Boulder County Parks and Open Space Hall Ranch 2
Road Repair and Stream Hazard Mitigation

South Saint Vrain Creek
Boulder County, Colorado

Prepared on October 21, 2016
By Amec Foster Wheeler

FINAL DESIGN REPORT

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Design Report
Streambank Restoration Project

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Introduction

Large portions of the Hall Ranch 2 access road were damaged by flood waters from Saint Vrain Creek during the September 2013 flood event. Flooding and high water velocities stripped sections of the gravel road surface, eroded gullies through the road surface and sub-base, damaged culverts, caused debris flows across the road and clogged roadside ditches with sediment and debris. Most significantly, the high water completely eroded a 240 foot section of the access road where the South Saint Vrain Creek shifted its channel into the road alignment. The purpose of the project is to restore access into the Hall Ranch 2 property and to provide erosion mitigation measures to protect the road up to the 100-year event.

Description & Location

The proposed road work and river realignment is located approximately 2.1 miles southwest of Lyons, CO off Old Saint Vrain Rd in Section 25, Township 3 North, Range 71 West. The project site is located at approximately 1450 Old Saint Vrain Road, Lyons, CO and within Boulder County Parks and Open Space property that is not currently open to the public. The drainage area at the point of the access road site is approximately 87 square miles and is within the South Saint Vrain Creek Watershed (U.S. Geologic Survey (USGS) Hydrologic Unit Code (HUC) 1019000501), and the Saint Vrain Sub-basin (HUC 10190005) which drains into the South Platte River.

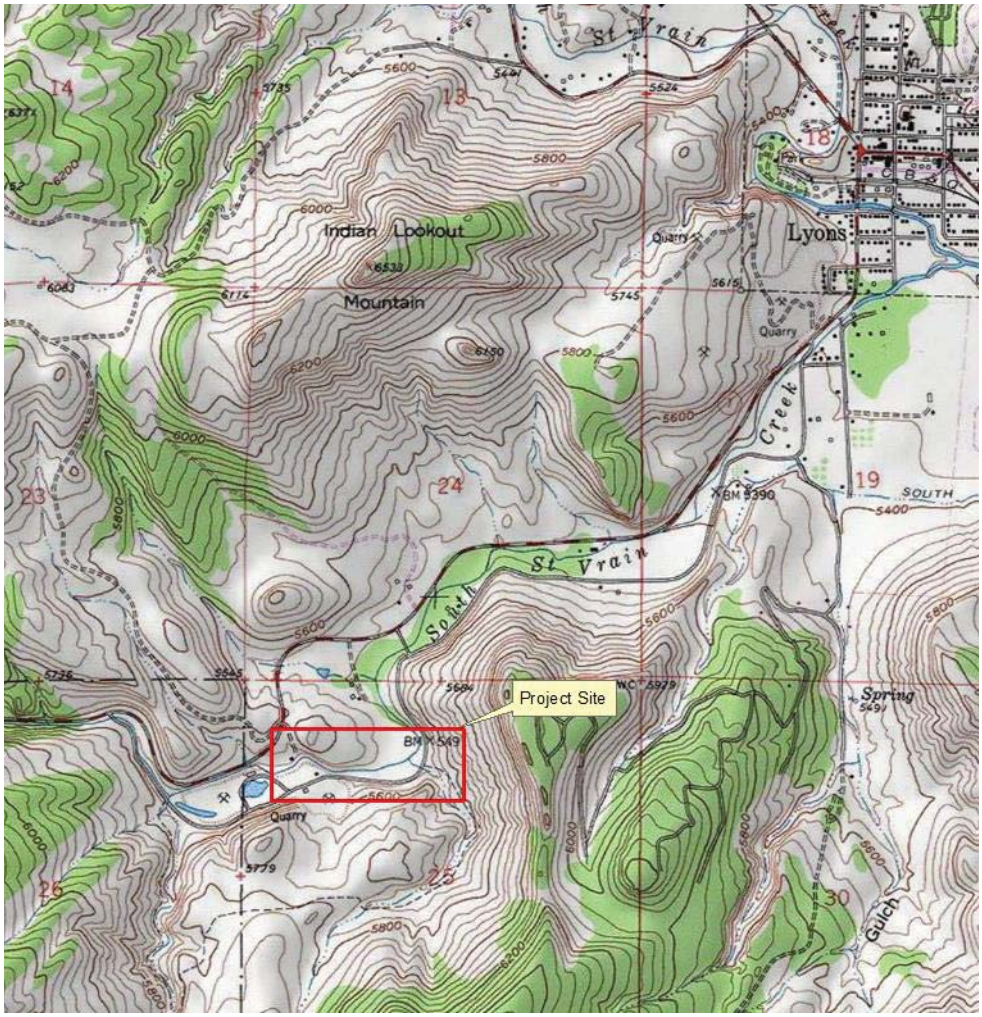

Figure 1 Project Site Location Map

Project Risks

- There is an inherent risk with any stream restoration project due to the complexities of natural river systems. The embankment protection is designed so that the 100 year event will not significantly erode the road and the stream channel is designed for the bankfull event.
- During construction the disturbed streambank is susceptible to excessive erosion. To mitigate this risk, the construction duration will be short to limit this exposure; and the specifications will require the contractor to stabilize the site at the end of each workday. Construction should take place during low flow periods if possible.
- The restored streambank is also susceptible to any large flow events after construction, especially before vegetation is established. Mitigation measures will use erosion control fabric on slopes of streambanks staked down with wood stakes and live stake plantings.

Project Objectives

Primary Objectives

The purpose of the project is to restore access into the Hall Ranch 2 property and to provide erosion mitigation measures to protect the road up to the 100-year event. Although the larger stream reach through the Hall Ranch 2 property would benefit from restoration the scope of this project only targets the road and the stream adjacent to the washed out portion of the road.

1. Restore the roadway to its pre-flood function and capacity consistent with current applicable construction codes and standards

2. Incorporate roadway drainage features that protect the roadway from erosion consistent with current applicable construction codes and standards

3. Realign creek sufficient to allow for reconstruction of roadway and integration of armoring and other protective measures to protect roadway from potential future flood events consistent with current applicable construction codes and standards

Design Basis

Road

The road section was designed according to Boulder County Multi-Modal Transportation Standards (BCMTS) for a Private Road. For this rehabilitation project, the determination was made by Boulder County Transportation to apply this construction standard given the very low traffic volumes. The surface of the roadway will be a gravel type surface to match the pre-flood surface type.

Considering the extremely low volumes of traffic expected for this segment, we recommend that the minimum structural section as identified in section 5.3.9.2 of the BCMTS for private roads be used.

Roadway Drainage

Although a normal crown throughout the alignment would be appropriate, we are utilizing a 2% cross slope toward the stream to eliminate the need for an improved roadside ditch on the east side of the road.

A low flow crossing is proposed in one location to accommodate ephemeral drainage flows above the road that connect to South Saint Vrain Creek. This ephemeral drainage area is located south of and above the road. It is a one square mile drainage area and requires the use of the Colorado Urban Hydrograph Procedure to determine storm runoff (Boulder County Storm Drainage Criteria Manual Section 304.4). Historically, the pathway for this drainage was to meet the road at STA 16+50 (Site 4 on the FEMA Project Worksheet) and flow along the road in a small ditch northward to a culvert then to outlet near the washed out portion of the road.

As part of this project, it is proposed to convey the ephemeral flow beneath/across the road at STA 16+32 and to establish a low profile channel between the road and the creek to carry low flows to the South Saint Vrain Creek. For conveyance at the roadway, a low flow crossing is proposed consisting of a concrete surface over two 38" x 24" culverts. Several alternatives were considered for this area including the following:

1. One large culvert, partially buried was considered beneath the concrete section of the low water crossing. This alternative was not brought to final design because of the slope coming into the culvert and the velocity of flow the culvert would experience from the 1 sq. mile drainage would cause this culvert to experience scour.
2. No culvert and only convey flows over the concrete section of the low water crossing. For this alternative the flows over the concrete section would be too high for small events.

The proposed design approach would accommodate ephemeral flows and protect the road from erosion in high flow events while also accomplishing natural resource management goals that are a high priority on county open space in addition to permitting considerations. These include:

- providing habitat connectivity in the riparian area for Preble's Meadow Jumping Mouse and other native species by providing a pathway under the road.
- preserving native vegetation along the roadside ditch that commonly support nesting birds.

While not included in the current FEMA Project Worksheet, it is anticipated that the elements of this structure would be eligible for inclusion under provisions for Construction Codes & Standards and/or for Hazard Mitigation Proposals. In addition to the environmental impacts, it also likely that this design would cost about the same or even less than clearing and upsizing the roadside ditch and associated culverts. If the culvert at Site 2 was upgraded to meet code the expected configuration and approximate size to pass the 10 year event for the 1 sq. mile drainage area would be 3-30" diameter culverts.

Stream

The South Saint Vrain Creek established a flowline within the road section during the flood and will need to be relocated when the road is re-constructed. While the road design does not have much flexibility in location, the creek could have many configurations. The goals of the creek alignment and river training structure configuration are listed below.

1. Provide hazard mitigation measures such that the road would be more resilient against future stresses.
2. Incorporate natural and vegetated solutions where feasible.
3. Present appropriate alternatives for funding requirements.

Stream Alternatives Considered

The designer considered the following alternatives:

A. **Alternative 1 Stable Channel with Natural Materials**. A stable channel will be designed utilizing an upstream stable cross section and energy grade along with a sediment grain analysis of the section. A new stream profile and alignment will be located adjacent to the roadway. The roadway embankment will be armored with boulder toe protection, and a combination of riprap and soil riprap planted with willow stakes.

B. **Alternative 2 Traditional Rock Riprap**. Rock riprap will be sized to stabilize the banks for the re-aligned stream channel utilizing a hydraulic model of the design to determine velocity and shear expected.

Alternative 1 Stable Channel (recommended)

A grain size distribution for a stable section upstream of the site indicates armoring has taken place. A D_{50} for the larger material was used to formulate a bank full, stable section for the reach being relocated assuming the new streambed would armor as the upstream section had. Boulder toe protection will be designed to withstand scour along the outside of the bend to the bank full depth, and riprap and soil riprap will be used to withstand tractive forces to a foot above the 100-year event depth through the section, see Appendix for design calculations. The soil riprap will be vegetated with native plantings (upland seed mix) in order to provide additional protection to the new embankment adjacent to the road.

A two stage channel cross-section with an expanded floodplain on the inside bend will be designed to allow flows to expand and take pressure off of the outside curve. Cobble material will be utilized on the inside of the bend and will be planted with native planting (willow stakes). The adjacent floodplain will be revegetated with mesic and upland seed mixes which were developed by Boulder County Parks and Open Space staff. Seed mixes are detailed in the Appendix.

Alternative 2 Traditional Rock Riprap

A traditional riprap design was also considered that utilized the stream cross section design for the first alternative. This allows for a bankfull section which will develop a meandering thalweg across the bottom, and will provide stability for the overall section. The toe of the outside bend would be thickened based on consideration of the additional tractive forces expected due to the radius of the bend. The inside of the bend would be stabilized with riprap due to the higher velocities expected.

References

Design references, programs, and criteria include the following:

1) *Stream Restoration Design*, National Engineering Handbook 654, USDA NRCS, 2007
2) Stream Restoration: A Natural Channel Design Handbook. NC Stream Restoration Institute, NC State University. 128 pp. Doll, B.A., G.L. Grabow, K.R. Hall, J. Halley, W.A. Harman, G.D. Jennings and D.E. Wise, 2003.
3) *Design of Riprap Revetment, Hydraulic Engineering Circular No. 11 (HEC-11)*, FHWA Publication Number: IP-89-016, 1989.
4) *Design of Roadside Channels with Flexible Linings, Hydraulic Engineering Circular No. 15,* FHWA Publication Number: FHWA-NHI-05-114, September 2005.

5) *Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance-Third Edition, Hydraulic Engineering Circular No. 23,* FHWA Publication Number: FHWA-NHI-09-112, September 2009.
6) *River Analysis System (HEC-RAS), Version 4.1.0,* Hydraulic Engineering Center (HEC), U.S. Army Corps of Engineers, January 2010.
7) Field Work by Amec Foster Wheeler, January 2016.
8) Flatirons Inc, Survey 2015 and 2016.
9) LiDAR collection 2014.
10) Design and construction experience from the Jamestown Colorado EWP work, which consisted of 83 rock grade control structures, boulder toe protection and in-situ cobble bank stabilization, completed in 2014.

Basic Site Data

Surveying and Site Visits

Topographic survey was collected during December 2015, and early January of 2016 by Flatirons Inc. This survey was used along with supplementary LiDAR collected in 2014 to form the basis of the topography and existing features at the site.

Geology

The site at the road damage is underlain by Permian-Pennsylvanian, sandstone, limestone. The road to the quarry is Tertiary-Cretaceous, granitiod and the quarry area is classified as Permian-Pennsylvanian, sandstone, conglomerate. A site **geology map** is included in the ***Appendix***.

Streambed and Bank Materials

The streambed and bank materials are composed of unconsolidated material deposited from the 2013 flooding event and modified by subsequent runoff events (Figure 2). The stream bed is armored with large cobble underlain by smaller gravels and sands.

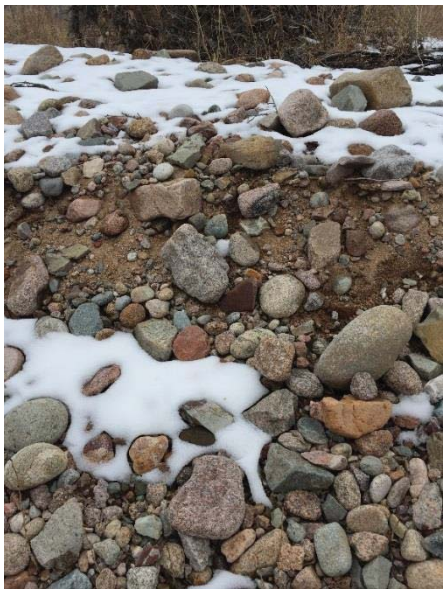

Figure 2 Unconsolidated material with limited vegetation on banks

The soils report is included in the ***Appendix*** with additional detail about the soils at the site.

Streambed Composition at Riffle

The following is a summary of the particle size categories pertinent to the hydraulic calculations for this project:

A pavement and sub-pavement sample was collected. The composite sample was analyzed and the results are below. This material is considered to be disturbed material and may not be representative of pre-flood conditions. However it is representative of the current channel bed and riffle sections.

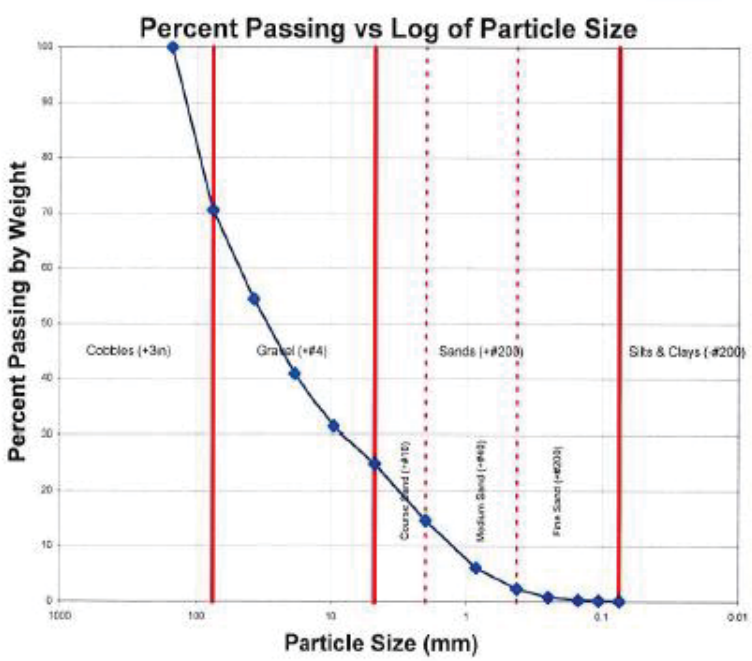

Figure 3 Channel Pavement and Sub-Pavement Material Distribution

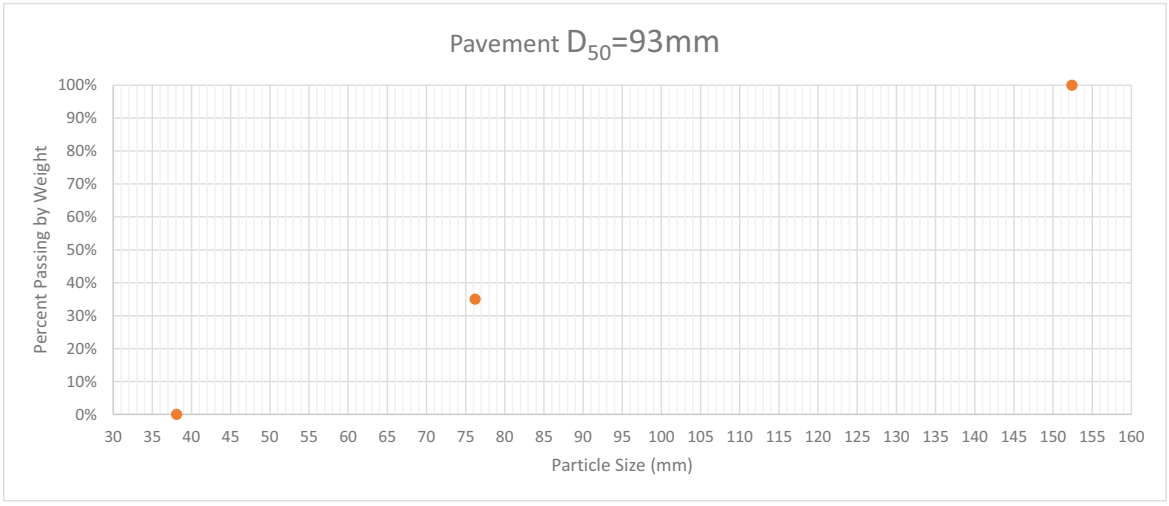

Figure 4 Channel Bed Pavement Material Distribution

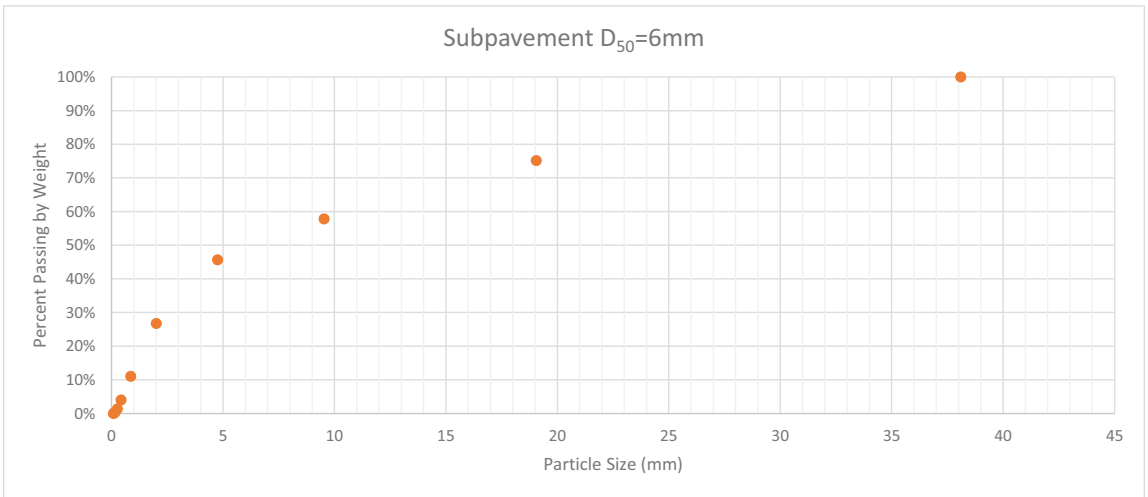

Figure 5 Channel Bed Sub-Pavement Material Distribution

Hydrology & Hydraulics

Hydrology

The project watershed is located Ponderosa Pine-Rocky Mountain juniper vegetation classification of the Southern Rocky Mountain province. The annual precipitation for the area is from 16 to 25 inches. The year long average temperature is between 45 to 48 degrees Fahrenheit. The terrain is mountainous with steep slopes consisting of gravely sandy loam soil compositions.

Flooding in 2013 precipitated the need to revisit the regulatory hydrology for the northern Front Range. The Colorado Department of Transportation (CDOT) in conjunction with the Colorado Conservation Board (CWCB) partnered to initiate a hydrologic analysis of several river systems impacted by the flooding (*Hydrologic Evaluation of the St. Vrain Watershed Post September 2013 Flood Event* included in the appendix). Peak flows were estimated at key locations in each watershed, rainfall runoff models were prepared and compared to updated flood frequency analyses and revised recurrence interval discharges were published. These newly published discharges for the Saint Vrain watershed were utilized as a basis for the hydrology for the design work.

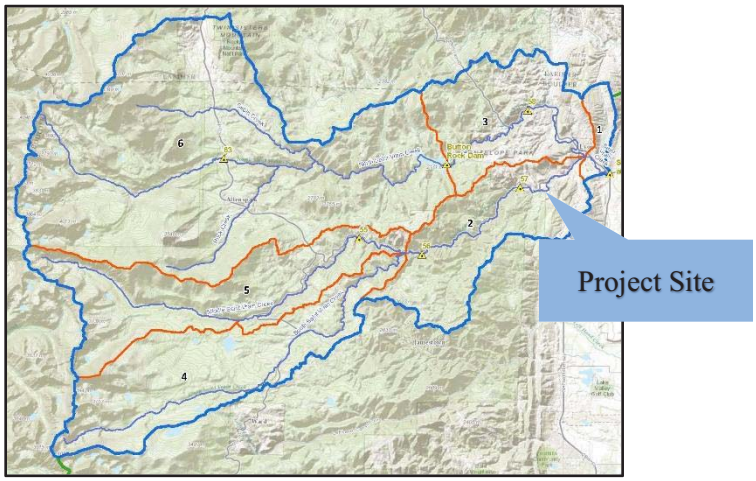

Figure 6 Saint Vrain Watershed Map (Blue) from CDOT 2014

The CDOT report published values for peak flow discharges for the 10, 25, 50, 100 and 500 year events at various locations along South Saint Vrain Creek. The project is located about midway between design points upstream of the confluence with Saint Vrain Creek and South Saint Vrain Creek and "The Narrows", upstream of the site. Peak flows were compared to these in relation to the watershed map provided in the report contained in the Appendix, and median values of peak flows between the two points were used to assess impacts for regulatory purposes:

Table 1 Peak Flows from CDOT Report as Compared to Calculated Values for the Project Site

Design Point	Description	Approximate Station (feet above confluence)	Drainage Area (square miles)	10-Yr (cfs)	25-Yr (cfs)	50-Yr (cfs)	100-Yr (cfs)	500-Yr (cfs)
J204B	South SVC at Little Narrows	19,616	83	1,464	2,980	4,496	6,598	13,435
Project Site	*Hall Ranch 2 Mitigation Area*	*12,531*	*87*	*1,535*	*3,029*	*4,715*	*6,916*	*14,092*
J234	South SVC above confluence with North SVC	2,692	91	1,605	3,168	4,933	7,234	14,748

In order to estimate bank full flows (between a 1.5 and 2.33 year event or Q_2), a variety of methods were utilized and the highest value was chosen for this conceptual design. The USGS published regional regression equations for Colorado for the estimation of natural streamflow in 2009. Utilizing the equations for the plains region, a Q_2 of 285 cfs was calculated. In CDOT's report Q_2 was not reported for this specific area therefore a simple extrapolation of the peak flow data gave a Q_2 of approximately 260 cfs. A flood frequency analysis of gage data was performed as a part of the CDOT report which gave a Q_2 of 958 cfs. The NRCS published a simple transfer equation relating the ratio of tributary areas and flood discharges Qu = Qg (Au/Ag)x , where the exponent, x varies from 0.5 to 1 depending on the differences in watershed lag times, areas, soils and vegetation. Since the two tributary areas are relatively similar in size and shape, an exponent of 1.0 was used to transpose the Q_2 for the combined streams to a Qu_2 of 385 cfs at the site where Qg_2 was 958 cfs and Au is 87 sq. mi. and Ag is 216 sq. mi. This value of 385 cfs was used as the bank full discharge for the design of stable section geometry.

Hydraulics

A stable stream has the capacity to move sediment load without aggrading or degrading. The area below the site experience significant avulsions (shift in channel location) abandoning the previous channel during the 2013 flooding, resulting in an unstable channel geometry. Evidence of resultant material deposition (mid channel bar formation) just downstream of the site is also indicative of an adverse channel bed slope change. In realigning the stream centerline, our goal was to provide a stable slope at which channel material can move through the stream system without causing undue aggradation or degradation of stream bed material. In order to analyze the stream's ability to move sediment through the design section it was necessary to calculate the critical dimensionless shear-stress. Utilizing this value, bank full geometry and mean depth could then be determined.

Figure 7 Mid-channel bar looking downstream from road cut

A channel substrate analysis was performed on samples collected upstream of the project area in a relatively stable reach. This "reference" reach was chosen due to relatively stable banks which were not significantly impacted by the 2013 floods. Armoring of the thalweg has since taken place, and riffle pool sequences are beginning to be re-established in this reach since the flood event. The stable water-surface slope was calculated to be between 0.80 ft/ft and 0.90 ft/ft and bank full mean depth was calculated to be between 1.8 feet and 2.0 feet. These values were used to guide the development of the hydraulic geometry through the new channel alignment. A multi-stage cross section was developed which will convey the bank full flow (Q_2) maintaining sediment discharge continuity as well as the 25-year discharge on a floodplain bench without causing undue stress on the channel bed or banks. Side slopes for the bank full channel were set at 2:1, recognizing that the bank and bed material will coarsen over time.

In order to assess the impacts of the design from a regulatory standpoint, an Existing Conditions hydraulic model was created for the project area utilizing a combination of post-flood LiDAR and supplemented with site specific survey data within the USACE's river analysis system, HEC-RAS v4.1.0.

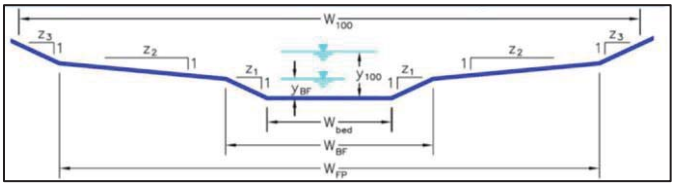

Figure 8 Example stable channel design template

The resulting Existing Conditions profile for the post-flood elevation data correlated well with the regulatory water-surface profile (Base Flood Elevations) published by FEMA for the South Saint Vrain Creek.

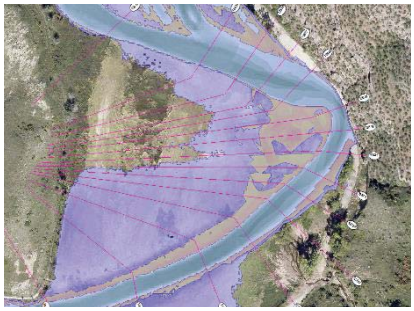

Figure 9 Existing Conditions Floodplain

A relocated channel alignment was laid out and a new ground profile was cut in order to meet the stable channel design criteria.

Both alternative hydraulic profiles were compared to the Existing Conditions profile in order to compare water-surface elevation increases, velocities and channel shear stress, and to assess bank full conditions. These parameters were then used to estimate bank stabilization measures for the recommended alternative.