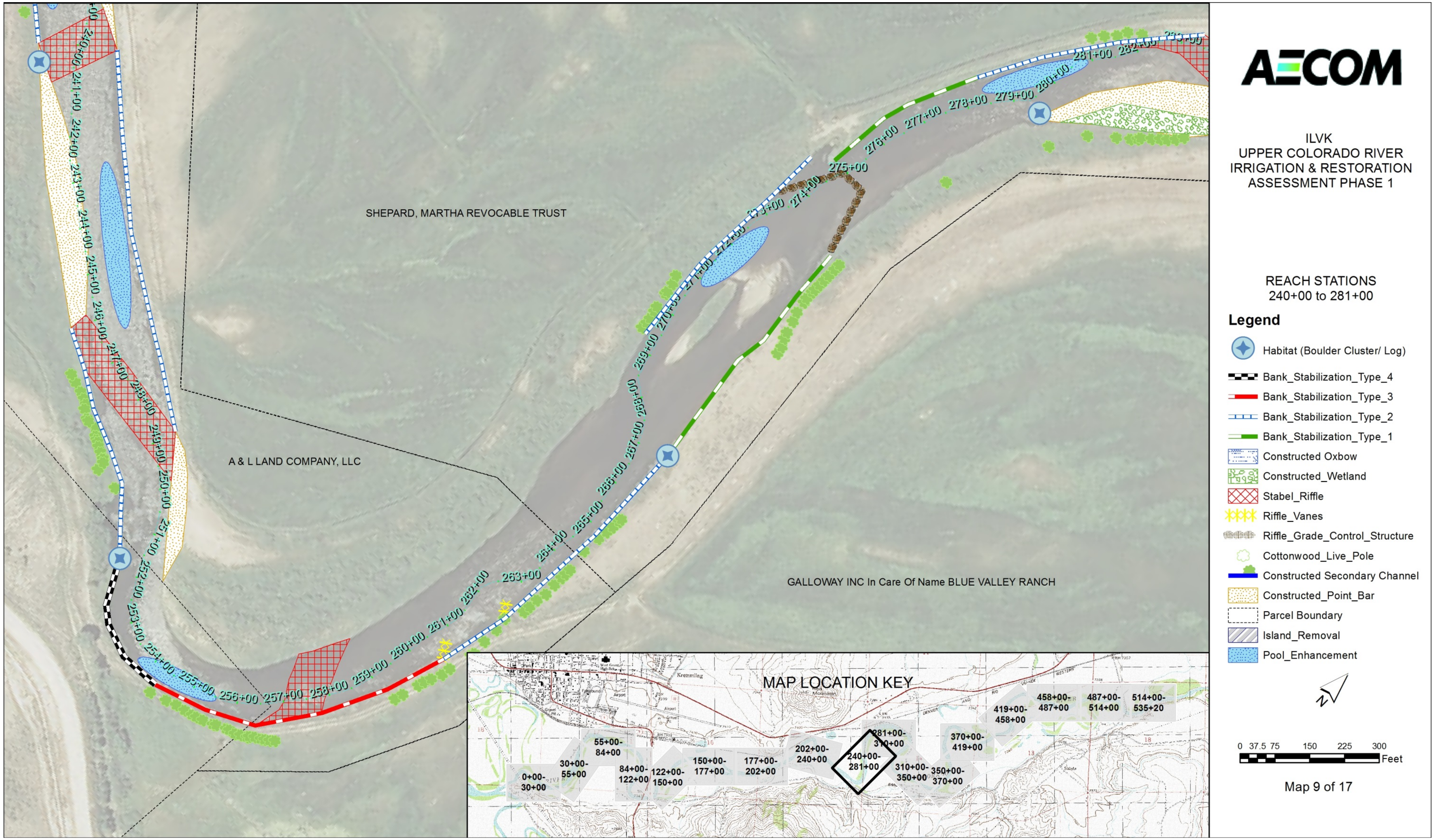
Map No. 8



AECOM
ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
240+00 to 281+00
Legend
Habitat (Boulder Cluster/ Log)
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Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
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Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
0 37.5 75 150 225 300 Feet
Map 9 of 17
SHEPARD, MARTHA REVOCABLE TRUST
A & L LAND COMPANY, LLC
GALLOWAY INC In Care Of Name BLUE VALLEY RANCH
MAP LOCATION KEY
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30+00-55+00
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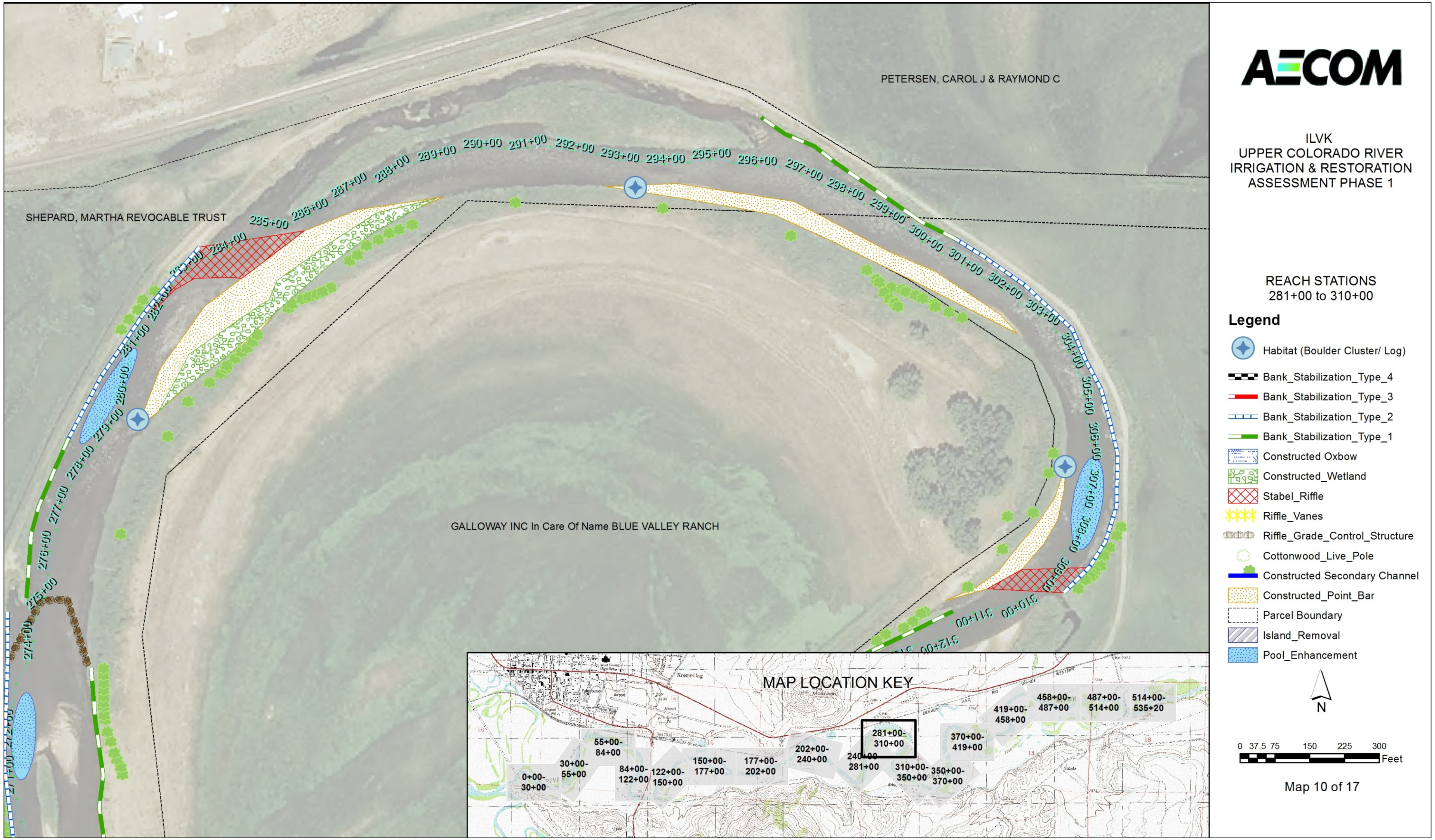
Map No. 9


PETERSEN, CAROL J & RAYMOND C
SHEPARD, MARTHA REVOCABLE TRUST
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AECOM
ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
281+00 to 310+00
Legend
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Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
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Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
N
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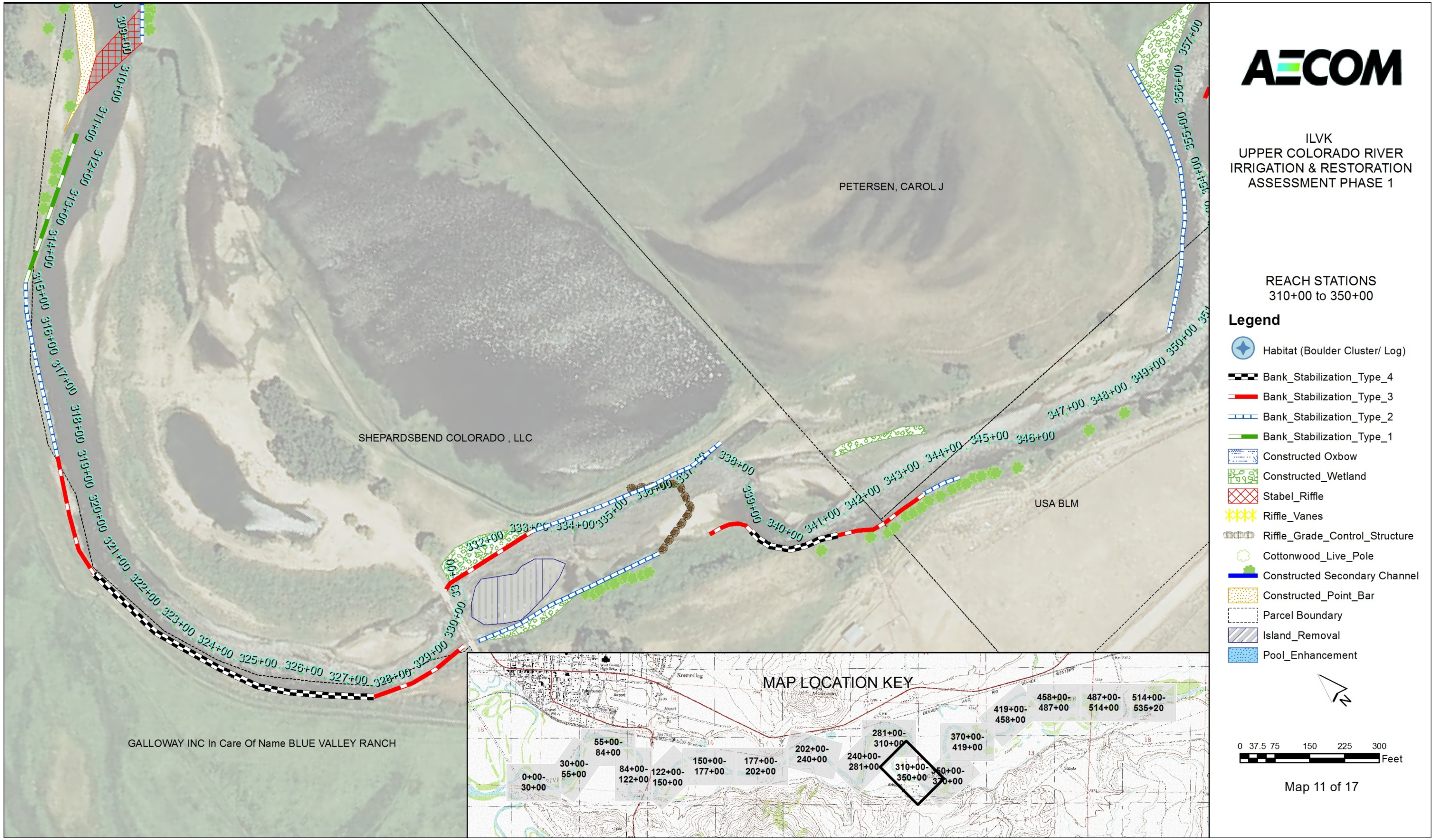
Feet
Map 10 of 17

Map No. 10


AECOM
ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
310+00 to 350+00
Legend
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Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
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Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
0 37.5 75 150 225 300
Feet
Map 11 of 17
PETERSEN, CAROL J
SHEPARDSBEND COLORADO , LLC
USA BLM
GALLOWAY INC In Care Of Name BLUE VALLEY RANCH
MAP LOCATION KEY
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30+00-55+00
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202+00-240+00
240+00-281+00
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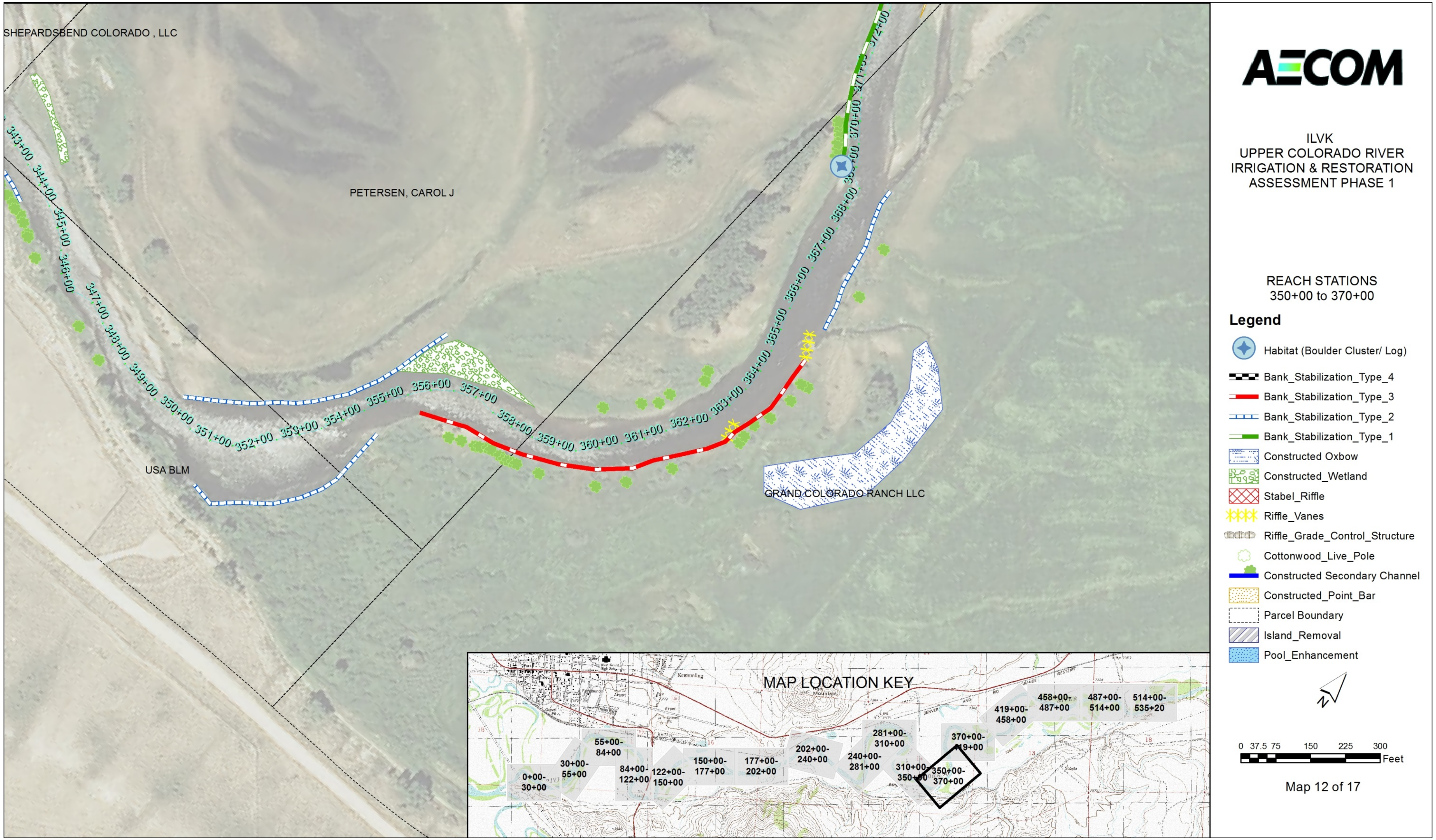
487+00-514+00
514+00-535+20

Map No. 11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PETERSEN, CAROL J
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GRAND COLORADO RANCH LLC
MAP LOCATION KEY
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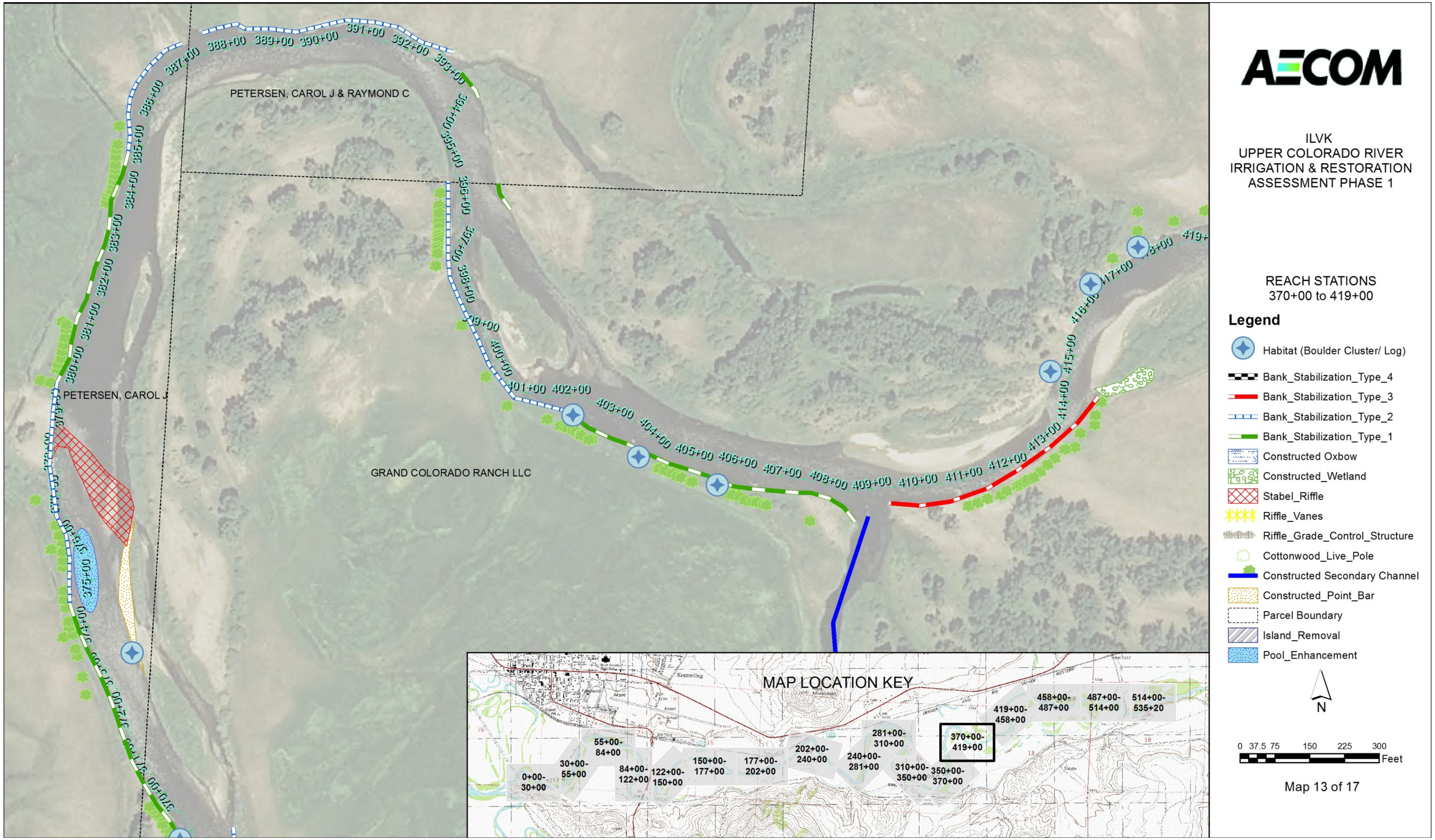
ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
350+00 to 370+00
Legend
Habitat (Boulder Cluster/ Log)
Bank_Stabilization_Type_4
Bank_Stabilization_Type_3
Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
Constructed Oxbow
Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
0 37.5 75 150 225 300 Feet
Map 12 of 17

Map No. 12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PETERSEN, CAROL J
GRAND COLORADO RANCH LLC
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417+00
MAP LOCATION KEY
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150+00-177+00
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350+00-370+00
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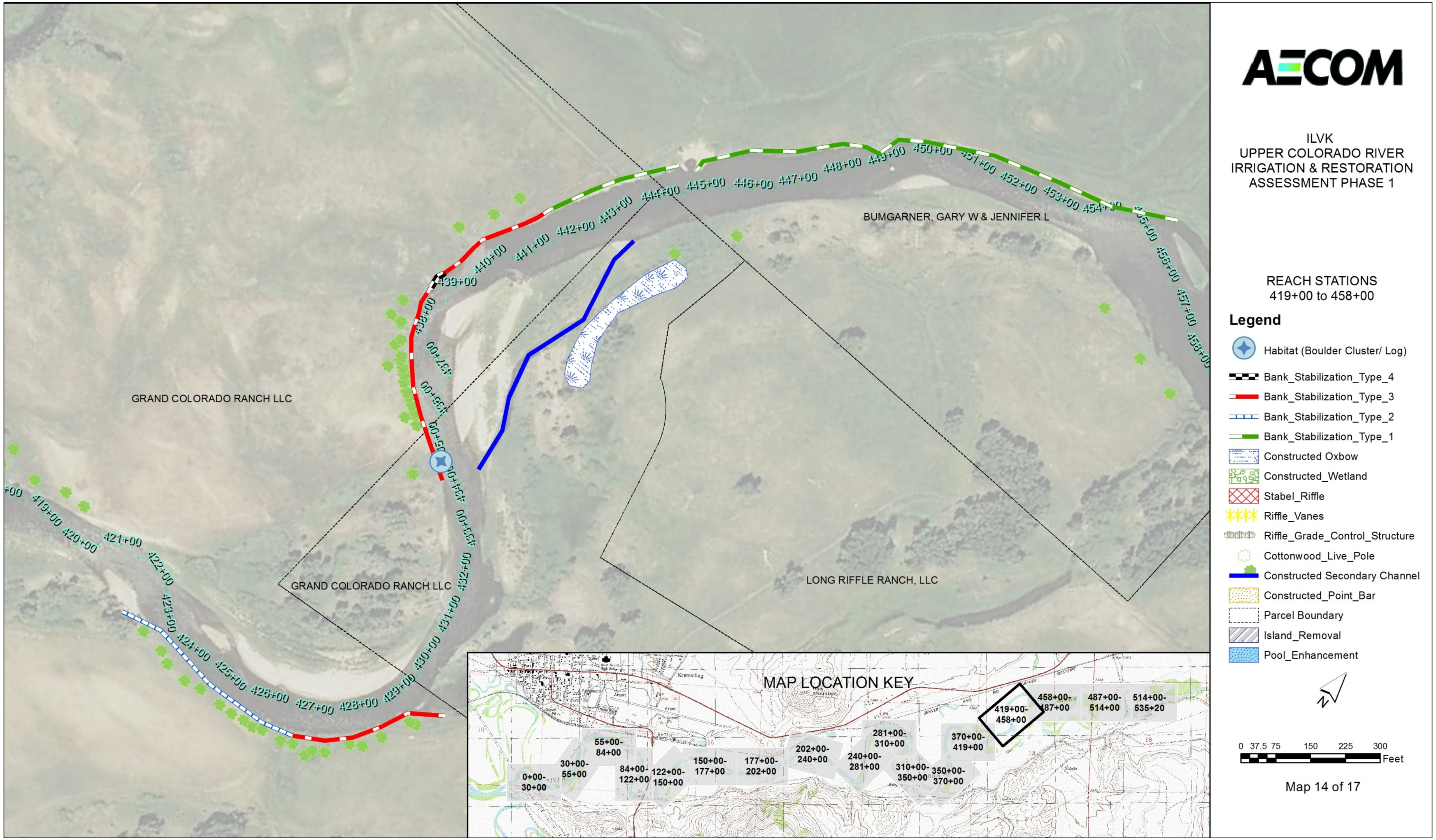
419+00-458+00
458+00-487+00
487+00-514+00
514+00-535+20
AECOM
ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
370+00 to 419+00
Legend
Habitat (Boulder Cluster/ Log)
Bank_Stabilization_Type_4
Bank_Stabilization_Type_3
Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
Constructed Oxbow
Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
N
0 37.5 75 150 225 300
Feet
Map 13 of 17

Map No. 13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ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
419+00 to 458+00
Legend
Habitat (Boulder Cluster/ Log)
Bank_Stabilization_Type_4
Bank_Stabilization_Type_3
Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
Constructed Oxbow
Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
0 37.5 75 150 225 300 Feet
Map 14 of 17
GRAND COLORADO RANCH LLC
GRAND COLORADO RANCH LLC
BUMGARNER, GARY W & JENNIFER L
LONG RIFFLE RANCH, LLC
MAP LOCATION KEY
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487+00-514+00
514+00-535+20

Map No. 14


BUMGARNER, GARY W & JENNIFER L
LONG RIFFLE RANCH, LLC
458+00
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461+00
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463+00
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484+00
485+00
486+00
487+00
MAP LOCATION KEY
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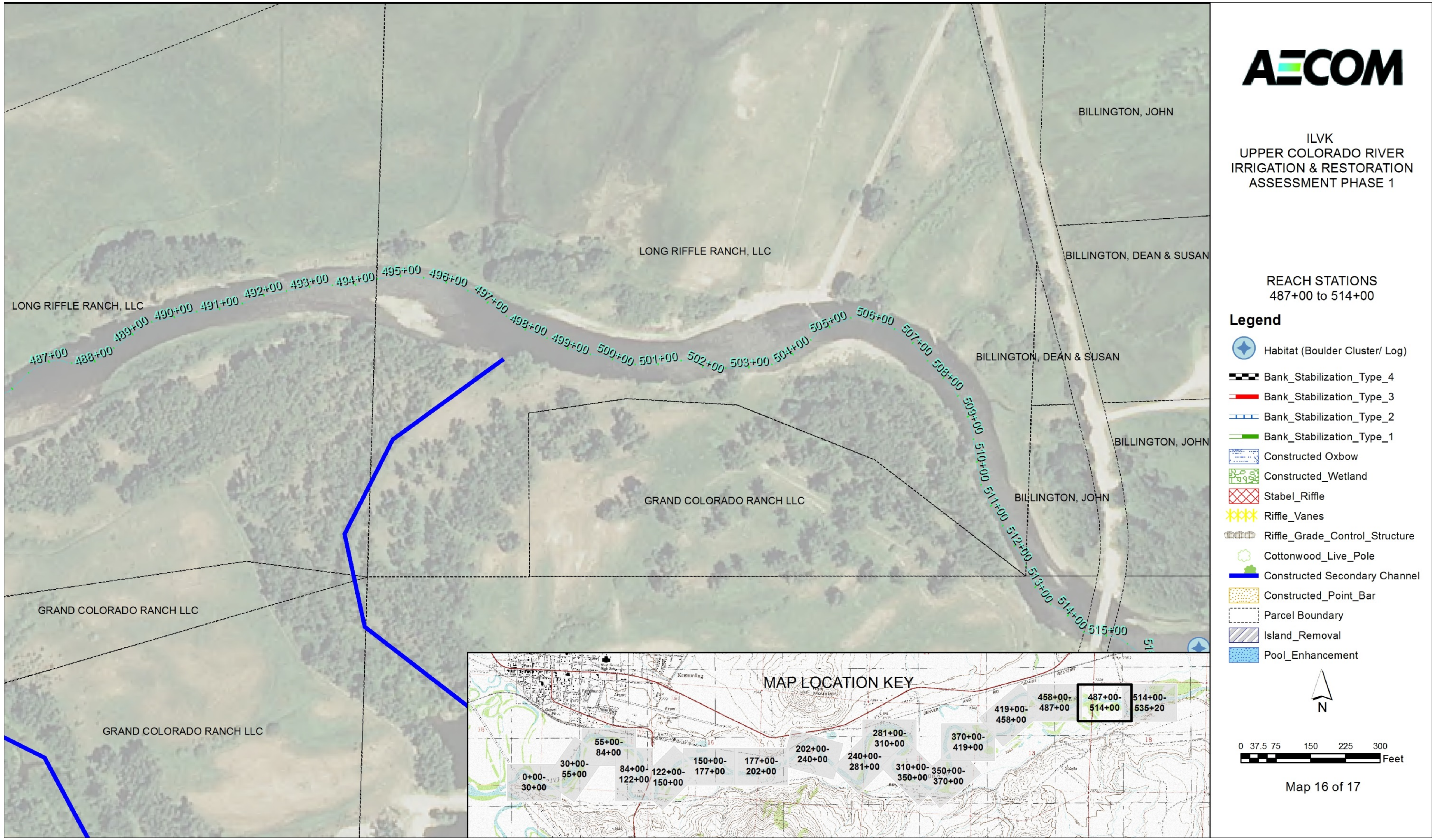
55+00- 84+00
84+00- 122+00
122+00- 150+00
150+00- 177+00
177+00- 202+00
202+00- 240+00
240+00- 281+00
281+00- 310+00
310+00- 350+00
350+00- 370+00
370+00- 419+00
419+00- 458+00
458+00- 487+00
487+00- 514+00
514+00- 535+20
AECOM
ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
458+00 to 487+00
Legend
Habitat (Boulder Cluster/ Log)
Bank_Stabilization_Type_4
Bank_Stabilization_Type_3
Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
Constructed Oxbow
Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
N
0 37.5 75 150 225 300
Feet
Map 15 of 17

Map No. 15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ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
487+00 to 514+00
Legend
Habitat (Boulder Cluster/ Log)
Bank_Stabilization_Type_4
Bank_Stabilization_Type_3
Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
Constructed Oxbow
Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
N
0 37.5 75 150 225 300
Feet
Map 16 of 17
LONG RIFFLE RANCH, LLC
LONG RIFFLE RANCH, LLC
BILLINGTON, JOHN
BILLINGTON, DEAN & SUSAN
BILLINGTON, DEAN & SUSAN
BILLINGTON, JOHN
BILLINGTON, JOHN
GRAND COLORADO RANCH LLC
GRAND COLORADO RANCH LLC
GRAND COLORADO RANCH LLC
487+00
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MAP LOCATION KEY
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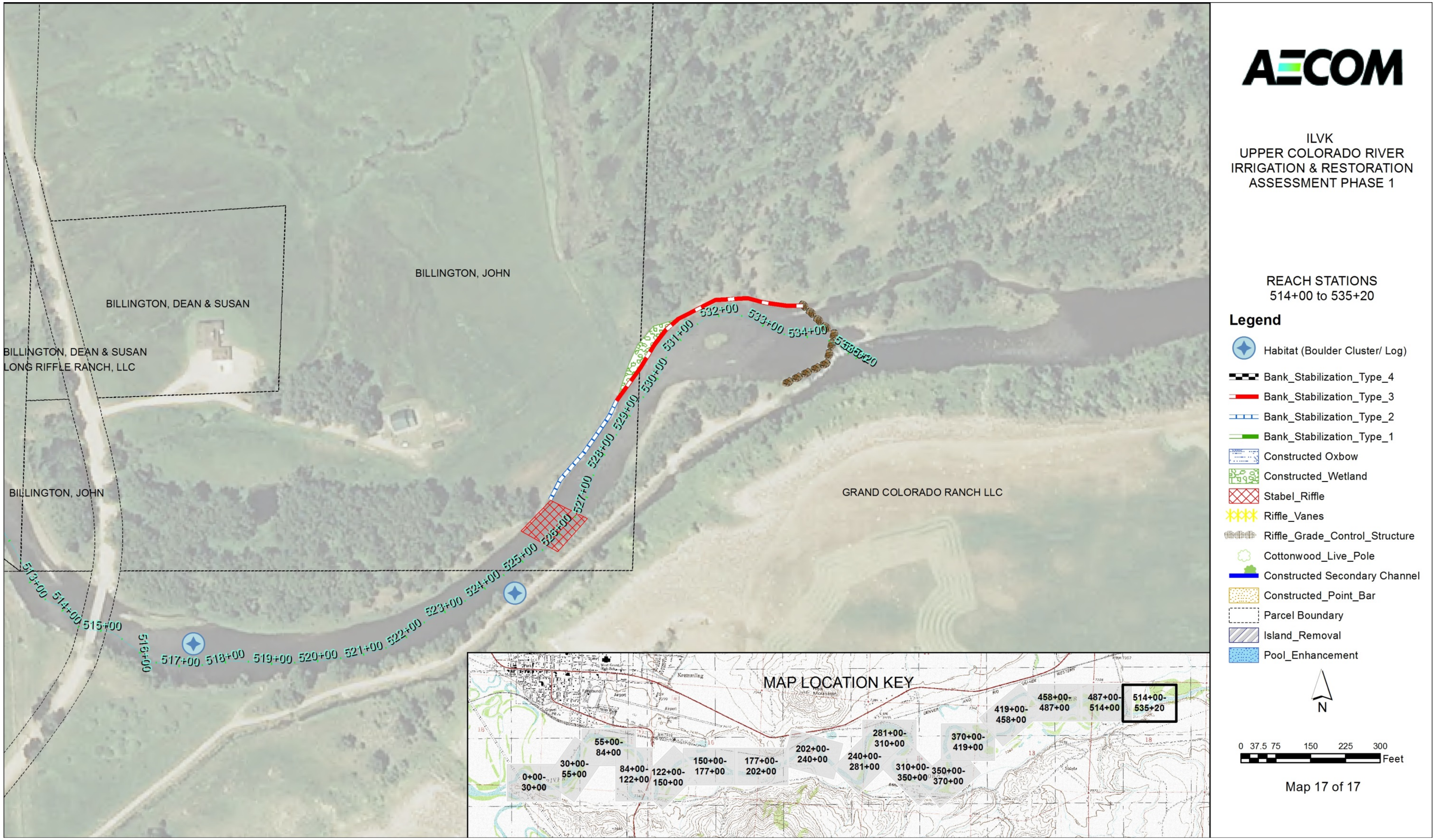
Map No. 16


BILLINGTON, JOHN
BILLINGTON, DEAN & SUSAN
BILLINGTON, DEAN & SUSAN
LONG RIFFLE RANCH, LLC
BILLINGTON, JOHN
GRAND COLORADO RANCH LLC
514+00
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514+00-535+20
AECOM
ILVK
UPPER COLORADO RIVER
IRRIGATION & RESTORATION
ASSESSMENT PHASE 1
REACH STATIONS
514+00 to 535+20
Legend
Habitat (Boulder Cluster/ Log)
Bank_Stabilization_Type_4
Bank_Stabilization_Type_3
Bank_Stabilization_Type_2
Bank_Stabilization_Type_1
Constructed Oxbow
Constructed_Wetland
Stabel_Riffle
Riffle_Vanes
Riffle_Grade_Control_Structure
Cottonwood_Live_Pole
Constructed Secondary Channel
Constructed_Point_Bar
Parcel Boundary
Island_Removal
Pool_Enhancement
N
0 37.5 75 150 225 300
Feet
Map 17 of 17

Map No. 17

Appendix C.
Reference List

Appendix C.
Reference List

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Phone number
Other Contact Information