60% Basis of Design Report – Brewbaker-Sorensson

Left Hand Creek

Natural Channel Design

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Introduction

This document explains the pre-construction design and analysis for the Boulder County Parks and Open Space Brewbaker-Sorensson Left Hand Creek stream restoration project. This project will provide an increase in aquatic resource function and services by restoring the stream channel to an appropriate dimension, pattern, and profile. The design team has collected and reviewed available project site-related information and/or data relating to the present and historical conditions of the Brewbaker-Sorensson reach and other reaches influencing this reach.

As an initial step for characterizing the reach, our team developed a base map of existing conditions from publicly available data sets. This base map includes a topographic survey, political/property boundaries, current and proposed land use, planning overlays, flood hazard areas, plant community extents, and the location of utility, transportation, recreational and flood control infrastructure. Existing LiDAR derived digital elevation models supplement data for surveyed cross-sections in the reaches of interest to develop 1-foot contours for construction. This base map serves as a resource for further analyses, flood modeling, and the design phases.

Project Location

The Brewbaker-Sorensson property is located at 41st Street and Oxford Road, at 40° 6' 48.415" N Latitude, 105° 15' 10.886" W Longitude in Section 29, Township 2 North, Range 70 West of the 6th Principle Meridian, in unincorporated Boulder County, Colorado (Figure 1). Left Hand Creek runs through the middle of the property. The project reach is along the creek from 100' downstream of the western property boundary to the eastern property boundary. The site is located in the Great Plains Region immediately east of the foothills of the Rocky Mountains and south of the St. Vrain Creek at approximately 5,350 feet elevation.

1.1 Project Background

In September 2013, a major flood event severely affected many areas in Northern Colorado, including Boulder County Parks and Open Space's Brewbaker-Sorensson Open Space property in Longmont, Colorado. This flood event and subsequent human interventions to protect infrastructure in the flood's path caused major damage to the riparian corridor and adjacent upland bench. Primary flood flows expanded as a sheet flow across the nearby pasture and riparian areas from the northwest, carving two large head cuts. High velocity flows severely eroded creek banks and scoured the channel bed throughout the reach, removing low flow channel definition and leaving mostly cobbles in the streambed. Much of the floodplain substrate now primarily consists of cobbles and lacks vegetation structure complexity and native plant species diversity.

On the eastern half of the property, the creek alignment was altered by high velocity flows and by earthwork to protect infrastructure during the flood event. Approximately 700 feet of the north bank was completely excavated to modify the creek geometry, relocating the channel to north. The excavated material was then piled on the top edge of the northern bank by the property's neighbor to the southeast resulting in the current main channel alignment that has non-engineered levees on both the north and south creek banks. The top of the bank is now about 15-20 feet above the water surface of the creek. These excavated soils on the top of the bank have further decreased the connection of the creek from an ecologically functioning floodplain and increased the disturbance to the soils and vegetation found along the stream. These disturbed soils are susceptible to erosion and

host a wide variety of weeds. The south bank in this reach was also graded leaving an area of between four and five acres that was lowered and flattened. The result is unsustainable bank character on both the north and south sides of the creek. Figure 1 and Figure 2 show the project site before and after the September 2013 flood event, respectively.

Figure 1: Project Site before September 2013 flood with a channel sinuosity ~ 1.23

Figure 2: Project Site after September 2013 Flood with a channel sinuosity ~ 1.04

A natural channel design restoration approach has been developed to address the flood damage within this reach. Restoration of the stream channel includes the reconnection of the stream with its floodplain and alterations of channel morphology through adjustments of stream pattern, dimension, and profile. This will be achieved by lowering the width-to-depth ratio of the stream; placement of instream bank stabilization and habitat structures, installing large woody material and boulders; and restoring riffles and pool features using cross-vane grade control structures. The design also includes modifications to the bed and bank. Plantings and transplant of riparian vegetation will stabilize creek banks. No net loss of wetlands will occur within the project reach, but wetlands will be relocated.

The project team consists of representatives from Boulder County Parks and Open Space with specialties in wildlife, plant ecology, resource planning and agriculture, and the consulting design team with specialties in fluvial geomorphology, engineering, and riparian ecology.

1.2 Project Purpose, Goals, and Objectives

The purpose of this project is to restore Left Hand Creek on the Brewbaker-Sorensson Open Space property where the flood flows and preventative anthropogenic efforts resulted in an unstable stream. The restoration of Left Hand Creek will be achieved by creating a pattern, dimension, and profile more appropriate to the valley type and stream type, giving the channel better connection to the floodplain. The floodplain connection and revegetation will result in an increased resiliency in the restored channel. The restoration of the channel will create a single, more defined, narrower channel with deeper pools. The narrowing of the channel increases sediment transport efficiency, while the deeper pools and riffles increase diversity of flow patterns, increasing aquatic habitat. The restoration will also allow the stream to connect with its floodplain, increasing its hydrologic connectivity, therefore allowing riparian habitat, including wetlands, to establish with a higher degree of diversity than pre-construction conditions. The riparian and stream improvements will provide increased aquatic resource functions and services.

The overall goal of the project is to improve the stream and riparian habitat through active restoration and planting/transplant of vegetation.

Project goals and corresponding objectives are listed below:

Goal 1 – Protect and improve the quality and extent of riparian and wetland habitat

Objectives:

1. Advance the recovery of a diversity of mature, native riparian vegetation
2. Improve, create, and maintain wildlife habitat
3. Protect flood-created wildlife habitat
4. Create diverse topography and micro-topography to support plant diversity
5. Protect existing, older cottonwoods and alders
6. Treat invasive plant species prior to and after construction
7. Treat the underlying causes of infestations
8. Address existing mature crack willows
9. Restore hydrology to pre-existing wetlands
10. Maintain fish passage
11. Improve in-stream habitat

Goal 2 – Restore stream channel and floodplain geomorphic processes

Objectives:

1. Determine proper stream channel geomorphology for this site
2. Stabilize the stream channel using natural features
3. Increase floodplain connectivity
4. Remove artificial berms that interfere with ecological processes but are not needed for infrastructure protection
5. Increase channel sinuosity
6. Address head-cuts and incision; reduce potential for further head-cutting and incision
7. Address appropriate flow-through at the east and west project boundaries
8. Control erosion

9. Create or leave micro-topography

Goal 3 – Restore riparian ecological processes

Objectives:

1. Plant native riparian species to restore floodplain
2. Incorporate dynamic system elements related to riparian ecology; integrate features that can evolve with the system
3. Protect existing or incorporate desirable flood features (e.g. fallen trees, embedded wood, large woody debris, root wads)
4. Consider beaver (analogue) features
5. Create hydrology that supports a diversity of wetland and riparian species

Goal 4 – Provide for agricultural use

Objectives:

1. Re-establish eastern property boundary
2. Allow for cattle crossing at Left Hand Creek between the north and south pastures
3. Address land user and livestock safety concerns

Goal 5 – Protect Life and Property

Objectives:

1. No-rise above or below project reach

1.3 Preliminary Permit Work

Preliminary permit work includes a review of all pertinent biological, archaeological, cultural, floodplain, and other local, state, and federal regulations that will affect this project during final design and construction. The design team will conduct necessary surveys and/or subcontracting companies as needed.

All work that will be completed within the floodplain and specifically in the floodway/channel of Left Hand Creek will require a separate Floodplain Development Permit. Because the work to be permitted has to be based on the final design and stamped by a Colorado licensed engineer, the permit process will not be completed until after the 60% design is completed. The permit requirements and approximate number of permits will be identified, allowing the documentation process to be clear during permit production.

During the floods of 2013, the historic channels migrated, aggraded, and degraded. As a result, the pre-flood FEMA effective model does not represent current existing conditions. We will utilize the best available hydrologic data for this effort. Based on this premise, we will develop our own existing and proposed condition hydraulic models for the project reaches. These models will be compared to the published base flood and ground elevations to inform the design. In the final design phase, the proposed improvements will be integrated into hydraulic models to provide guidance and recommendations that will result in a no-rise condition.

1.4 Flood, Ecosystem, and Geomorphic Risk Assessment

Our design team is committed to open, deliberate, and clear communication about all calculated risks and perceived risks that are identified during the assessment, design, and stakeholder

involvement processes. *Hazard* is the event occurrence alone. *Risk* can be defined as the probability of an event occurring, multiplied by the cost/damage incurred by the occurrence of the event. Examining hazard alone can unintentionally minimize the impacts of risk to stakeholders. The primary risks that are apparent to the proposed design team include flooding, impacts to infrastructure and human life, ecosystem degradation, and geomorphic degradation. These risks will be mitigated through channel restoration, native plant revegetation, and grading a large floodplain bench.

A useful graphic concept that demonstrates the hierarchical relationship between different types of risk present in rivers and streams outside of developed landscapes is the Stream Function Pyramid (Harman, et al., 2012). In this model, proper river hydrology is the foundation upon which hydraulic flood processes are based. Processes at each stage of this pyramid, proceeding from hydraulic, to geomorphology, to physicochemical, and finally to biology, are based on all underlying processes (see figure below).

Figure 3: Stream Function Pyramid (Harman, et al., 2012)

This pyramid can also be used to understand the correlation between categories of risk. Our identification of risk is guided by this concept, yet further informed by our analyses of infrastructure.

The increased probability of a specific biological or ecological disturbance is often harder to define than hydrology, hydraulic, or geomorphic probabilities. The total and categorical risk of not doing restoration is used as a baseline for our design alternative analysis process and in the discussion of these alternatives during the stakeholder engagement process. In addition, these risks illustrate the structure and scoring of our multi-criteria decision analysis framework. The next sections will further explain our analysis of each step of the Functional Pyramid to inform the project design.

2 Hydrology

Hydrologic data is considered based on a combination of existing peak flow data and regional regression equations from the USGS StreamStats website (USGS, 2017). The majority of the Left Hand Creek watershed is used for agriculture or is undeveloped. The reach is west of the City of Longmont. According to the USGS StreamStats delineation, the watershed is 61.7 square miles with a mean annual precipitation of 21.95 inches per year.

The watershed delineation is shown in Figure 4. Peak flow statistics for the project reach are listed in Figure 5 below and are broken into the Foothills region and the Mountain region.

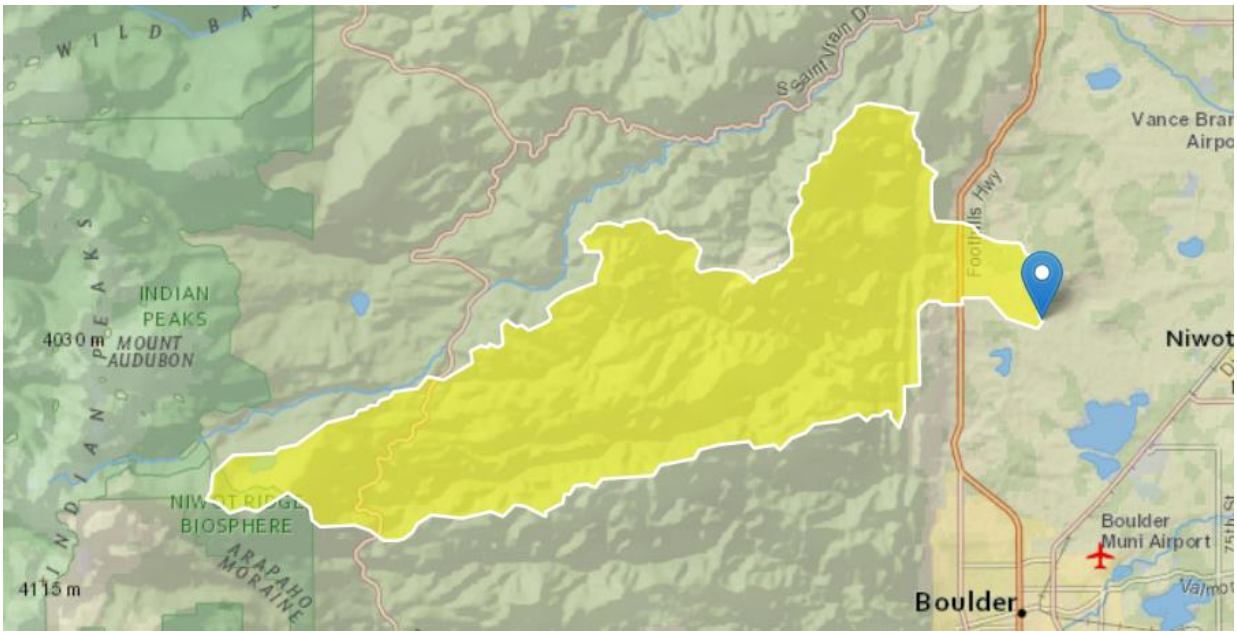

Figure 4: Left Hand Creek watershed 61.7 square miles at 40.11172, -105.24933 (USGS, 2017)

Peak-Flow Statistics Flow Report [41 Percent (25.1 square miles) Foothills Region Peak Flow 2016 5099]

PIl: Prediction Interval-Lower, Plu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SEp
2 Year Peak Flood	266	ft^3/s	117
5 Year Peak Flood	689	ft^3/s	87
10 Year Peak Flood	1130	ft^3/s	80
25 Year Peak Flood	1920	ft^3/s	80
50 Year Peak Flood	2670	ft^3/s	83
100 Year Peak Flood	3630	ft^3/s	88
200 Year Peak Flood	4740	ft^3/s	94
500 Year Peak Flood	6470	ft^3/s	104

Peak-Flow Statistics Flow Report [59 Percent (36.5 square miles) Mountain Region Peak Flow]

PIl: Prediction Interval-Lower, Plu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SEp
2 Year Peak Flood	266	ft^3/s	49
5 Year Peak Flood	394	ft^3/s	44
10 Year Peak Flood	487	ft^3/s	41
25 Year Peak Flood	585	ft^3/s	40
50 Year Peak Flood	713	ft^3/s	39
100 Year Peak Flood	810	ft^3/s	36
200 Year Peak Flood	896	ft^3/s	36
500 Year Peak Flood	1060	ft^3/s	33

Figure 5: Current USGS Peak Flow Regression (USGS, 2017)

2.1 Regional Curve

Regional curves are developed using real-world bankfull cross-sectional areas collected with field-identified bankfull elevations throughout representative reaches of a watershed. When bankfull cross-sectional areas are compared to drainage areas within a watershed, a best-fitting line at a slope of around 0.67 is common on river restoration projects. Regional curves are used in many river restoration projects as a way to predict appropriate bankfull cross-sectional areas based on watershed response factor and drainage area. It has been found through study of relationships among watershed parameters that the cross-sectional area is related to the mean annual precipitation of the watershed. During the development of the regional relationships, members of the design team have observed that the offset of the curve is proportional to the mean annual precipitation. The empirical relationship of this offset to the mean annual precipitation is termed the watershed response factor (WRF). The WRF is calculated as follows.

$$WRF = 0.3354 * Mean\ Annual\ Precip\ (in.) + 1.4593$$

The design bankfull cross-sectional area (XSA) is then calculated by multiplying the watershed response factor by the drainage area (DA) taken to the 2/3 power, shown in the equation below:

$$XSA = WRF * DA^{\frac{2}{3}}$$

Using a regional curve for the Denver-Metro area, design bankfull cross-sectional areas fell significantly lower than would be expected for the drainage area. Due to the high agricultural diversions upstream of the project reach, discharges arriving on-site are significantly less than what would be predicted for the size of the drainage area and the mean annual rainfall. Data was collected, upstream and downstream of the project area, to create a mini-regional curve for the Left Hand Creek watershed. To generate a mini-regional curve, reaches are observed and measured near the project reach. Measurements include bankfull area, bankfull width, max depth, mean depth, etc. These measurements are then compared to the size of the reaches' drainage area. Relationships to these parameters are then identified and used to generate design parameters. This mini-regional curve was used to calculate an appropriate bankfull cross-sectional area to drainage area relationship. Using the field estimated bankfull cross-sectional areas measured during the development of the mini-regional curve the WRF was back calculated to be 4.1. The design bankfull cross-sectional area was calculated to be: $XSA = 4.1 * 61.7^{\frac{2}{3}} = 64\ square\ feet$. The actual design bankfull cross-sectional area of 70 square feet was used to convey the design bankfull discharge.

3 Hydraulics

Hydraulic models of existing and proposed conditions are used to identify where infrastructure is vulnerable to flood inundation, channel stability, and sediment transport continuity, and inform channel and floodplain design. Results are used to inform preliminary no-rise certification efforts.

Post-flood, existing condition hydraulic models for the project reach need to be updated with surveyed cross-sections and existing LiDAR digital elevation models for better resolution along this reach.

3.1 Floodplain connectivity

Proper floodplain connectivity is important for developing stable stream hydraulics. Natural channel design creates a meandering multi-stage bankfull channel contained by a floodplain terrace buffer. The multi-stage channel allows flows to spread gradually as discharge increases within the bankfull channel. Once discharge exceeds design bankfull, the floodplain terrace again allows for flows to spread gradually before finally reaching the floodplain limits. The floodplain terrace follows a less sinuous design than the bankfull channel as a way to confine the bankfull flows.

3.2 Sediment Transport Analysis

Sediment supplies, as well as the stability of the channel, bank, and bed, have been assessed for this project, as sediment transport played an important role in the impacts from the 2013 floods.

Hydraulic modeling of existing conditions is used, in conjunction with geomorphic assessments, to identify areas of sediment and flow "bottlenecks" (e.g., steep to less steep channel slope transitions) and areas where bank and hillslope scour are of concern. Combined with sediment data collected from the channel and flow duration curves generated from the USGS gage on Left Hand Creek near the project site, a basic sediment transport capacity analysis upstream and along the project reach was conducted. These models were used for the following purposes:

- To guide iterative design of channel and floodplain for a more resilient river corridor; and
- To assess channel stability and sediment continuity under existing and proposed conditions by assessing bed shear and downstream variation in stream power.

The design team used shear forces applied at multiple discharges, the sediment transport competency calculation, and the predicted particle size. The team has calculated unit stream power and shear stress as hydraulic geometry parameters by discharge during the design phase and compared them to the large ranges that are displayed in the existing conditions. The existing applied shear force ranges from 0.04 – 4.75 psf. Our design is based on keeping all applied shear forces below the 100-yr discharge threshold of 3 psf with a design unit stream power below the threshold of 67 lbs/ft-s.

4 Geomorphology

Analysis of the watershed and site assessment data by our team of scientists, engineers, and landscape architects has been used to guide the development of objectives, based on the goals initially defined by the project goals statement and refined by the stakeholder engagement process. A stream resilience assessment, SQT Evaluation (U.S. Army Corps of Engineers, 2017), has been used to analyze various elements of the stream to determine the importance of restoration. Higher scores indicate better performance, as shown in the example scorecard in Table 1. A design scorecard will also be used to illustrate the anticipated functional improvements or lift on the stream performance.

Table 1: Existing Condition Functional Assessment Quantification Tool- Not Functioning 0.18 (U.S. Army Corps of Engineers, 2017). See Appendix 3 – Wyoming Stream Quantification Tool User Manual (Beta Version) for information on the tool used to generate these tables.

EXISTING CONDITION ASSESSMENT						Roll Up Scoring			
Functional Category	Function-Based Parameters	Measurement Method	Field Value	Index Value	Parameter	Category	Category	Overall	Overall
Hydrology	Catchment Hydrology	Catchment Assessment	F2	0.5	0.50	0.49	Functioning At Risk	0.18	Not Functioning
	Reach Runoff	Curve Number	60	0.73	0.73				
		Concentrated Flow Points							
		Soil Compaction							
	Flow Alteration	Q_Low, Measured / Q_Low, Expected	0.67	0.25	0.25				
Hydraulics	Floodplain Connectivity	Bank Height Ratio	2	0	0.00	0.00	Not Functioning		
		Entrenchment Ratio	1.4	0					
Geomorphology	Large Woody Debris	LWD Index	10	0.3	0.30	0.28	Not Functioning		
		# Pieces							
	Lateral Stability	Erosion Rate (ft/yr)	0.5	0.2	0.30				
		Dominant BEH/NBS	H/M	0.3					
		Percent Streambank Erosion (%)	25	0.3					
	Riparian Vegetation	Left Riparian Width Ratio	30	0.38	0.43				
		Right RiparianWidth Ratio	20	0.2					
		Left Woody Vegetation Cover	40	0.83					
		Right Woody Vegetation Cover	40	0.83					
		Left Herbaceous Vegetation Cover	20	0.67					
		Right Herbaceous Vegetation Cover	30	0.53					
		Left Non-native Plant Cover (%)							
		Right Non-native Plant Cover (%)							
		Left Hydrophytic Vegetation Cover (%)							
		Right Hydrophytic Vegetation Cover (%)							
		Left Stem Density (stems/acre)	50	0					
		Right Stem Density (stems/acre)	50	0					
		Greenline Stability Rating							
	Bed Material Characterization	Size Class Pebble Count Analyzer (p-value)							
	Bed Form Diversity	Pool Spacing Ratio	3.5	0.50	0.38				
		Pool Depth Ratio	2	0.64					
		Percent Riffle	80	0.00					
	Plan Form	Aggradation Ratio							
		Sinuosity	1.04	0	0.00				
Physicochemical	Temperature	Mean Daily Aug Temp (ºC)							
		MWAT - 7-day average temperature							
	Nutrients	Chlorophyll							
Biology	Macroinvertebrates	WSI							
		RIVPACS							
	Fish	Number Native Fish Species (% of expected)							
		SGSN Absent Score							
		Game Species Biomass (% Increase)							

Existing conditions were assessed with a combination of LiDAR and survey-grade GPS data. The assessment evaluated stabilities and instabilities found within the reach. The assessment also evaluated the existing plan, profile, and cross-section of the reach. The area was studied using a Watershed Assessment of River Stability and Sediment Supply process (Rosgen, 2007). With the aid of stakeholder input for goals and objectives, our team developed a collection of potential design

alternatives that optimized existing conditions while improving the reach stability. A reference reach on Lone Pine Creek in Livermore, CO was selected as an example to work towards in the design. Geomorphic conditions of the existing site, the reference reach, and the proposed design are explained in more detail below.

4.1 Geomorphic Assessment

4.1.1 Existing Reach

The design team, using survey grade GPS survey equipment on March 23, 2017, collected geomorphic data. Pre-construction data included the longitudinal profile and 11 cross-sections. Bankfull indicators were noted in the field and used to estimate the existing average bankfull channel dimension as 76.5 square feet (range from 55 to 85 square feet), with an average bankfull width of 57 feet. The calculated bankfull discharges ranged from 330 – 790 cfs. The average slope through the reach is 1.28%. The drainage area of the project reach is 61.7 square miles.

Graphs of the longitudinal profile (Figure 6) and two sample cross sections (Figure 7 and Figure 8) are shown below.

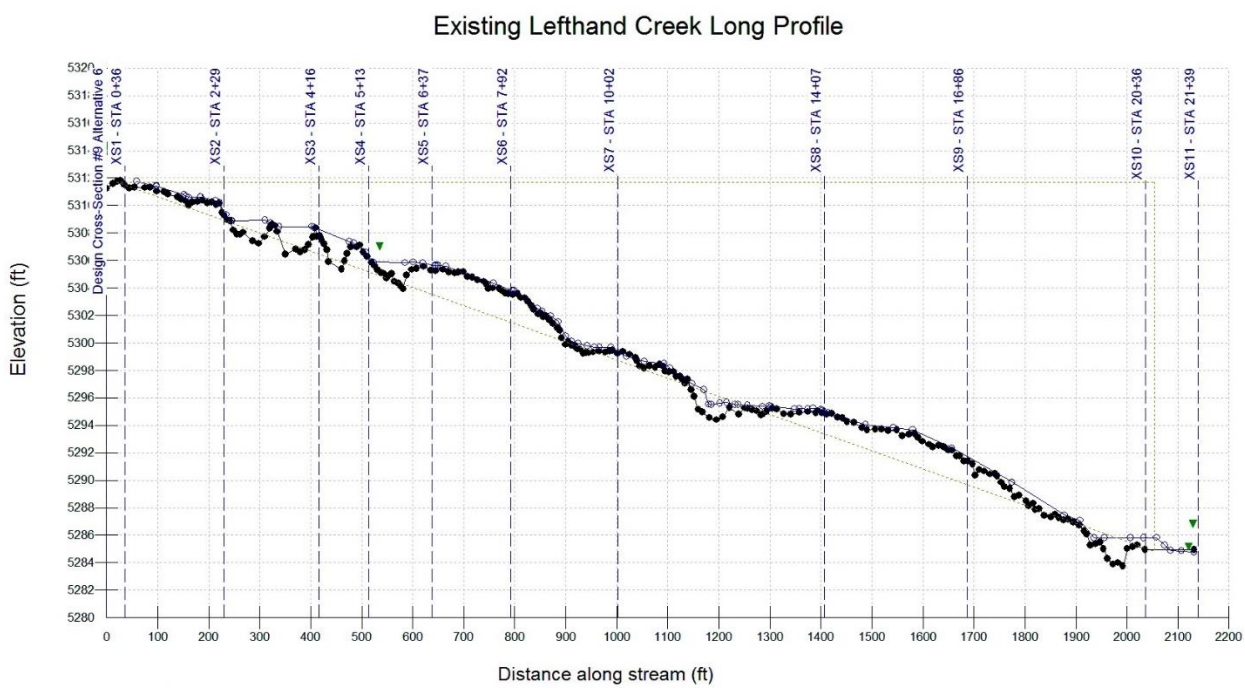

Figure 6: Longitudinal Profile with Channel Bed and Water Surface Measured Existing Slope 1.3%

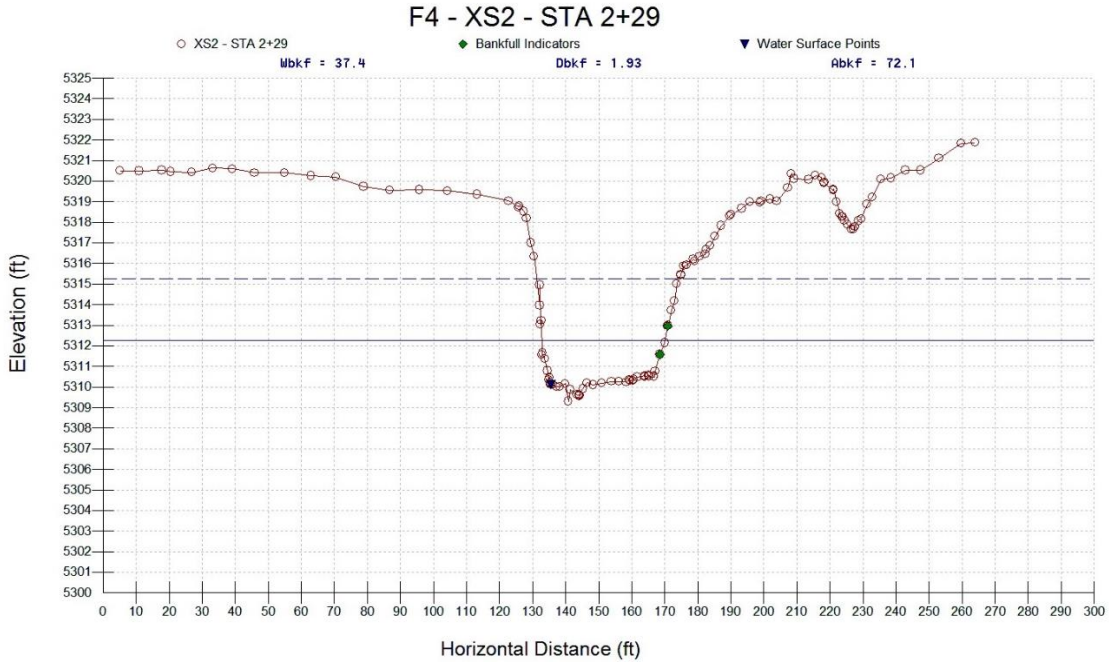

Figure 7: Sample Upstream Cross-Section F4 - Channel Entrenchment Ratio 1.3 and BHR 2.2

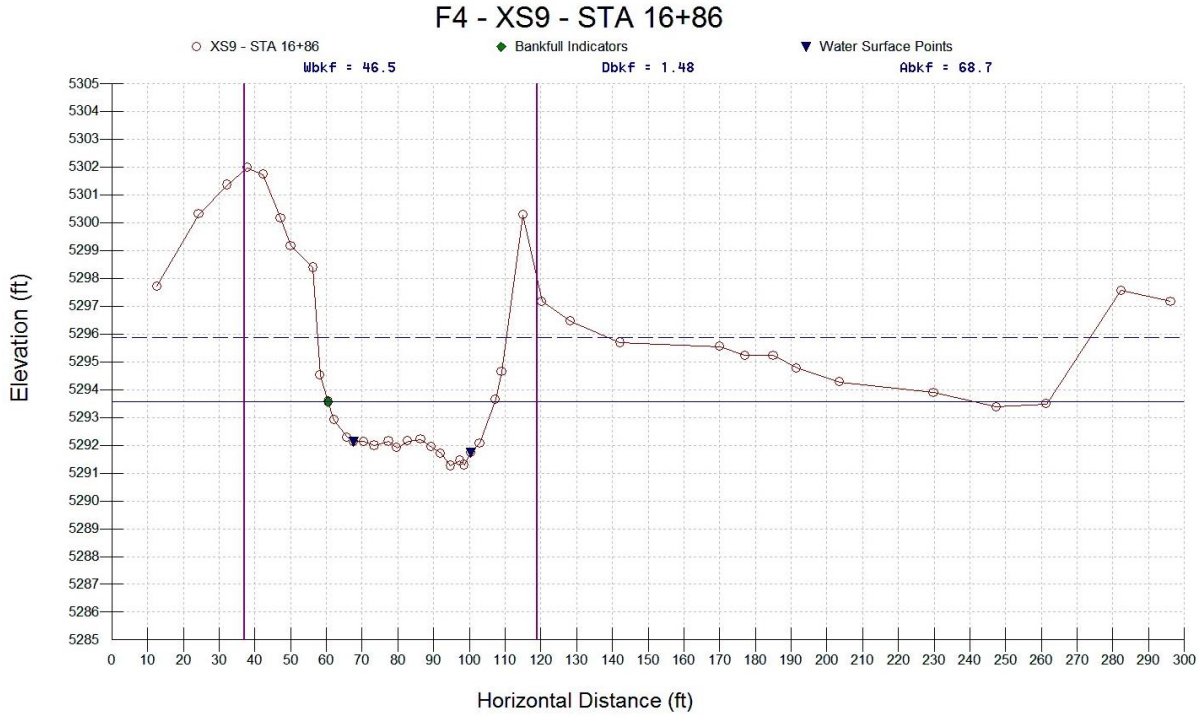

Figure 8: Sample Downstream Cross-Section

Methodologies described by Harrelson and others (1994) were used to collect the pebble count data on three riffles through the project reach. Table 2 summarizes the pebble count data. Figure 9 displays the particle size distribution graph of the pebble count data.

Table 2: Pebble count data collected through the Brewbaker-Sorensson project reach on 7/19/2017

Location: Brewbaker-Sorensson (Left Hand Creek)					Date: 7/19/2017			Observers: KL, NS						
						Riffle 1		Riffle 2		Riffle 3		Cumulative		
	Particle	Millimeters	size finer than (mm)	Riffle 1	Riffle 2	Riffle 3	Item %	% Cum	Item %	% Cum	Item %	% Cum	total	Item %	% Cum
Sand	Silt/Clay	<0.062	0.06	5	2	1	4.90%	4.90%	1.96%	1.96%	1.01%	1.01%	8	2.64%	2.64%
	Very Fine	0.125 - 0.25	0.25		11	4	0.00%	4.90%	10.78%	12.75%	4.04%	5.05%	15	4.95%	7.59%
	Medium	0.25 - 0.50	0.50		9	5	0.00%	4.90%	8.82%	21.57%	5.05%	10.10%	14	4.62%	12.21%
	Coarse	0.50 - 1.0	1.00	10	1	4	9.80%	14.71%	0.98%	22.55%	4.04%	14.14%	15	4.95%	17.16%
	Very Coarse	1.0 - 2	2.00	2	6	10	1.96%	16.67%	5.88%	28.43%	10.10%	24.24%	18	5.94%	23.10%
Gravel	Very Fine	2 - 4	4.00	6		10	5.88%	22.55%	0.00%	28.43%	10.10%	34.34%	16	5.28%	28.38%
	Fine	4 - 5.7	5.70	3		4	2.94%	25.49%	0.00%	28.43%	4.04%	38.38%	7	2.31%	30.69%
	Fine	5.7 - 8	8.00	3		6	2.94%	28.43%	0.00%	28.43%	6.06%	44.44%	9	2.97%	33.66%
	Medium	8 - 11.3	11.30			3	0.00%	28.43%	0.00%	28.43%	3.03%	47.47%	3	0.99%	34.65%
	Medium	11.3 - 16	16.00	1	1	6	0.98%	29.41%	0.98%	29.41%	6.06%	53.54%	8	2.64%	37.29%
	Coarse	16 - 22.6	22.60	8	1	2	7.84%	37.25%	0.98%	30.39%	2.02%	55.56%	11	3.63%	40.92%
	Coarse	22.6 - 32	32.00	8	5	4	7.84%	45.10%	4.90%	35.29%	4.04%	59.60%	17	5.61%	46.53%
	Very Coarse	32 - 45	45.00	6	9	5	5.88%	50.98%	8.82%	44.12%	5.05%	64.65%	20	6.60%	53.14%
	Very Coarse	45 - 64	64.00	4	19	2	3.92%	54.90%	18.63%	62.75%	2.02%	66.67%	25	8.25%	61.39%
Cobble	Small	64 - 90	90.00	14	13	9	13.73%	68.63%	12.75%	75.49%	9.09%	75.76%	36	11.88%	73.27%
	Small	90 - 128	128.00	10	12	9	9.80%	78.43%	11.76%	87.25%	9.09%	84.85%	31	10.23%	83.50%
	Large	128 - 180	180.00	6	5	2	5.88%	84.31%	4.90%	92.16%	2.02%	86.87%	13	4.29%	87.79%
	Large	180 - 256	256.00	6	2	5	5.88%	90.20%	1.96%	94.12%	5.05%	91.92%	13	4.29%	92.08%
Boulder	Small	256 - 362	362.00	6	2	2	5.88%	96.08%	1.96%	96.08%	2.02%	93.94%	10	3.30%	95.38%
	Small	362 - 512	512.00	2	4	1	1.96%	98.04%	3.92%	100.00%	1.01%	94.95%	7	2.31%	97.69%
	Medium	512 - 1024	1024.00	2			1.96%	100.00%	0.00%	100.00%	0.00%	94.95%	2	0.66%	98.35%
	Large - Vry Large	1024 - 2048	2048.00				0.00%	100.00%	0.00%	100.00%	0.00%	94.95%	0	0.00%	98.35%
	Bedrock					5	0.00%	100.00%	0.00%	100.00%	5.05%	100.00%	5	1.65%	100.00%
	Sum	--		102	102	99							303		

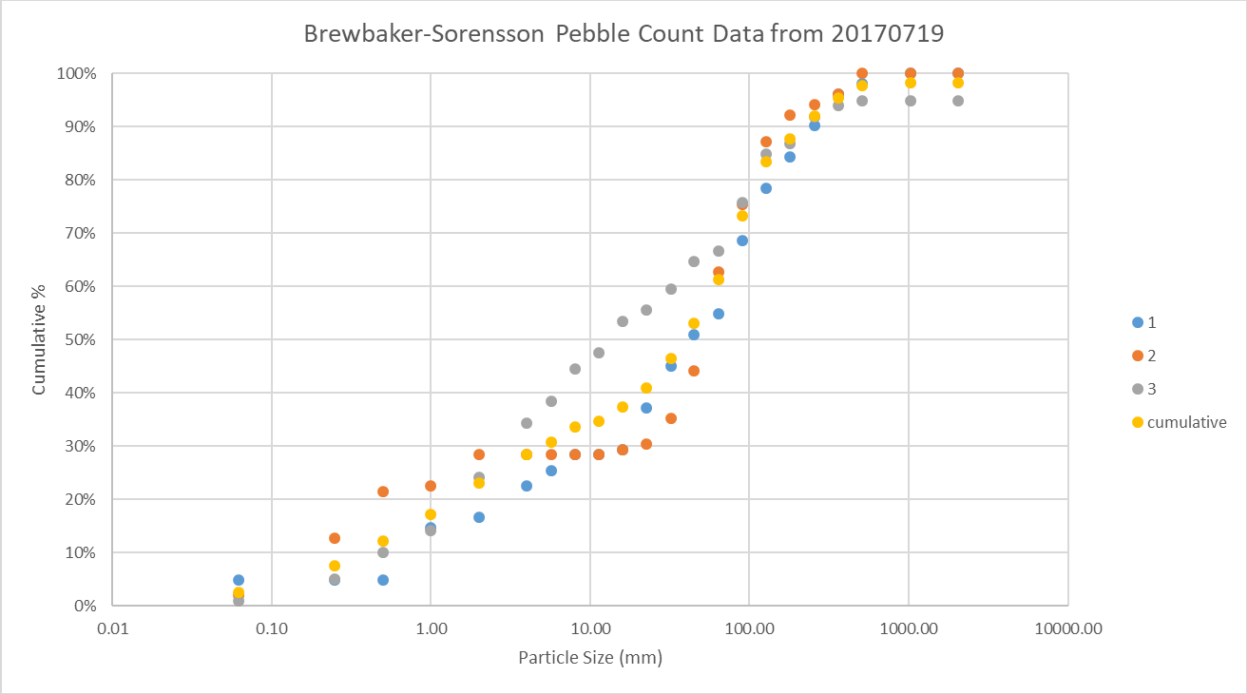

Figure 9: Particle size distribution for pebble count data collected on Brewbaker-Sorensson project reach on 7/19/2017

4.1.2 Reference Reach

Lone Pine Creek in Livermore, CO was surveyed, July 18, 2017, as a reference reach (Harrelson, Rawlins, & Potyondy, 1994) for this project due to its similar surrounding land use and relative stability elevation, distance from the foothills. The drainage area of Lone Pine Creek at the surveyed reach is 86.3 square miles. The mean annual precipitation is 18.5 inches. The reach slope is 0.4%. The average pool-to-pool spacing is 90 feet (ranging from 34 to 157 feet). At the time of the survey, there was a heavy presence of beaver within the surveyed reach. Like the project reach, this reach is approximately the same distance from the mouth of a canyon as it makes the transition from the foothills onto the plains. A number of "reference" parameters were collected from this site and used to help guide the project design. These parameters include: the average radius of curvature on the site is 41 feet (ranging from 20 to 69 feet), the average meander wavelength is 157 feet (ranging from 127 to 176 feet), and the average belt width is 48 feet (ranging from 35 to 69 feet).

Reaches were surveyed on Left Hand Creek above and below the project reach (Figure 10) to better identify the relationship between drainage area and bankfull cross-sectional area. This data has been used to develop the mini-regional curve for the project (Table 3).

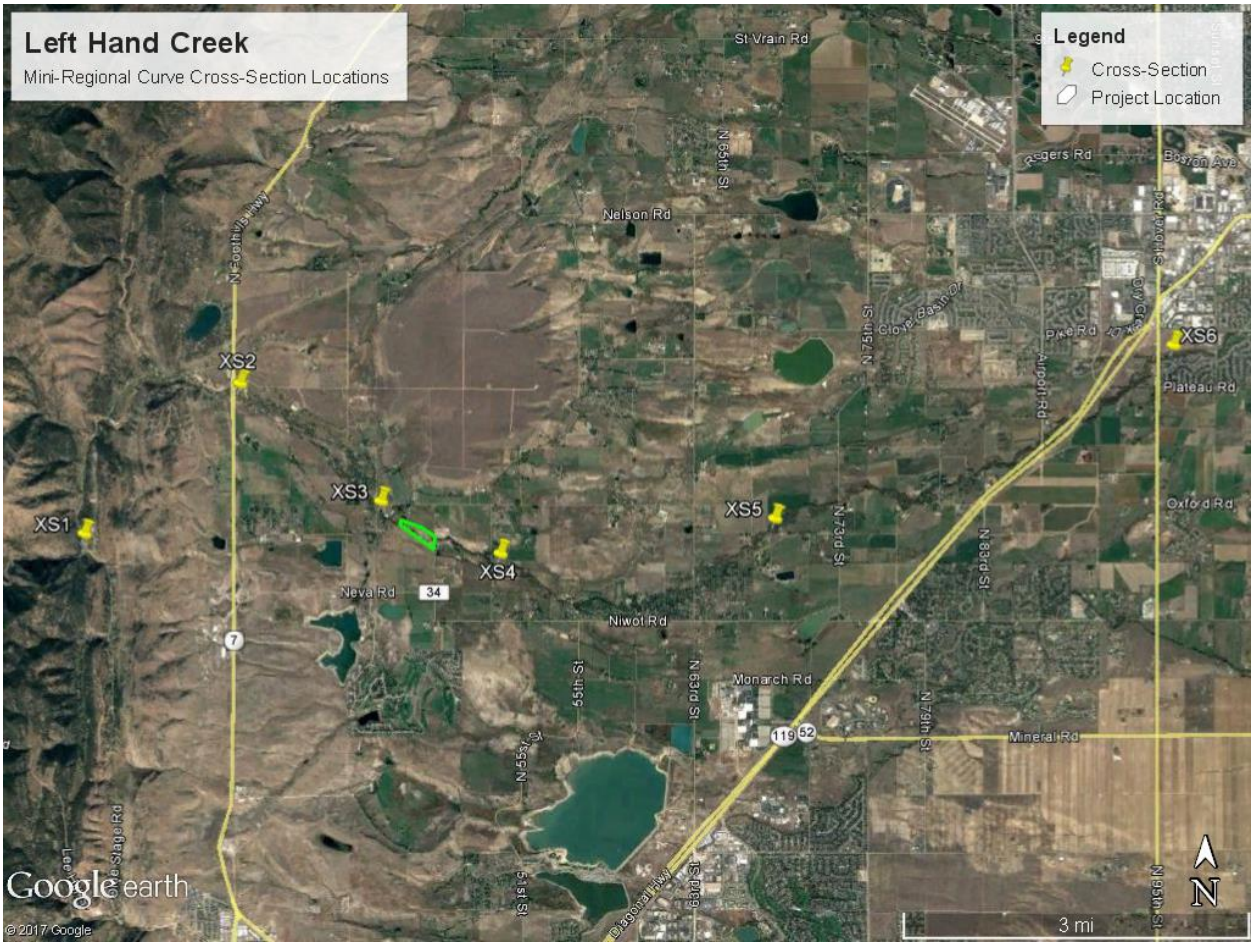

Figure 10: Left Hand Creek Mini-Regional Curve cross-section locations.

Table 3: Left Hand Creek mini-regional curve data. Data collected July 2017.

Left Hand Creek mini-regional curve cross-section data

Cross-Section	Latitude	Longitude	Drainage Area (sq mi)	Bankfull cross-sectional area (XSA) (sq ft)	Bankfull Dishcarge (cfs)	Drainage Area $(DA)^{2/3}$	$XSA/(DA^{0.67})$	Width (ft)	Depth (ft)	Slope (%)	roughness coefficient (n)	WDR	Type
1	40.11117	-105.307	47.3	85	510	13.25	6.42	42	2	2	0.055	20	B3/2
2	40.12993	-105.282	58.2	80	175	15.22	5.26	70	12	1.25	0.045	60	C4/3
3	40.11522	-105.259	61	72	410	15.71	4.58	30	23	0.75	0.04	13	C4/3
4	40.10869	-105.239	62.1	47	260	15.90	2.96	26	1.8	0.75	0.035	14	C4/3
5	40.11302	-105.194	63.9	56	310	16.21	3.46	22	2.5	0.5	0.035	9	E4/3
6	40.13458	-105.129	70.4	69	301	17.29	3.99	30	2.3	0.25	0.03	13	E4

4.1.3 Proposed Design

To create a resilient design, the team is using a multi-stage channel approach. This method builds a low-flow channel followed by a sloped inner berm bench, which leads to the bankfull channel followed by an additional sloped bankfull bench, and eventually connects to the floodplain over yet another sloped floodplain terrace (Figure 11). The discharge used by the design team for bankfull riffle design is 350 cfs; using a bankfull cross-sectional area of 70 square feet, a bankfull width of 32.5 feet, and a width-to-depth ratio of 17. The selected design discharge results in a watershed response factor of 4.1, which is in line with expectations from other drainage basins within the Front Range when adjusted for slope and rainfall. There is a high degree of uncertainty with the bankfull elevations, but multi-stage channel design creates a level of resiliency to protect against uncertainties. The multi-stage channel helps to ensure that there is enough capacity within the channel and "active" floodway to convey seasonal and flood flows. The multi-stage channel reduces shear stresses within the cross-section, effectively "opening" up the channel at different stages. As the flows increase, they are spread out across the terraces; decreasing the velocities, reducing the energy of the flowing water. The pattern of the design bankfull channel has a pool-to-pool spacing of 3.8 to 5.7 times the bankfull width, radius of curvatures of 2.1 to 3.3 times the bankfull width, tangent riffle lengths of 1 to 4 times the bankfull width, and a meander belt width of 2.1 to 4.7 times the bankfull width.

The design inner berm cross-sectional area is 42% of the design bankfull channel cross-sectional area, or 29.4 square feet. The width of the inner berm is 19.2 feet, and the inner berm width-to-depth ratio is 13.6. The flood terrace has a cross-sectional area 277% the bankfull cross-sectional area, approximately 194 square feet. The flood terrace width-to-depth ratio is 3.9 times that of the bankfull width to depth ratio, or 67. The average width of the design flood terrace is 114 feet. The 100-year floodplain is designed to convey 6,500 cfs, keeping the applied shear stress below the average boundary shear stress of 2 to 3 pounds per square foot. The 100-yr floodplain depth is approximately 3.7 feet, with a slope of 1.3%. The minimum 100-yr floodplain width, assuming velocities of five feet per second is 350 feet. Using the pattern layout of the channel, this width ranges from 80 to 225 feet.

A sample design cross-section is shown in Figure 11.

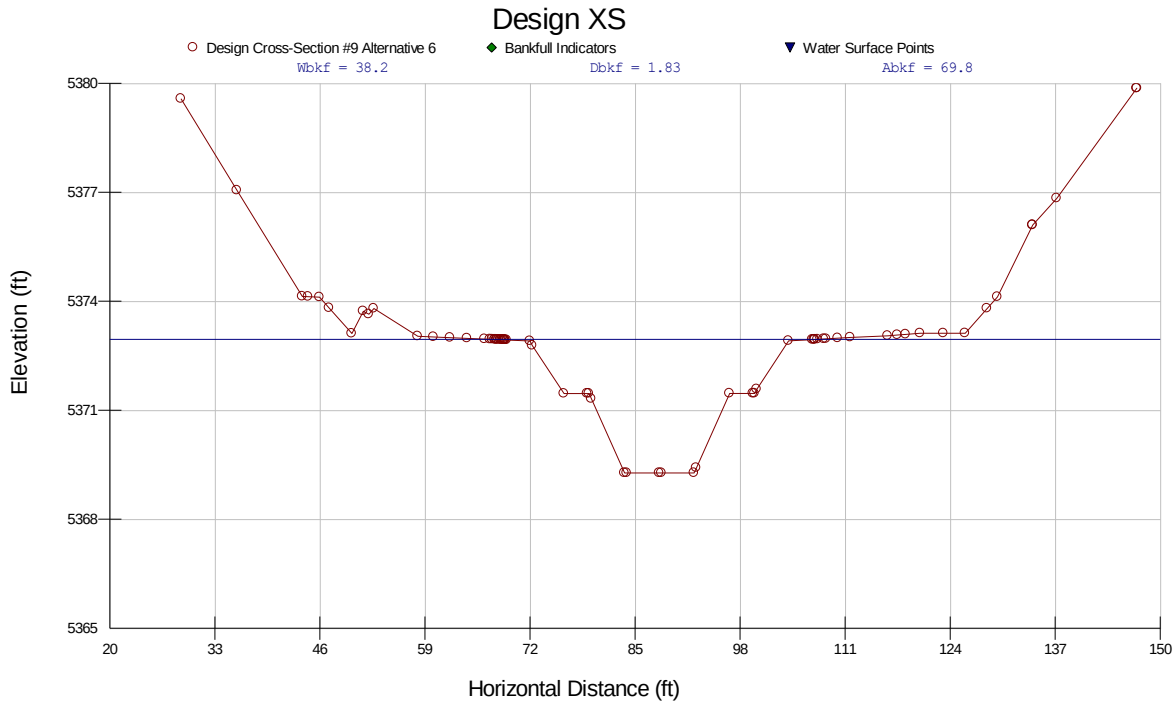

Figure 11: Sample design riffle cross-section

Dimensionless ratios calculated from data obtained from the reference reach survey on Lone Pine Creek which were used to both check and influence design parameters for the Brewbaker-Sorensson Reach on Left Hand Creek. *Dimensionless ratios* are ratios of quantities such that their units cancel out, leaving them as pure numbers or "dimensionless". Dimensionless ratios make it possible to take data from a reference reach and scale that data to reaches with seemingly different sizes and configurations (NRCS, 2007). When using reference data it is important to understand where the reference data is coming from, along with understanding the inherent differences between the channels. It is important to compare the watersheds, channel types (Rosgen, A classification of natural rivers, 1994), slopes, geology, soils, vegetation, etc. All of these parameters, and others, can influence the pattern, profile, and cross-sectional dimension of the reaches.

Table 4 shows the reference parameters in comparison to the design parameters. The rows highlighted in gray in the table are the scalable dimensionless ratios. The idea is to use the parameters of seemingly stable reaches collected during a reference reach survey and apply them to a design. Utilization of dimensionless ratios makes these parameters scalable. The Lone Pine Creek reference reach had a flatter slope than the disturbed reach and a higher sinuosity than the design reach. The channel sinuosity is defined as the ratio between the channel length as compared to the valley length. The project reach had a pre-flood sinuosity of 1.23 that is very close to the design sinuosity of 1.17. The current sinuosity of the reach is 1.06. The design team has optimized through routing the potential for sediment transport in the reach with a profile that is represented by an average reach slope in the range of 1.0% – 1.4%. There is an inverse relationship between sinuosity and slope. As sinuosity increases, increasing with the increase in reach length, the slope of the channel decreases; and vice versa. By reducing the slope, or increasing the sinuosity of the reach, the design team has reduced the number of grade-control structures required within the project

reach. Shear stress through the project reach is decreased with the decrease in slope. Shear stress decreases with the decrease of channel slope. The ecological diversity and functional uplift is significantly improved with a higher sinuosity through hyporheic exchange of water and nutrients. The anthropogenic manipulations have resulted in an impaired stream morphology that may look "correct", at a sinuosity less than 1.1, but is not functioning at a high level.

Table 4: Reference Reach (Lone Pine Creek) and Design Reach (Brewbaker-Sorensson Reach, Left Hand Creek) geomorphic parameters. Notice rows highlighted in gray are dimensionless ratios. It is the comparison and use of these dimensionless ratios that help inform the design.

Reference Reach and Design Reach Comparisons

Cross-section

	Reference Riffle			Existing Typical Riffle	Design Riffle	Reference Pool			Existing Typical Pool	Design Pool
	Mean	Min	Max			Mean	Min	Max		
Bankfull (BKF) width (ft)	24	18	32	42	32	21	17	24	23	35
Mean depth (ft)	1.4	1.2	1.4	1.5	2.12	1.9	1.2	2.0	1.9	2.1
Max depth (ft)	2.5	2.3	2.7	2.6	3.6	3.2	3.1	3.5	2.3	6.4
Floodprone width (ft)	85	65	127	46	80	91	77	101	25	80
BKF area (ft^2)	34	30	39	77	68	39	35	45	45	75
Width to depth ratio	18	11	26	29	15	12	8	15	12	17
Max depth to mean depth	2.0	1.9	2.2	1.7	1.7	2.6	2.6	2.9	1.2	3.0
Entrenchment ratio	3.5	2.5	4.0	1.1	2.5	4.5	3.3	5.9	1.1	2.5

Pattern

	Reference Reach		Typical Existing		Design	
	Min	Max	Min	Max	Min	Max
Pool to pool spacing (ft)	91	157	193	405	122	181
Meander wavelength (ft)	139	176	327	739	219	320
Belt width (ft)	72	86	108	143	35	167
Radius of curvature (ft)	24	69	30	633	66	104
Channel Sinuosity	1.875		1.060		1.165	
Pool to pool spacing/BKF width	3.8	6.2	4.6	9.6	3.8	5.7
Meander wavelength/BKF width	5.8	9.7	7.7	17.4	6.9	9.7
Belt width/BKF width	3.0	4.7	2.5	3.4	2.1	4.7
Radius of curvature/BKF width	0.8	3.8	0.7	14.9	2.1	3.3

Profile

	Reference Reach	Typical Existing	Design
Channel Slope	0.4%	1.3%	1.04%

To provide protection to existing cut banks, increase habitat complexity with the project reach, and to help balance grading materials on-site, three vernal depressions, near stations 7+50, 13+50, and 15+50 have been introduced to the design surface. During seasonally high flow events, the vernal depressions are designed to become saturated. They are not design to hold water, or expose ground water during low flow periods.

Design riffle slopes through the Brewbaker-Sorensson project reach range from 1.74 to 3.78 percent, or a riffle slope ratio (riffle slope/reach slope) of 1.4 – 2.9. The design bankfull slope is gentler, ranging from 1.02 to 1.37 percent. At the lowest flows, the difference in relative depth between the pools and riffles is great, and variations in water surface due to these features are more apparent. As the flows increase to bankfull, the relative depth of the pools and riffles converge reducing the variation in water surface slope, which approaches the bankfull slope.

A phenomenon occurs in natural systems called slope reversals. Figure 12 demonstrates slope reversals, notice that riffle slopes tend to get flatter and pools slopes get steeper as flows increase to bankfull stage.

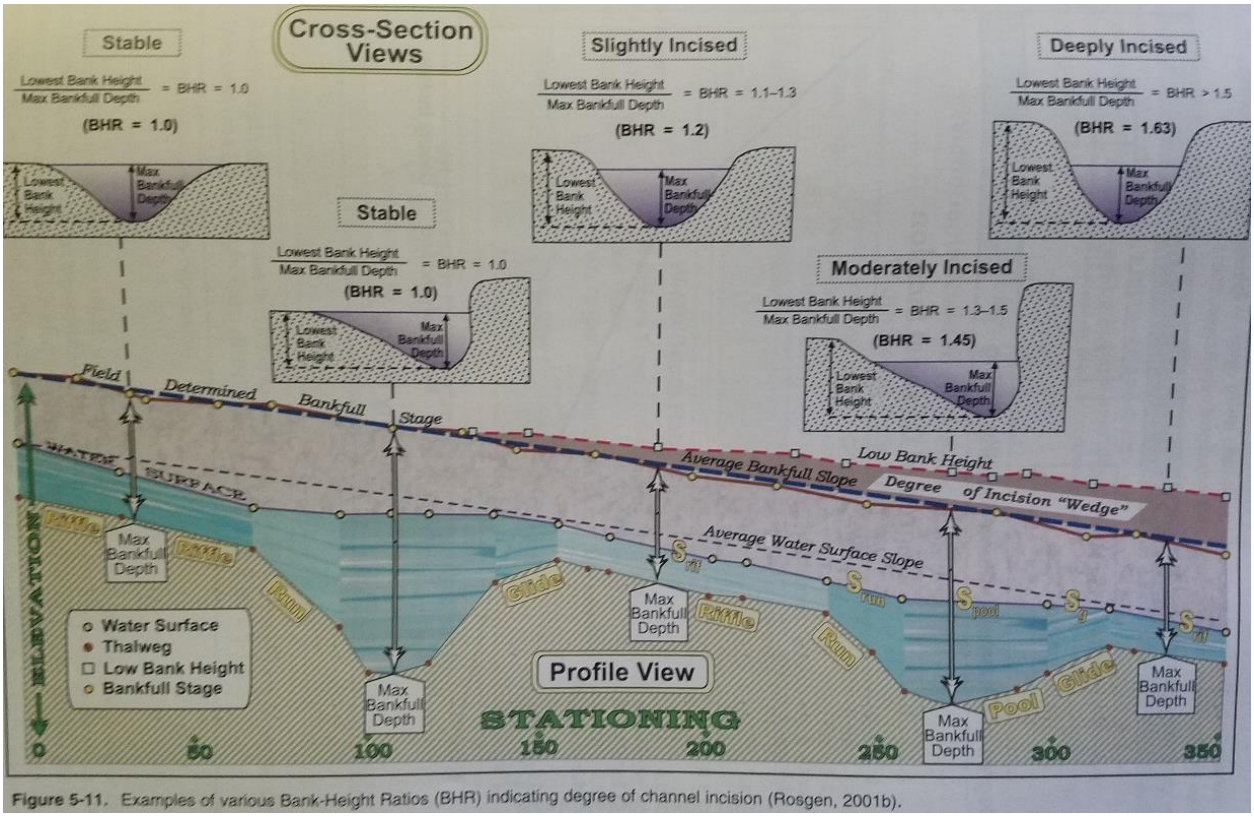

Figure 5-11. Examples of various Bank-Height Ratios (BHR) indicating degree of channel incision (Rosgen, 2001b).

Figure 12: Example of channel profile and water surface slopes. Figure 5-11 from WARSSS (Rosgen, 2006)

Slope reversals provide ecological and habitat benefits. This phenomenon improves hyporheic exchange within riffles; it creates heterogeneous sorting of riffle substrate, this is based on individual riffle slopes; it improves fish drift and feeding lanes; and it helps remove nitrogenous waste from potential spawning areas.

Steep, low flow, riffles carry inherent risks. The more steep the slope of the riffle the higher the calculated shear stress. To mitigate for this risk, the design of the channel should be such that, as the stage increases, the riffle slopes decrease. At bankfull stage, the slope of the energy grade line should be approaching the bankfull slope.

Figure 13 shows a three-stage channel. The first stage is the inner berm, or low flow, channel. The second stage is the bankfull channel. In addition, the final stage is the floodplain channel before the design surface ties into the existing ground surface.

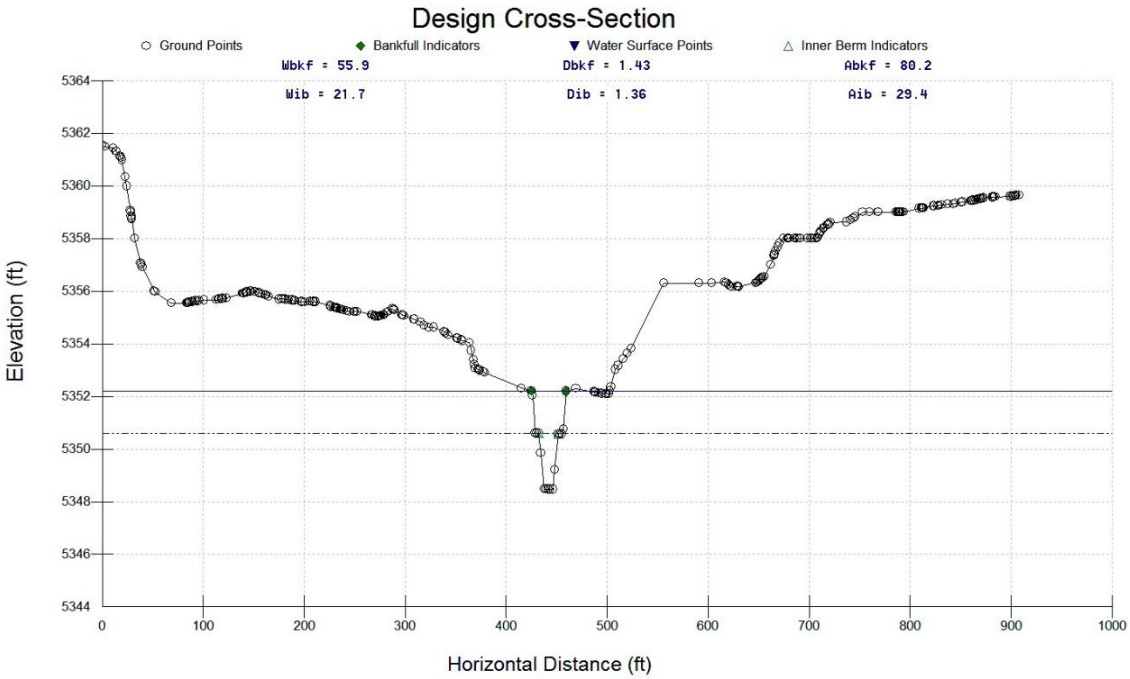

Figure 13: Design cross-section, three-stage channel

The range of riffle slope ratios through the design cross-section (Figure 13) and plotted the discharge shear stress distribution as predicted by discharge are shown in Figure 14 and Figure 15.

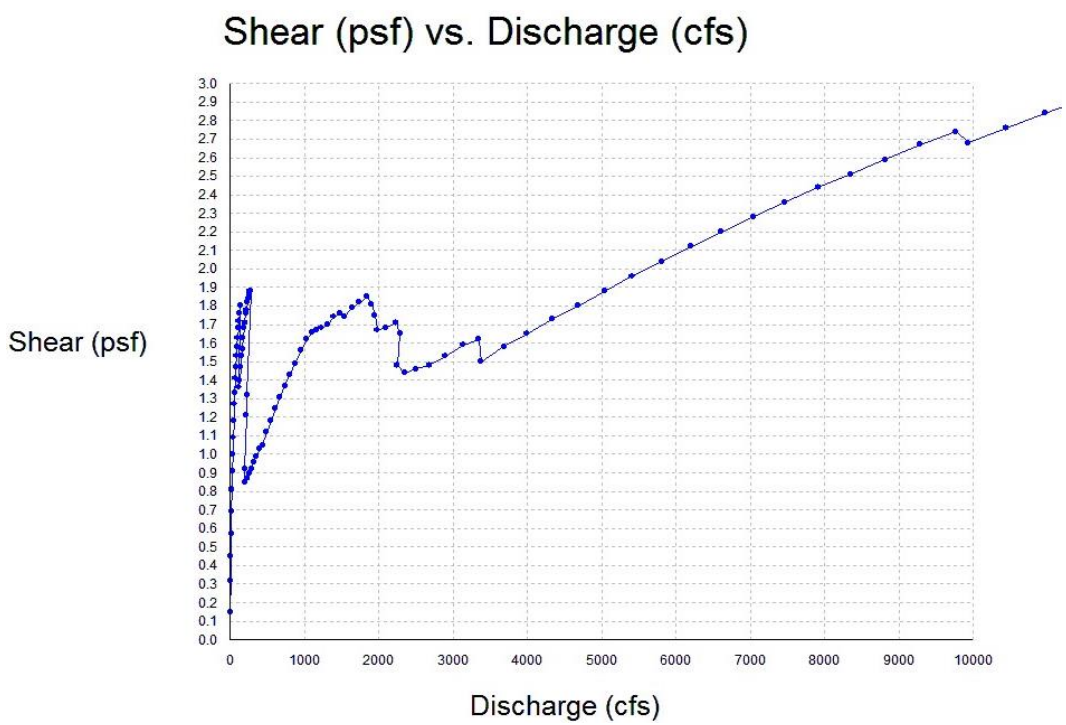

Figure 14: 10,300 cfs 100-year riffle slope ratio 2.0.

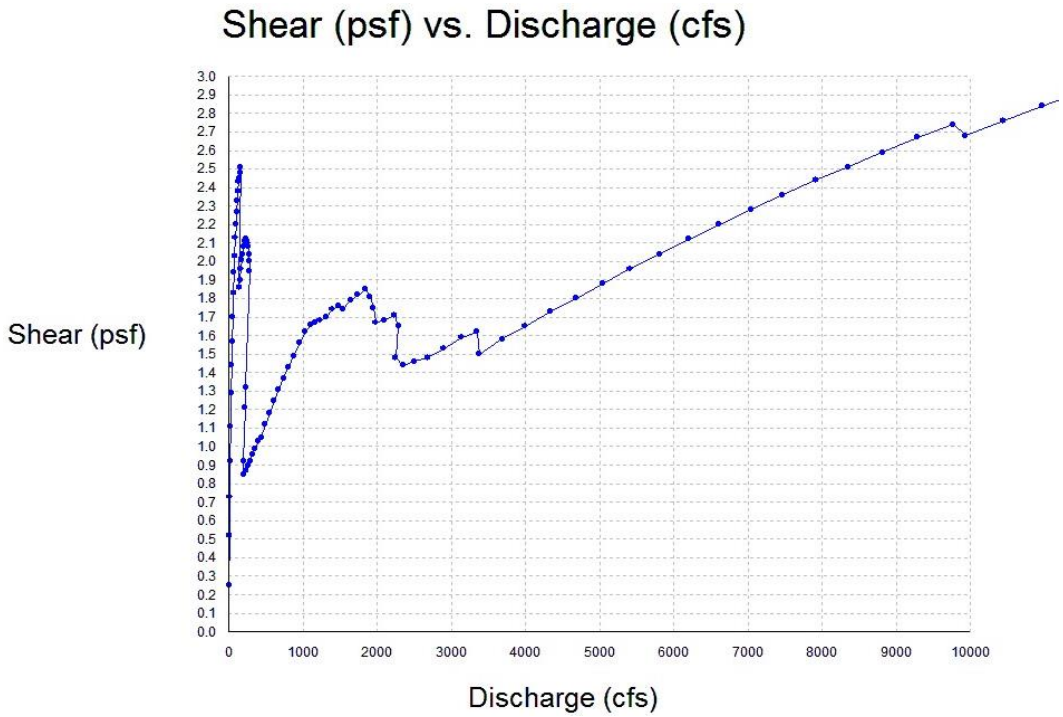

Figure 15: 10,300 cfs 100-year riffle slope ratio 3.2.

Both the slope and Manning's 'n' values change relative to the stage of water in the channel. The design shear stresses for the reach range from 1.0 to 2.5 psf. The discharges analyzed range from zero flow to 10,000 cfs (approximately the 100-year discharge, based on the FIS). The design build process for deciding riffle substrate armoring is based on evaluating the existing substrate available for armoring, and adjusting the slopes and lengths of riffles to accommodate the design parameters while trying to maximize the utilization of available on-site materials.utilizing the materials available on-site. The riffles are designed to be threshold riffles and forces impacting the substrate should not be sufficient to move the particle beyond the incipient point of motion. The prediction of the incipient point of motion of these particles is based on analytical data collected and published by Leopold, Wolman, and Miller (1964) and data collected by Rosgen (2006) (Figure 16).

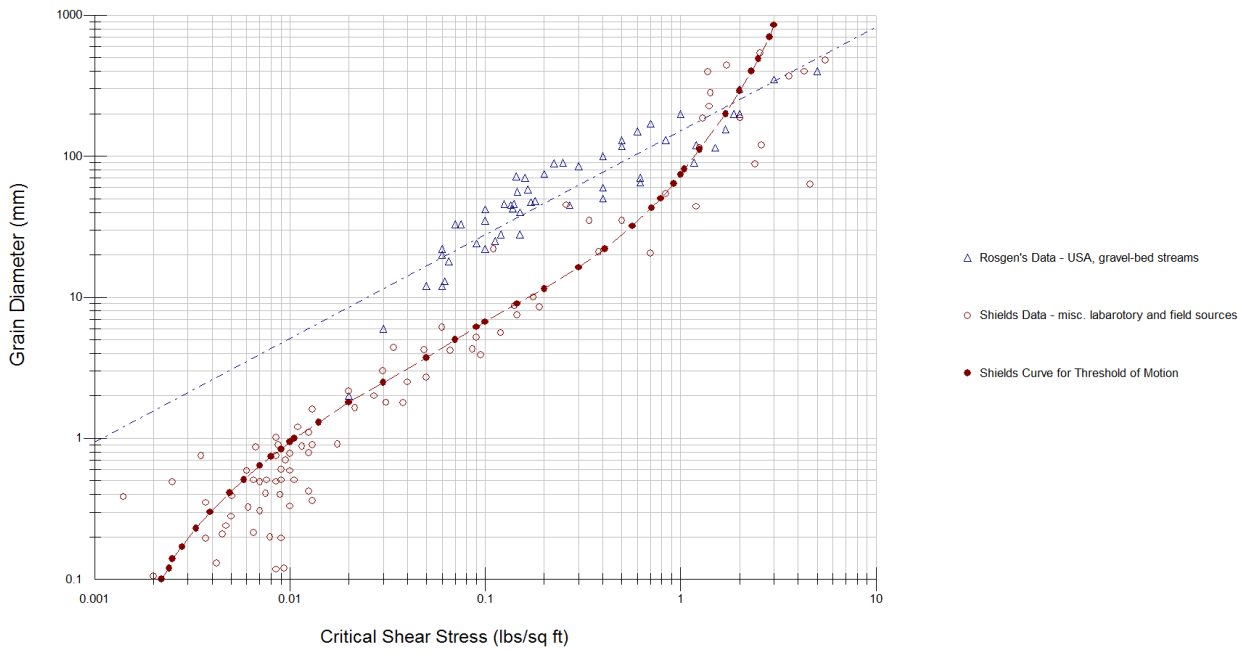

Figure 16: Shield's entrainment function with Rosgen data overlay.

Figure 17: Photo demonstrating existing substrate on Brewbaker-Sorensson project reach.

The existing substrate (Figure 17) based on three riffle cross sections was analyzed and is displayed in Figure 9. The cumulative D50 = 40 mm (32 - 45), D84 = 128 mm (128-180), and D90 = 256 mm (180-256) (Table 2). Successful construction of steeper riffle sections depends on onsite quality control and quality assurance of the materials being placed for riffle armoring. Our design team will use the Leopold, Wolman, and Miller (1964) relationship to predict the required D50 based on shear stress for all shear values less than 1 psf, and will use the Rosgen dataset (2006) to predict the D90 of the riffle based on all shear stresses greater than 1 and less than 2.5 psf.. North State Environmental will sort harvested substrate material, as approved by 5SSR, during construction to be adequate to armor the riffles at their constructed slopes. In the event that North State

Environmental is unable to harvest coarse enough riffle material for the threshold riffles, they will be provide quarried material at an acceptable gradation for the riffle substrate. Based on the geomorphic assessment and channel departure/trajectory, it is highly probable that all necessary riffle substrate will be available on site and the import of materials for the riffles will not be necessary, except for the construction of the downstream constructed riffle.

4.2 Soils

Soil type dictates the sediment transport factor of a project design based on the soil's necessary shear stress for stability. The USDA publishes a web database with documented soil types across the country (NRCS, 2017). Through the use of this database, soils for the project reach and reference reach can be compared to predict appropriate maximum bank slopes to create a stable system.

4.2.1 Project Reach

The USDA recorded eight soil types near the existing project reach. Of these eight soil types, five are varieties of clay loam. The clay loams surrounding the project reach are all mixed with gravels and cobbles, which classify them as well draining and are in medium to high runoff classes. The project area is bordered on the south by Terrace escarpments, which consist mostly of cobble and stony colluvium on top of sandstone and shale. The creek flows through Niwot soils, which are made up of an alluvium mix of loam over sand, and gravel. Niwot soils are considered to be poor draining, have a low water storage capacity, and are in a very low runoff class. The average depth to the water table in Niwot soils is usually between 18 and 36 inches.

Figure 18 shows the soil delineation map of the project reach vicinity. Table 5 lists the acres of each soil type.

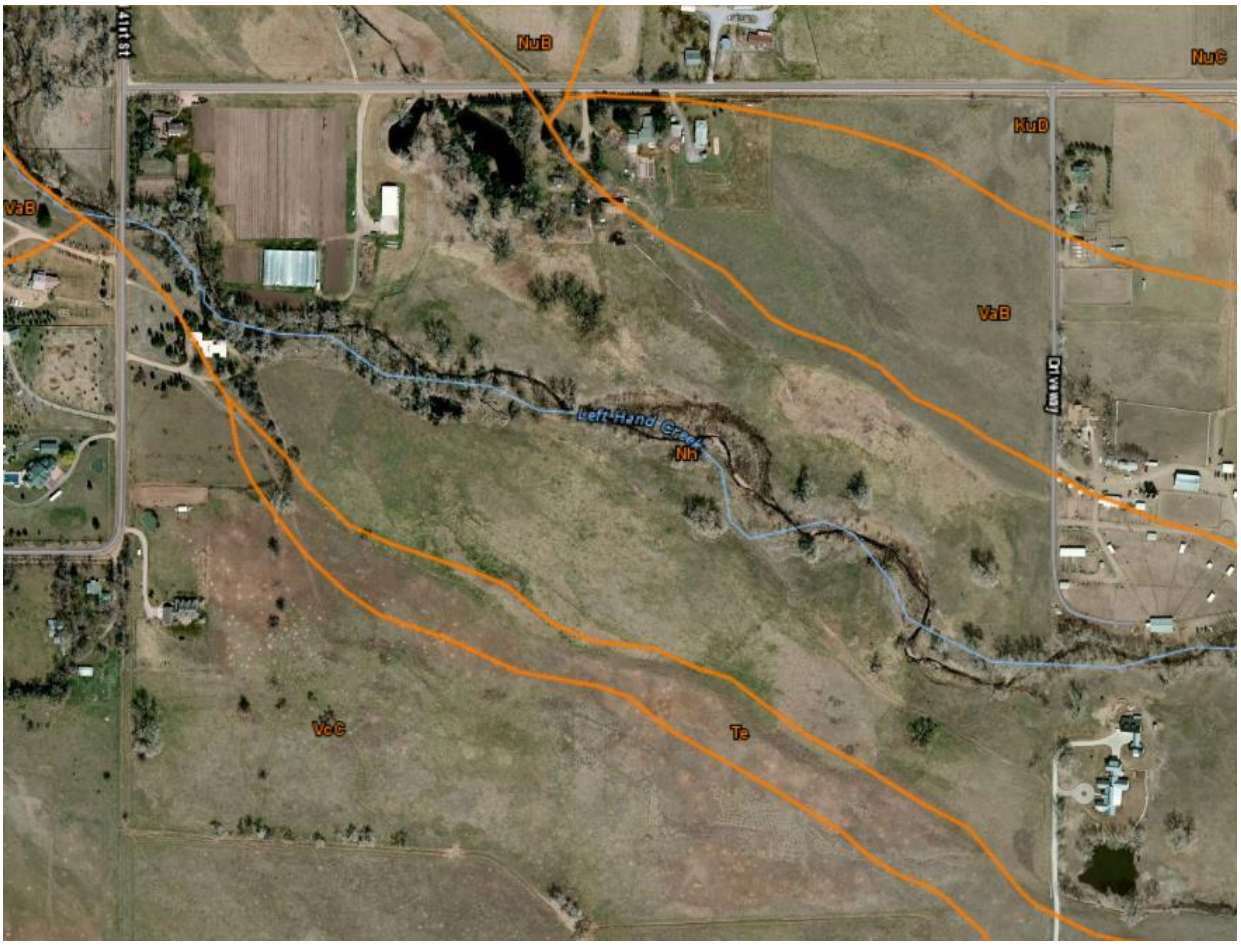

Figure 18: Soil Delineation of Project Reach (NRCS, 2017)

Table 5: Project Reach Soil Type Breakdown (NRCS, 2017)

Boulder County Area, Colorado (CO643)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
KuD	Kutch clay loam, 3 to 9 percent slopes	18.4	7.5%
Nh	Niwot soils	102.4	41.8%
NuB	Nunn clay loam, 1 to 3 percent slopes	1.7	0.7%
NuC	Nunn clay loam, 3 to 5 percent slopes	7.2	2.9%
Te	Terrace escarpments	13.0	5.3%
VaB	Valmont clay loam, 1 to 3 percent slopes	32.1	13.1%
VcC	Valmont cobbly clay loam, 1 to 5 percent slopes	70.1	28.6%
Totals for Area of Interest		**244.9**	**100.0%**

4.2.2 Reference Reach

Lone Pine Creek in Livermore, CO sits at the base of a hill and has more soil type diversity than the project reach. In this area, the USDA identified 10 soil types ranging from sandy loams to rock outcrops. These soils allow the creek flexibilty to move through the floodplain. A variety of vegetation is supported in these soils. Lone Pine Creek meanders through Poudre fine sandy loam, which contains primarily sand, and Table Mountain loam, which contains a mix of clay and silt. Both soil types have very high water storage capacities, low runnoff classifications, and are well-draining. Poudre fine sandy loam has an average depth to water between 12 to 36 inches, while Table Mountain loam has an average depth to water of deeper than 80 inches.

Figure 19 shows the soil delineation in the vicinity of the reference reach on Lone Pine Creek in Livermore, CO. lists the acreage of each soil type.

Figure 19: Soil Delineation of Reference Reach (NRCS, 2017)

Table 6: Figure 15: Reference Reach Soil Type Breakdown (NRCS, 2017)

Larimer County Area, Colorado (CO644)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
25	Connerton-Barnum complex, 3 to 9 percent slopes	21.7	5.0%
45	Haplustolls-Rock outcrop complex, steep	0.8	0.2%
46	Harlan fine sandy loam, 1 to 3 percent slopes	56.5	13.1%
47	Harlan fine sandy loam, 3 to 9 percent slopes	117.6	27.3%
57	Kirtley loam, 3 to 9 percent slopes	29.0	6.7%
58	Kirtley-Purner complex, 5 to 20 percent slopes	74.4	17.3%
84	Poudre fine sandy loam, 0 to 1 percent slope	27.2	6.3%
86	Purner-Rock outcrop complex, 10 to 50 percent slopes	44.6	10.4%
96	Satanta loam, 3 to 5 percent slopes	1.4	0.3%
105	Table Mountain loam, 0 to 1 percent slopes	57.2	13.3%
Totals for Area of Interest		**430.4**	**100.0%**

5 Physiochemical

5.1 Temperature

Low water temperature is necessary for creating an atmosphere suitable for supporting healthy ecosystems in cold-water rivers and streams. Direct sun exposure of surface water increases the water temperature as well as the evaporation rate and decreases the dissolved oxygen. By using multi-stage channel design and revegetating the benches and banks, water temperature is lowered because of the increased water depth throughout the reach and the development of shady areas.

In addition, high turbidity caused by bank erosion increases water temperature and inhibits necessary oxygen regulation in the water. Stabilizing the banks with appropriate side slopes and revegetation of native plants decreases dissolved solids in the water. Planting bank cover also introduces organic carbon into the system in the form of leaf litter.

6 Biology

To gain an understanding of the pre-flood ecological conditions of Boulder Creek, reviews were conducted of relevant sources developed prior to the 2013 floods. A hydroseres map (Figure 20) was generated to assist in informing the placement of plants and seeds. The map is relative to design bankfull elevation along the project reach. Such an effort is essential toward the development of appropriate ecological restoration goals and designs.

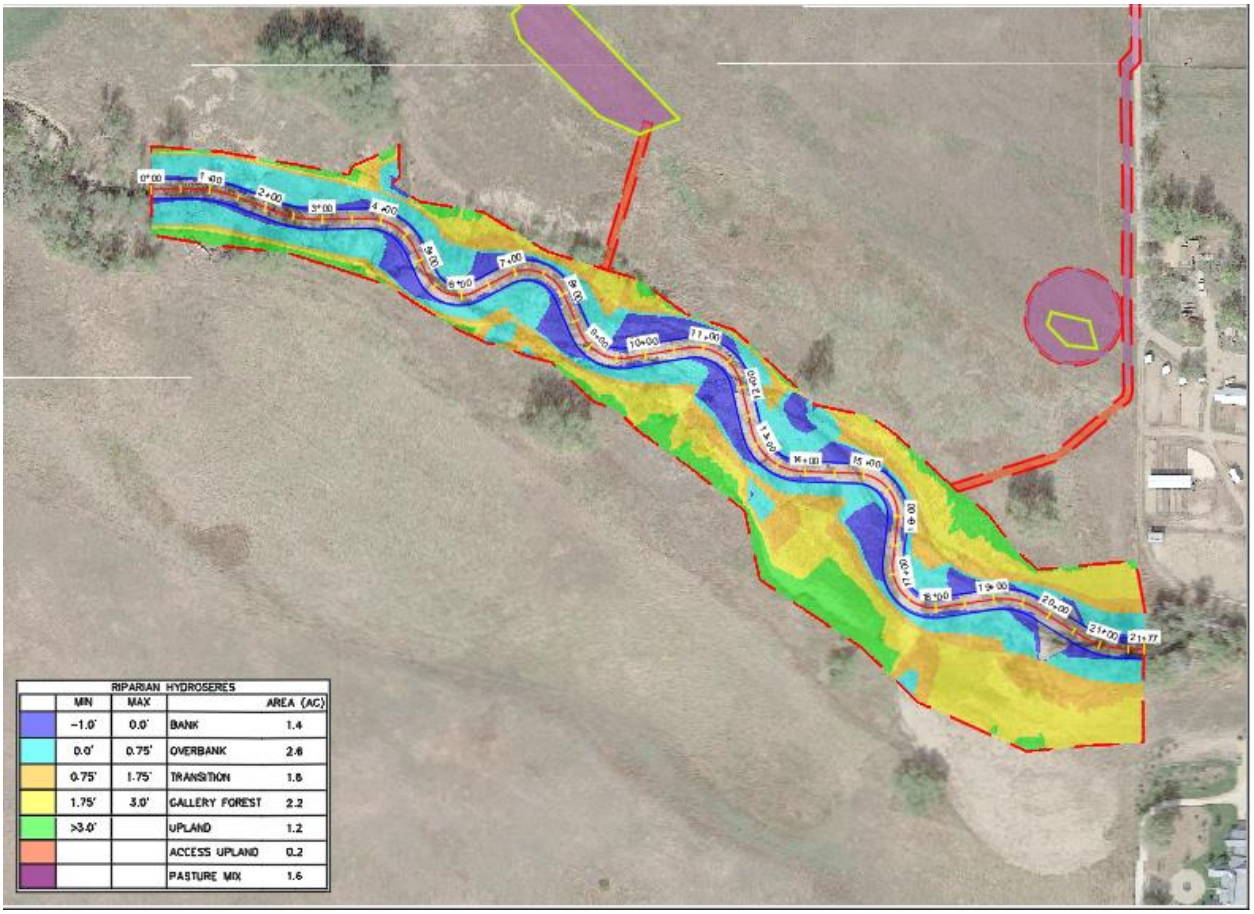

Figure 20: Hydroseres map.

6.1 Vegetation

Based on an understanding of potential native plant communities, species conservation status, and other biological data generated by our assessments, habitat requirements are defined for key species. Native vegetation that supports and sustains local habitats will be utilized for the project and will be planted based on hydroseres, or vegetation zones. AloTerra has developed a planting plan, detailing selected seed mixes and plantings for the hydroseres. Riparian vegetation reduces water velocity during flood conditions, allowing for deposition of sediment onto the floodplain, and increases native fish habitat by creating shaded cover and diverse aquatic habitats within the reach.

Planting plans are developed based on hydroseres, soil types, soil moistures, hydrology, shade conditions, and the site-specific revegetation goals. Because the success of revegetation efforts is inextricably linked to soil amendments, soil surface protection, and other plant protection measures (e.g., fencing), AloTerra has provided specifications for such elements. Specifications include weed and nitrogen content of topsoil and mulch, quality and ratings of erosion fabric, and weed content of target native seed lots. Finally, because it is essential to begin plant materials development at least one year prior to installation, AloTerra has developed a schedule and strategy for the development of ecotypic (locally adapted) and other native vegetation required by the planting plan.

Working collaboratively with local entities, local cuttings, and seed materials and produced appropriate container stock (where appropriate) for this project will be collected. AloTerra has

worked to understand the opportunities and limitations of developing species listed in the planting plan, and have outlined strategies to overcome any possible limitations to acquiring the right species at the right time for Left Hand Creek.

6.2 Wetland Assessment

The wetland delineation was completed on July 14, 2017 by AloTerra Restoration Services and is included in the design sheet set in Appendix 1 –Design Plan Sheet Set – Brewbaker-Sorensson Left Hand Creek Restoration. The majority of the wetlands will be undisturbed as they reside outside of the proposed project Limits of Disturbance. Very few acres of wetlands lie within the design alignment and will be permanently impacted. Temporary wetland impacts will occur from the necessity of crossing the wetlands to build the design alignment. Some of the existing channel will be filled and revegetated, while some of the channel will be incorporated into the design channel and, therefore, undisturbed. A new channel bed will be built as well.

7 Design Development

In order to produce an optimal design, our design development includes: (a) Bioengineering elements (slope protection, transverse structures, soil-covered rip-rap, vegetated soil lifts, etc.); (b) Channel alignment and floodplain connectivity; (c) Wetland grading plans; (d) Revegetation plans; (e) Soil amendment and mulch plans; (f) Construction access and erosion control plans; (g) Other design elements necessary to meet project goals; (h) Preliminary details and as-built; (i) Size calculations for materials; (j) Opinion of probable cost; and (k) Final report.

Input provided by the representatives of the BCPOS has been invaluable in developing design elements that optimize the design to meet the goals and objectives of the project. Their involvement and expertise has helped shape the project.

7.1 MCDA

Multi-Criteria Decision Analysis (MCDA) is a process that uses a numerical scoring system to compare project design alternatives based on goals and objectives. A goal is an overarching principle that guides decision-making, while an objective is a more specific and measureable step that can be made to meet the goal. Goals and objectives are identified, and the shareholders give each objective a weighting factor based on its level of importance. Each design alternative is then given a ranking from 1 to 5 on how it achieves the objectives. Objective scores for each design option are multiplied by their weighting factors and summed to make the overall score (MCDA Matrix Score) for each option. Options are then ranked and compared, with the lowest value being the most optimal.

The design team evaluated six alternative designs, including the option of doing nothing. Through the input of shareholders, the objectives were given weighing factors based on what they felt were the most important. Based on the MCDA for this project, the preferred alternative was Option #6. When costs of the restoration were considered, Option #6 was still the preferred alternative. The complete MCDA can be found in

Appendix 2 – MCDA for Brewbaker-Sorensson Left Hand Creek Restoration.

7.2 Specific Design Elements for Left Hand Creek

Primary design concepts that have been addressed throughout the design process include:

- Establishing proper cattle crossing over Left Hand Creek;
- Discouraging invasive plant species;
- Stabilizing the stream channel using natural channel design;
- Increasing floodplain connectivity;
- Removing artificial berms;
- Revegetating riparian and floodplain areas with native plant species;
- Maintaining flood-created habitat areas.

The design plans show existing features as necessary to allow the evaluation of project impacts. Design plans will be printed at the standard size (11x 17 inches) and will be made to meet the statutory requirements for plans filed for the public record.

7.3 Opinion of Probable Cost

To assist with stakeholder communication and cost/benefit analysis, the engineer's opinion of probable cost (EOPC) for each alternative is included in the MCDA.

To address this regional post-flood restoration climate situation and to provide BCPOS with the most accurate cost estimate possible, we used a two-phase approach. In the first phase of cost estimating, the historical comparison of past projects and construction costs is used only for preliminary design and alternatives analysis. In the second phase, 30% Design plans of the preferred alternative are used as the basis for refinement of the EOPC. Refinement is accomplished by utilizing software that considers inputs critical to a general contractor's costs such as: (a) Production speeds of excavation and grading; (b) Haul truck capacity and stocking; (c) Haul Distances; (d) Number times needed to handle material; (e) Fuel costs; (f) Operator and Laborer hourly rates; (g) Seed, plants, rock, erosion matting, and other materials costs; and (h) Time to completion of standard river restoration structures. Our team members use the influence of these inputs along with proposed sequences and timing of construction to produce anticipated cost estimates.

7.4 Design Optimization

Thirty percent designs are refined by employing two key design optimization methods. The first is through an iterative design process. From the identification of a preferred alternative to the production of a final design, have developed multiple design iterations, adjusted by feedback from stakeholders and our internal review, converging on an optimal solution that balances risk with the achievement of goals and objectives. The second method we use is a 3D design process that utilizes the "Breakline" program written by members of our team in 2002. This program allows comparison of existing and proposed surfaces to determine accurate cut and fill quantities. Our team adjusts variables within the Breakline program until the proposed design matches the existing topography to the greatest extent practical. By using this approach, we are able to minimize cut and fill, while retaining the integrity and geomorphic stability of the design.

Below are design assumptions:

1.) The low end of the bankfull assessment of 250 cfs is the best potential for revegetation, but for resiliency through a nested channel approach is to be designed up to the high range of the bankfull discharge at 750 cfs.
2.) The design is for resiliency up to the 100-yr discharge of 6,500 cfs.
3.) The 100-yr floodplain width is designed to keep the 100-yr 6,500 cfs discharge below a threshold shear stress of 3 psf.
4.) The 100-yr floodplain width is designed to keep the 100-yr 6,500 cfs discharge below a threshold design unit stream power below the threshold of 67 lbs/ft-s.
5.) The pool-pool spacing is based on the bankfull width of 32 ft and a design slope of 1.0-1.1%. Figure 17 below as well as the Lone Pine Creek analysis was used as a reference for the pool-pool spacing.

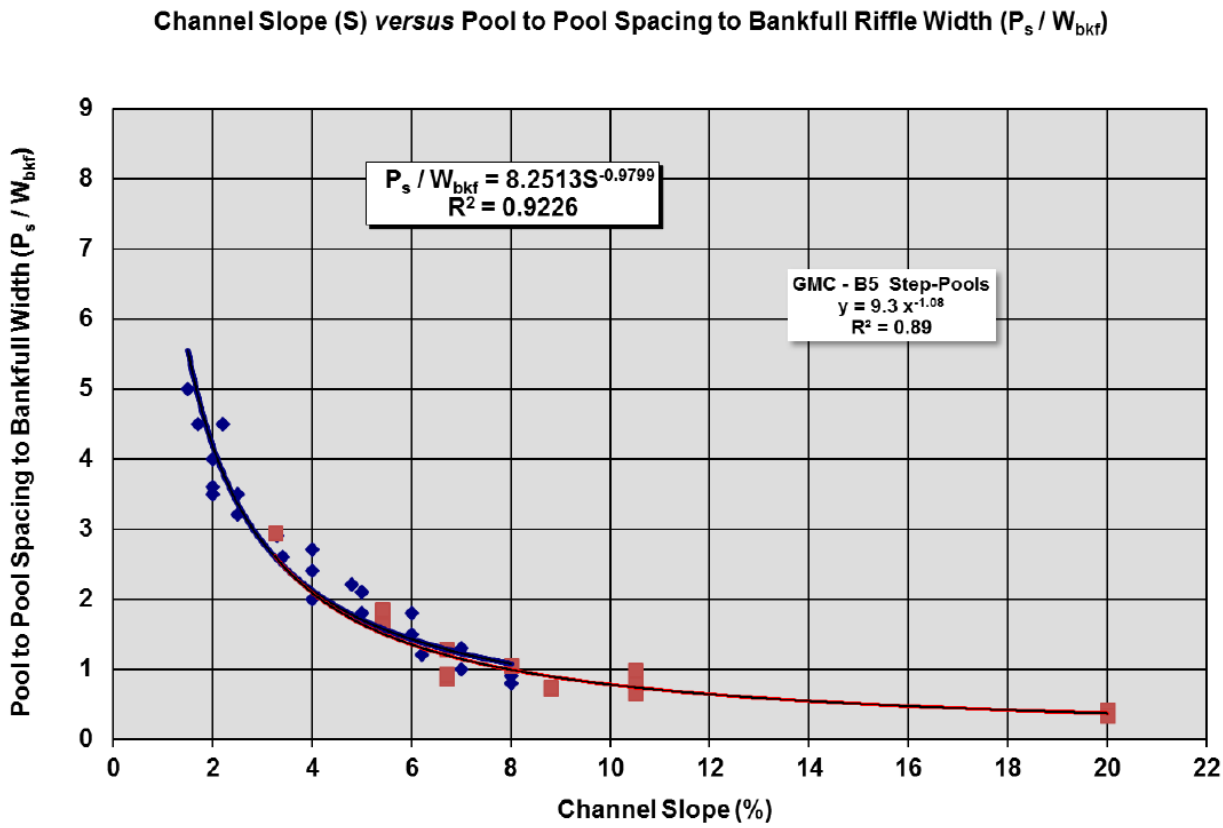

Figure 21: Pool-to-Pool Spacing for Step-pool systems

6.) All removed vegetation is designed to be reused in the floodplain or structures.
7.) Design channel Manning's "n" is 0.035 with a floodplain Manning's "n" of 0.06.

8 Designed Functional Uplift

The Stream Functions Pyramid, developed by Harman (2009), mentioned in section 1.4, describes properties affecting stream function in a hierarchical order. The pyramid consists of five functional tiers, from top to bottom: biology, physicochemical, geomorphology, hydraulic, and hydrology. The

function of each tier is dependent on the tiers preceding it. For example, for the biology tier (the top tier of the pyramid) to be functioning, each of the lower level tiers (physicochemical, geomorphology, hydraulic, and hydrology tiers) also need to be functioning. Disruption to any of the tiers will have an impact on the biology within the system. A functional lift quantification tool for stream restoration projects, also known as the Stream Quantification Tool (SQT), has been developed based on the functional framework identified by the Stream Functions Pyramid (Harman and others 2016). This tool attempts to quantify the function of each of the tiers.

The SQT is a tool used to quantify the stream function of an existing river reach; it is also used to demonstrate the expected change in function within a river reach due to a proposed action. Improvements to the functional framework of the system, from the existing condition to the proposed condition, of any of the tiers of the Stream Functions Pyramid result in an increase in function of the system, or functional uplift.

The stream will be enhanced/restored to achieve a functional uplift for the purpose of restoration of stream function that was lost during the September 2013 flood. The preliminary figures below help document the projects proposed functional uplift. This project is proposed to have a very significant functional uplift at 227% functional change based on the figures below.

Table 7: Proposed Condition Functional Assessment (U.S. Army Corps of Engineers, 2017). See Appendix 3 – Wyoming Stream Quantification Tool User Manual (Beta Version) for information on the tool used to generate these tables.

PROPOSED CONDITION ASSESSMENT						Roll Up Scoring		
Functional Category	Function-Based Parameters	Measurement Method	Field Value	Index Value	Parameter	Category	Category	Overall	Overall
Hydrology	Catchment Hydrology	Catchment Assessment	F2	0.5	0.50	0.49	Functioning At Risk	0.51	Functioning At Risk
	Reach Runoff	Curve Number	60	0.73	0.73				
		Concentrated Flow Points							
		Soil Compaction							
	Flow Alteration	Q_Low, Measured / Q_Low, Expected	0.67	0.25	0.25				
Hydraulics	Floodplain Connectivity	Bank Height Ratio	1	1	0.86	0.86	Functioning		
		Entrenchment Ratio	2.5	0.71					
Geomorphology	Large Woody Debris	LWD Index			1.00	0.81	Functioning		
		# Pieces	30	1					
	Lateral Stability	Erosion Rate (ft/yr)	0.2	0.67	0.59				
		Dominant BEHI/NBS	M/M	0.5					
		Percent Streambank Erosion (%)	10	0.67					
	Riparian Vegetation	Left Riparian Width Ratio			0.64				
		Right RiparianWidth Ratio							
		Left Woody Vegetation Cover	50	0.78					
		Right Woody Vegetation Cover	50	0.78					
		Left Herbaceous Vegetation Cover	50	0.93					
		Right Herbaceous Vegetation Cover	50	0.93					
		Left Non-native Plant Cover (%)	10	0.83					
		Right Non-native Plant Cover (%)	10	0.83					
		Left Hydrophytic Vegetation Cover (%)							
		Right Hydrophytic Vegetation Cover (%)							
		Left Stem Density (stems/acre)	150	0					
		Right Stem Density (stems/acre)	150	0					
	Bed Material Characterization	Greenline Stability Rating							
		Size Class Pebble Count Analyzer (p-value)							
	Bed Form Diversity	Pool Spacing Ratio	4.25	1.00	1.00				
		Pool Depth Ratio	2.75	1.00					
		Percent Riffle	60	1.00					
		Aggradation Ratio							
	Plan Form	Sinuosity	1.22	0.83	0.83				
Physicochemical	Temperature	Mean Daily Aug Temp (ºC)							
		MWAT 7-day Average							
	Nutrients	Chlorophyll							
Biology	Macroinvertebrates	WSII							
		RIVPACS							
	Fish	Number Native Fish Species (% of expected)							
		SGSN Absent Score							
		Game Species Biomass (% Increase)							

Table 8: Function Based Parameters Summary (U.S. Army Corps of Engineers, 2017). See Appendix 3 – Wyoming Stream Quantification Tool User Manual (Beta Version) for information on the tool used to generate these tables.

FUNCTION BASED PARAMETERS SUMMARY			
Functional Category	**Function-Based Parameters**	**Existing Parameter**	**Proposed Parameter**
Hydrology	Catchment Hydrology	0.50	0.50
	Reach Runoff	0.73	0.73
	Flow Alteration	0.25	0.25
Hydraulics	Floodplain Connectivity	0.00	0.86
Geomorphology	Large Woody Debris	0.30	1.00
	Lateral Stability	0.30	0.59
	Riparian Vegetation	0.43	0.64
	Bed Material		
	Bed Form Diversity	0.38	1.00
	Plan Form	0.00	0.83
Physicochemical	Temperature		
	Nutrients		
Biology	Macros		
	Fish		

Table 9: SQT Functional Based Report Card (U.S. Army Corps of Engineers, 2017). See Appendix 3 – Wyoming Stream Quantification Tool User Manual (Beta Version) for information on the tool used to generate these tables.

FUNCTIONAL CATEGORY REPORT CARD			
Functional Category	**ECS**	**PCS**	**Functional Change**
Hydrology	0.49	0.49	0.00
Hydraulics	0.00	0.86	0.86
Geomorphology	0.28	0.81	0.53
Physicochemical			
Biology			

Table 10: Functional Uplift Summary (U.S. Army Corps of Engineers, 2017). See

Appendix 3 – Wyoming Stream Quantification Tool User Manual (Beta Version) for information on tool.

FUNCTIONAL CHANGE SUMMARY	
Exisiting Condition Score (ECS)	0.18
Proposed Condition Score (PCS)	0.51
Change in Functional Condition (PCS - ECS)	0.33
Existing Stream Length (ft)	1887
Proposed Stream Length (ft)	2180
Change in Stream Length (ft)	293
Existing Functional Foot Score (FF)	340
Proposed Functional Foot Score (FF)	1112
Proposed FF - Existing FF	772
Functional Change (%)	227%

9 Construction

The stream will be enhanced to obtain maximum sediment movement while maintaining the proper width-to-depth ratios and pool-to-pool spacing. These will be constructed according to design plans. Boulder structures will be installed to control and direct flows. Substantial amounts of materials including gravel, boulders, and logs will be harvested on-site for the instream structures when possible. The channel bed will be graded and shaped to achieve the best sediment movement while increasing habitat. Planting of new riparian vegetation will also be part of the construction. Construction is scheduled to begin in August of 2018. Monitoring Goals and Objectives.

The success of the restoration project is based on the achievement of the monitoring goals and objectives listed below. Success monitoring is recommended to be conducted with a monitoring period of a minimum of five years. Each objective has monitoring criteria listed below.

Goal 1 - Create a net increase in aquatic resource function and services

- Objective 1: Increase in Functional assessment SQT values from existing conditions/ downstream disturbed conditions during the monitoring period.
- Monitoring: Annually document the Functional assessment SQT rating and report potential problem areas.

Goal 2 - Reconnection of the stream to the historic floodplain

- Objective 2: Improve floodplain connectivity by creating a realigned multi-stage channel design to allow flows to expand gradually onto designed discharge stage benches.
- Monitoring: Annually re-survey two 500-foot typical reaches and perform a geomorphic assessment to document bank height ratio and entrenchment ratio from a minimum of two permanent cross-sections in each 500-foot reach. Report any problem areas.

Goal 3 - Restore the stream channel dimension to a stable reference condition that limits fine sediment supply from in-channel bank erosion

- Objective 3: Less than a 33% change in channel bankfull width at typical riffle, run, pool and glide cross-sections over the five-year period, and less than a 40% change in cross-sectional area.
- Monitoring: Annually re-survey two 500-foot typical reaches and perform a geomorphic assessment to document cross-section width and area in each 500-foot reach. Report any additional problem areas that fall outside of the typical reaches.

Goal 4 –Restore the stream channel profile to a stable reference condition

- Objective 4: Less than a 25% change in reach slope over the five-year period, and no significant head-cuts or stream migration.
- Monitoring: Annually re-survey two 500 ft typical reaches and perform a geomorphic assessment to document reach slope. Report any additional problem areas that fall outside of the typical reaches.

Goal 5- Restore native riparian plant community

- Objective 5: 150 stems /acre of desirable woody species after five years
- Monitoring: Establishment of 8, 12' X 12' randomly placed vegetation plots. All four corners of the plots will be monumented with rebar. Re-survey annually of the vegetation plots within the five year monitoring period

Goal 6 – No loss of wetlands

- Objective 6: As compared to the existing wetland delineation and downstream conditions, no net loss in wetland area at Year 2 and Year 5 post-construction monitoring.
- Monitoring: Year 2 and Year 5 wetland delineation, map, and assessment will be completed.

Goal 7 – Deeper and periodic pools for energy dissipation throughout the reach

- Objective 7: The area of the channel with low flow pool depths will be greater than 1.5 ft deep for a majority of the restored channel after 5 years.
- Monitoring: Annually re-survey two 500 ft typical reaches and preform a geomorphic assessment of areas of low flow pool depths greater than 1.5 ft that provide adequate energy dissipation.

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Appendix 1 –Design Plan Sheet Set – Brewbaker-Sorensson Left Hand Creek Restoration

Appendix 2 – MCDA for Brewbaker-Sorensson Left Hand Creek Restoration

Appendix 3 – Wyoming Stream Quantification Tool User Manual (Beta Version)