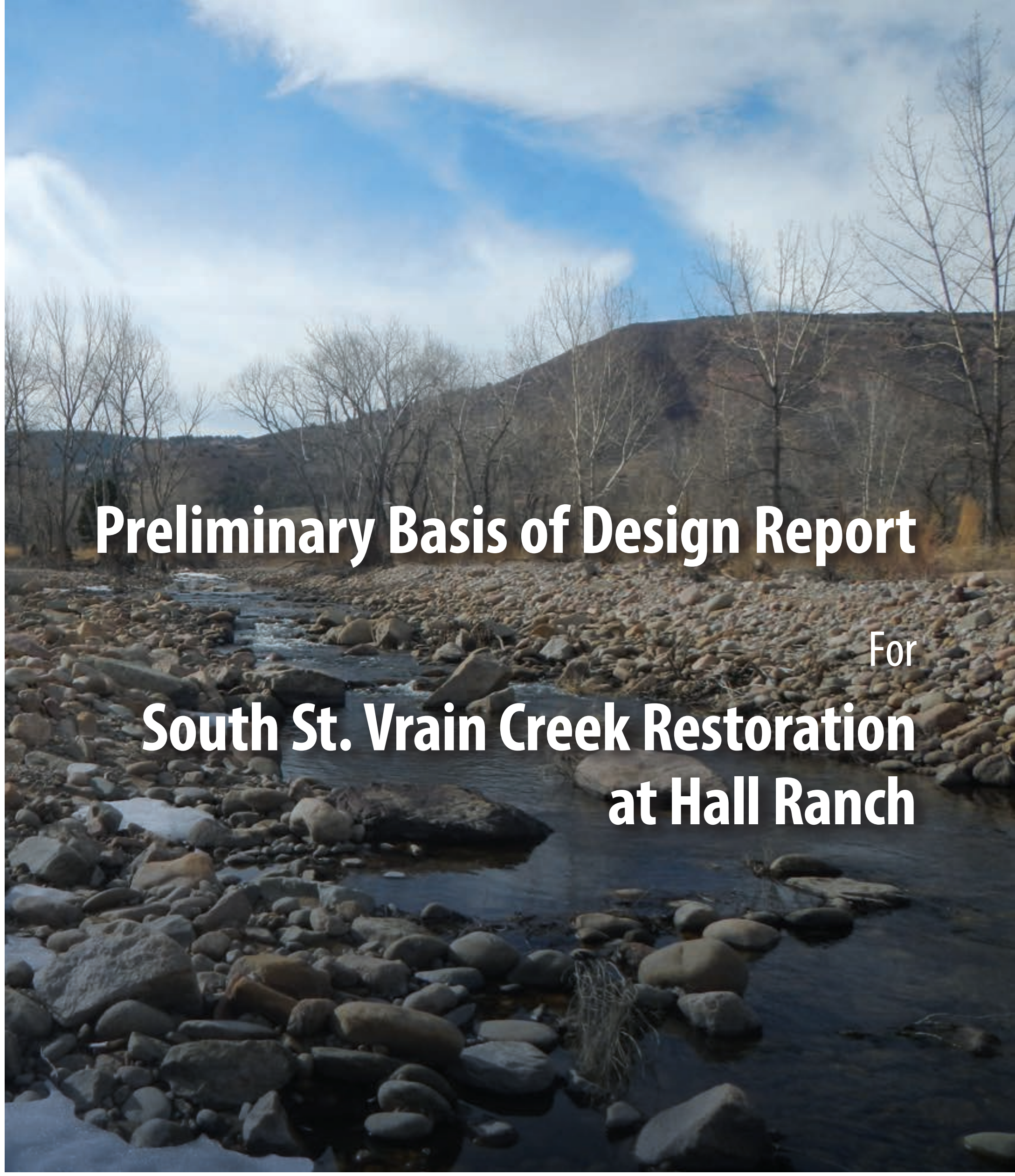


Preliminary Basis of Design Report

For

South St. Vrain Creek Restoration at Hall Ranch

September 2016

Submitted by:

Matrix Design Group

In association with:

THK Associates, Inc.

ERO

otak

Prepared for:

Boulder County, Colorado

Boulder County

Executive Summary

The South St. Vrain Creek's headwaters originate at the continental divide and flow east to the confluence with the North St. Vrain Creek. The South St. Vrain Creek experienced damage to the stream course, banks, riparian and upland areas, as well as ditches, bridges, roads and private homes from the 2013 flood. Multiple planning and design projects are concurrently taking place through this area to repair flood damage. Boulder County Parks and Open Space (BCPOS) retained this Design Team to develop a restoration plan for a 3.2 mile stretch of the South St. Vrain Creek.

Below is an excerpt developed by the St. Vrain Creek Channel Flood Recovery Design-Build Services (Otak, 2016) which can be also applied to the South St. Vrain Creek:

> *"St. Vrain Creek is an alluvial system that was highly altered during the historic 2013 flood event. Natural alluvial channels in lower gradient reaches generally meander through the valley, occasionally shifting lateral and/or vertical position on the landscape during large flood events. In the case of the recent flood, St. Vrain Creek experienced an episodic shift in the channel planform and cross-section geometry and substantial sediment aggradation and deposition occurred throughout the project area. As a result, the channel widened as the banks receded and new flow paths formed through the floodplain. If given enough time, the channel may eventually adjust to the severely altered condition. However, this process could take many years, and without intervention, the channel could continue to shift position. To minimize the threat to existing infrastructure, engineered improvements are required to stabilize the channel and restore ecologic function."*

This Flood-Planning and Preliminary Design Services for the South St. Vrain Creek Restoration at Hall Ranch (Project) was funded through a Community Development Block Grant Disaster Recovery (CDBG-DR) Resilience Planning Program grant by the State of Colorado Department of Local Affairs (DOLA) through Boulder County Parks and Open Space (BCPOS) for 30% design services for a 3.2 mile reach of the South St. Vrain Creek in Boulder County. The Project limits extend from upstream of the Andesite Quarry to the eastern Old St. Vrain Road bridge. The planning area contains lands managed by BCPOS along with private properties and the City of Longmont.

The Project is on a fast track and is following DOLA (current CDBG-DR planning grant) and Emergency Watershed Protection (EWP) - guidelines and requirements. The Project team is working quickly and diligently as to not jeopardize EWP funding. Both DOLA and EWP have been kept informed about the Project, and based on initial reviews, have concurred with the major elements of the plan and have commended the work completed to date.

Design Team and Partners

The Matrix Design Group Team (Design Team) consists of five different firms across a range of disciplines. All of the team members have worked together on flood recovery projects. Below are descriptions of each firm's role on this Project:

- **Matrix—**Project management, channel restoration design, hydrology and hydraulics
- **Otak**—Channel restoration design, fluvial geomorphology, and sediment transport
- **THK**—Native revegetation and public engagement
- **ERO**—Environmental resources and permitting
- **Blue Mountain Consultants**—Fishery biology

Project Goals and Purpose

The goals of this Project are to provide a conceptual design for a 3.2 mile reach of the South St. Vrain Creek that restores and improves the channel and surrounding floodplain areas to a safe, natural, resilient, functioning, and ecologically rich habitat. This Project will use qualitative research, quantitative data, and community input to inform a resilient design that shall utilize natural system principles and onsite materials to expedite recovery from the 2013 floods and set up for better performance in future flood events. Components to meet goals include incorporating natural channel diversity and character, re-establishing floodplain benches for lateral connectivity, reducing longitudinal connectivity constraints, improving flow conveyance and sediment transport to maintain environmental values, promote naturally functioning stream processes, protect public and private infrastructure, improve public safety, repair unstable erosion scars in high-risk areas, and revegetate denuded areas.

While the design of the 3.2 mile reach is funded under DOLA, EWP has allocated funding for physical construction along two reaches in this Project. The Design Team will be refining and updating the designs throughout EWP project areas to advance them from 30% to 80% designs. This will be partly funded through CDBG-DR funds along with funds from BCPOS. These design refinements will occur in the Fall of 2016 with the same Design Team. This will allow further development of hydraulic models and more detailed design.

Figure 1. South St. Vrain Creek

Public Engagement

This planning and preliminary design services for this 3.2 mile Project took place over a four month period. The Design Team held 6 public meetings (1 that was conducted prior to contract for the South St. Vrain Working Group) and 1 site visit to gather public input about the Project goals, background information and existing conditions, issues and concerns, Project alternatives and the preferred alternative. In June, the Design Team also met individually with each landowner in the 3.2 mile corridor to hear their interests, ideas, and concerns regarding their properties. Finally, there have been numerous other points of contact with the public, including meeting individuals in the field, phone calls, e-mails, and the Project web site and on-line comment forms. Based on these public contacts, as well as information provided by BCPOS on public comments received between September 2013 and May 2016, the Design Team developed an issue-based decision making process, which has been previously vetted on other projects, that led to the development of a preferred alternative, 30% stream restoration design and report.

Site and Geomorphic Assessment

Background information from various sources along with an in-depth watershed site assessment took place as part of this Project. Work was coordinated between existing and concurrent projects along with downstream restoration activities. Base mapping information was compiled from LiDAR and ground survey, along with existing and concurrent projects from multiple sources. Field sediment sampling took the form of in-situ bedload and suspended sediment sampling coupled with bed and bank sampling of the creek itself in the form of pebble counts. A riparian and wetland assessment was also completed to determine sensitive vegetation and habitats in the area along with areas needed to be revegetated to provide ecological and biological benefits to the corridor.

Hydrologic data was compiled from existing studies for the project area and was validated to verify accurateness of channel forming hydrology and ascertain flood hydrology for the project area. A 100-year design flow of 7,234 cubic feet per second (cfs) and a 1.5-year discharge of 470 cfs along with multiple recurrence intervals in-between were used to develop hydraulic models for the 3.2 mile reach.

Hydraulic models in both 1D and 2D were developed to evaluate floodplain impacts and determine complex hydraulic conditions. 1D hydraulic evaluations for floodplain permitting showed minimal rises in the floodplain at only a few locations. Design refinements will occur to ensure that no habitable structures or infrastructure are impacted by recommended designs. The EWP reaches will be further refined to show no rise in the base flood elevations from proposed activities.

A geomorphic assessment based on the River Styles stream classification methodology (Brierley and Fryirs, 2005) was used to determine dominant controls and spatial extent of behavior of the stream and floodplain to develop a reach-specific stream evolution model for the South St. Vrain Creek. The South St. Vrain Creek can be described as a confined valley with floodplain pockets in the canyon reach and a partly-confined, alluvial valley throughout the remainder of the project area. A stream evolution model (SEM) was also developed to understand morphological responses to disturbance within a stream system and can help determine channel trajectories. From the SEM it was determined that all reaches along the South St. Vrain are still adjusting and can expect to undergo further flood response.

Bed mobility and sediment transport modeling were also conducted in conjunction with the geomorphic assessment and classification. Results from this analysis helped to inform reach-scale geomorphic stability and trajectories, as well as site-specific restoration strategies. It was determined the South St Vrain Creek's bed can be readily mobilized due to the creek's steep slope and finer bed material. The sediment transport analysis determined that there are various potential aggradation and degradation reaches spread throughout this project area and that the channel is still adjusting since the flood. An effective discharge of about the 1-Year event was determined for the South St. Vrain Creek.

Figure 2. South St Vrain Creek

Aquatic and terrestrial species were also evaluated throughout the project area to understand the species and habitats that exist through the corridor along with how to provide additional benefit to these species throughout the restoration work. Fish passage through this reach is not a concern for larger salmonids but aspects throughout the corridor could cause a hindrance to the native long-nose dace and long-nose sucker. Channel function throughout this reach could also be increased by the use of a multi-stage channel with an inner-berm, a connected floodplain, instream cover and input of various carbon sources in the form of woody material and plantings. Evaluations of the federal, state and local threatened and endangered species; migratory birds and raptors; and other wildlife potentially found in the project area were conducted. It was determined that these species do exist in the project area and will be taken into consideration in both the design and construction phases.

Alternatives and 30% Design

The Design Team developed issues and alternatives that addressed the concerns along this stretch of the South St. Vrain Creek. Issues were developed from site assessments, hydraulic modeling and comments from stakeholders. Alternatives developed as part of this stream restoration project included floodplain connectivity, channel complexity, revegetation and infrastructure protection. These alternatives can be used in combination and various ways as necessary throughout the corridor. The alternatives were prioritized based on core values identified from the project goals statement to determine which alternative met the majority of the core values. The prioritization of these alternatives was then used to develop restoration techniques for South St. Vrain Creek. It was determined that floodplain connectivity would be the preferred alternative and priority restoration technique. Overflow channels were also developed as part of floodplain connectivity to activate existing or post flood channels for ecological and biological benefits along with the potential for sediment storage.

Once the project goals and the preferred alternative were established, stream restoration designs for the entire 3.2 mile reach were developed. The overall design employed a natural channel design process that developed designs based upon geomorphological factors and site constraints. Investigations with regard to stable channel planform, dimensions and profile took place to develop typical sections for various locations along the corridor. A range of bankfull depths and widths were established along different pool, riffle and meander sections with different slopes. Where public safety or infrastructure were not of concern, the river was given a certain degree of freedom to move, since it is a natural process for a creek to laterally migrate through a river valley. In areas where public safety and infrastructure were of concern, the creek was stabilized under normal flow conditions using bio-engineering techniques and then further protected with offset buried revetment. These plans also include additional design elements that could be evaluated more in depth through future studies.

From the analysis and the designs came a 30% plan set for the entire 3.2 mile reach. This plan set includes plan and profiles of the main channel along with overflow channels, typical and actual cross sections, channel planform dimensions, stream restoration details, and a revegetation plan including bio-engineering measures. Pool-riffle structure designs and elevations are also included. Additional design elements also included in this plan and report were aspects with regard to large woody material management, the Longmont Diversion structure, South Ledge and Meadows combined diversion, the Otto diversion, the Old St. Vrain Road, detention, and the Andesite Quarry.

Table of Contents

1. Matrix Design Group Team Overview

The Matrix Design Group Team (Design Team) consists of five different firms across a range of disciplines. All of the team members have worked together on flood recovery projects. Below are descriptions of each firm's role on this Project.

- **Matrix**—Project management, channel restoration design, hydrology and hydraulics
- **Otak**—channel restoration design, fluvial geomorphology, and sediment transport
- **THK**—native revegetation and public engagement
- **ERO**—environmental resources and permitting
- **Blue Mountain Consultants**—fishery biology

Below is an organization chart of the team along with descriptions of each team and their role on the Project and key members that provided analysis and design as part of this Project.

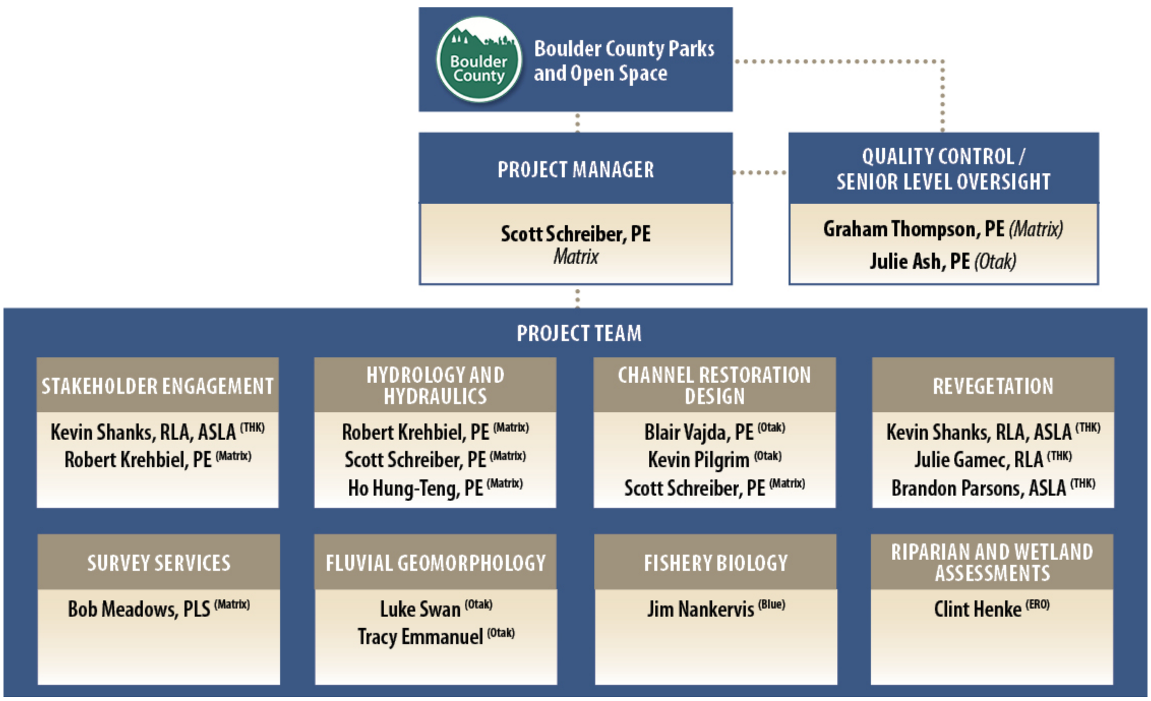


Figure 3. Organization Chart

2. Project Funding

Funding for this study was through a Community Development Block Grant Disaster Recovery (CDBG-DR) Resilience Planning Program grant through the State of Colorado Department of Local Affairs (DOLA). The grant was applied for by Boulder County Parks and Open Space (BCPOS). The amount of the grant request was for $300,000 to evaluate a 3.2 mile reach of the South St. Vrain Creek. In order to receive grant funding from DOLA certain design requirements must be met. Coordination with representatives with DOLA have taken place multiple times throughout this design, either at public meetings or design review calls.

While the project scope, funded by DOLA, included an engineering analysis and survey of the entire 3.2 miles of the South St. Vrain Creek, two sub reaches of the Project are eligible for Emergency Watershed Protection (EWP) funding for a natural channel stream restoration for needed parts of the reach from the Hall 2 property to downstream of the new fish passage diversion for the South Ledge and Meadows Ditches at approximately 2.2 miles on the South St. Vrain Creek (EWP #1) and directly upstream of the eastern bridge for the Old St. Vrain Road where it ties into Highway 7 (EWP #2). Both EWP reaches currently have funding allocated for actual construction. EWP #1 has $1,573,189 and EWP #2 has $161,630 for budgeted for actual construction. Design guidelines from EWP that were followed as part of this Project can be found on their website: coloradoewp.com.

3. Project Location

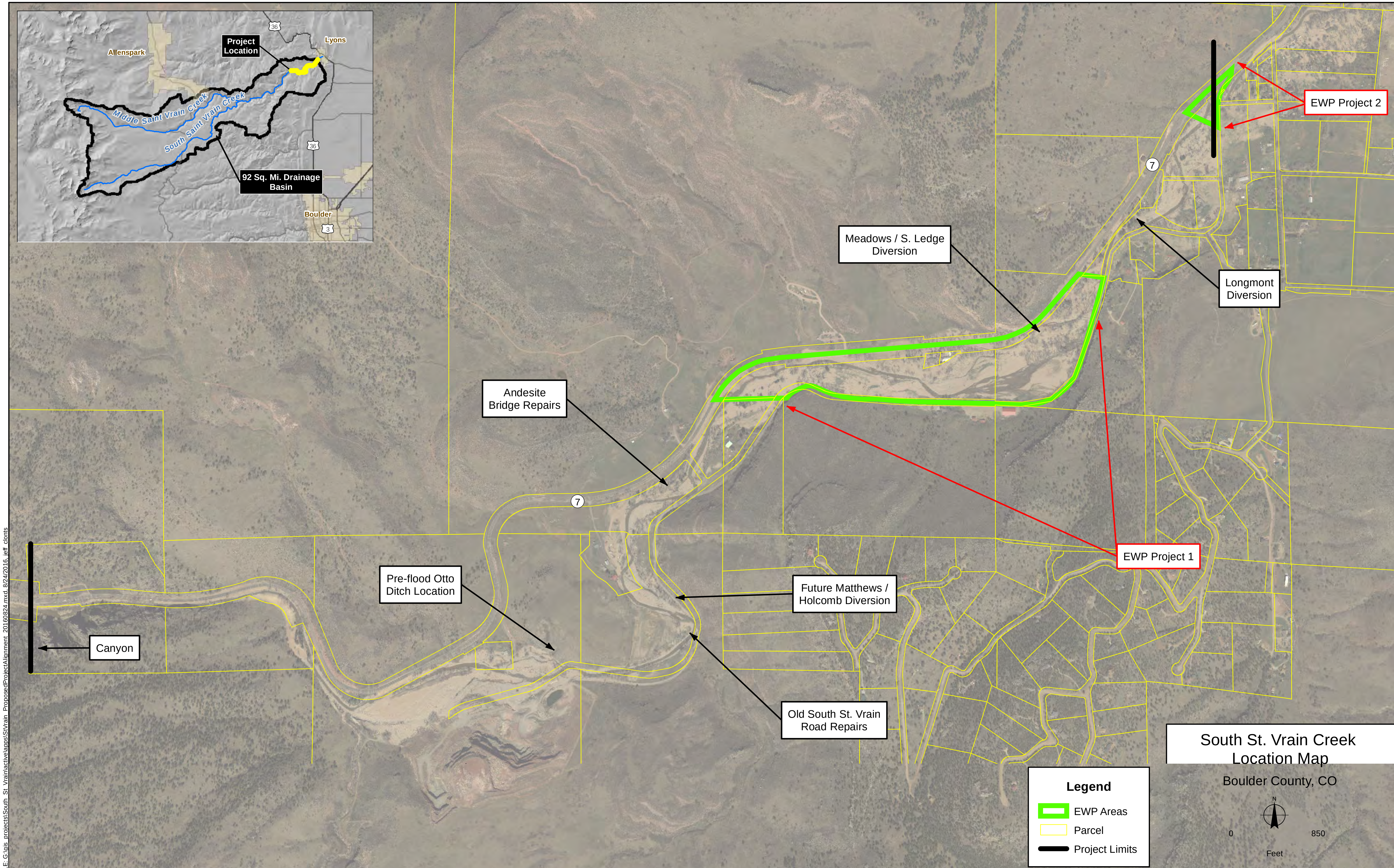
The project area is located just west of the town of Lyons along the South St. Vrain Creek from the County's Custode Open Space property, in the canyon at the US Forest Service Boundary, to the eastern-most Old St. Vrain Road bridge at the downstream end. Boulder County through its Parks and Open Space Department, owns and manages a nearly continuous 3.2 mile section of the creek through this reach including Custode, Hall Ranch 2, and Hall Ranch (also referred to as Hall Meadows) Open Spaces. Colorado State Highway 7 borders the planning area to the north, and Old St. Vrain Road (CR 84S) borders the planning area on the south. The planning area also contains a few private properties, as well as land owned by the City of Longmont. The Andesite Quarry (Colorado Division of Reclamation, Mining, and Safety permit number M-1977-141, also referred to as the Lyons Quarry) is located on the County's Hall Ranch 2 Open Space property. Reclamation for the mine site is the responsibility of the mine operator; however, the section of creek across Hall Ranch 2 Open Space is included in the planning area.

The South St. Vrain Creek at this location has a drainage area of approximate 92 square miles and is located about a half a mile upstream from the confluence with the North St. Vrain Creek. The South St. Vrain Creek headwaters originate at the continental divide in the area of Brainard Lake near Nederland, CO. From there it flows east towards the Peak to Peak Highway (Highway 72) and receives tributary inflow along the way at a few locations. The creek then reaches it confluences with the Middle St. Vrain Creek near Highway 7, and runs parallel to Highway 7 through US National Forest property within the canyon and into the project area. Beyond the project area the creek enters the Town of Lyons and the confluence with the North St. Vrain Creek.

Throughout the entire 3.2 mile reach there are existing projects, proposed projects, mining activities, and destroyed infrastructure in the form of bridges and diversions. Coordination with concurrent projects has taken place throughout this design process to ensure a holistic design is developed. The locations of these pertinent aspects have been included on the Vicinity Map on the following page.

Along with the entire 3.2 mile stretch there are two reaches of the creek that are eligible for funding from the EWP Program. One of these reaches is located in about the middle of the project area, in the Hall Meadows area, while the second reach is located at the very downstream end of the project area near the bridge on the Old St. Vrain Road. The EWP projects will be discussed more in depth later in this document.

Much of the project area is located over depositional landforms called alluvial valleys and alluvial fans. These are landforms located where channel gradient rapidly decreases, reducing stream energy and causing much of the transported sediment load to deposit. As the sediment load drops out, the stream will adjust form and/or shift position within the valley and/or fan. In more natural configurations, these landforms serve the function of absorbing stream energy by spreading flows and trapping sediment, and thus providing much benefit to downstream locations. Through the Project area, the South St. Vrain has been converted to a single thread channel to support various land uses. The result of this change in land use is that much of the energy that would be dissipated across a broad historic floodplain is then increased as it is transmitted downstream. The impact of this was seen in the September 2013 floods as the channel rapidly expanded, cut new paths via avulsions, and frequently shifted position through the valley. Restoring landform and floodplain function (e.g., energy dissipation, sediment moderation) are essential components of this project. This concept is developed further in Chapter 8 Geomorphology.



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a. 2013 Flood Impacts and Aftermath (Grant Application)

Disaster damage occurred along the entire 3.2 mile reach, including to the stream course, banks, riparian and upland areas, as well as ditches, a Longmont water supply line, bridges, roads and private homes. The very severe damage in this project area was due to the volume and velocity of water immediately exiting the canyon and entering the valley. The braided channels, avulsions, deposition and flooding patterns formed as a result of this energy and volume seeking its path through the loose alluvial fields, combined with the constrictions of existing canyon walls, roads, bridges, ditches and home infrastructure. As a result, numerous locations within the 3.2 mile project area are unstable, eroding and channelized, undefined and prone to shifting paths, have aggraded or degraded in elevation, and temporarily linearized and hardened. Severe impacts outside of the creek bed include washed away or damaged bridges, roads, ditches, and pipeline infrastructure, and damaged and continuously flooding homes, or homes and roads that continue to be under the threat of new flooding. Specific impacts include:

- In sections, the low flow channel location of South St. Vrain Creek is now on a perched, aggraded, braided, channel midway in the floodplain cross section.
- The post-flood low flow channel location of the stream is now adjacent to Highway 7. The high flow channel is along the toe of Old South St. Vrain Creek Road. Emergency work completed in spring 2014 moved the low flow channel north toward Highway 7 in another new flood created channel.
- The Longmont water main crossing was exposed by the floodwater along the split flow channel that now serves as the post-flood low flow channel. Longmont has been working to reinforce this water line and to further protect it by relocating the low flow channel back to its pre-flood location.
- The South Ledge Ditch headgate was located off-channel and served by pipe diversion from the pre-flood channel before the flood. The diversion and headgate were destroyed by the flood when the channel relocated.
- The Meadows Ditch headgate was a channel edge diversion from the pre-flood channel. While part of the headwall remains, the diversion itself is non-functional due to damage to the headgate, inlet sedimentation, and the stream gradient change at the headgate.
- A stream hard point was created following the 1969 flood. The hard point was created using overburden and waste rock from the immediately upstream Andesite Quarry to protect the downstream overbank pasture. Unfortunately, this hard point directs flow against the highway embankment and towards the homes further downstream. During the 2013 flood, this hard point caused water to flow against the left bank adjacent to the Colorado Highway 7 and washed away enough of the highway to cause its closure until it could be temporarily repaired. It was also a source of flooding concern to the residents on the left bank further downstream.
- The bridge providing access to the Andesite Quarry and the upstream access to the homes along Old South St. Vrain Creek Road was washed away during the 2013 flood. This is a County bridge that will be replaced.
- A portion of Old South St. Vrain Creek Road approximately 1300' upstream of the Andesite Quarry bridge and adjacent to a major rock outcrop has washed away, eliminating the major access to the former quarry for remediation purposes and for future use as access to a new County open space/recreation area. Boulder County is currently working with FEMA on repair of the road. However, the creek will continue to impact the road at this location.

- A stream avulsion occurred during the 2013 flood that resulted in a new post-flood low flow channel mostly located on non-County owned property. During the avulsion, the cutting of the new channel included eroding a portion of the edge of Colorado State Highway 7, to a post-flood location at the toe of the repaired highway embankment.

Various ongoing factors are currently posing a severe threat to the health, safety and welfare of the community. Mainly, this type of threat is to private homes, bridges, roads, ditches and pipeline infrastructure. These risks are in the form of potential new flooding that could cause damage to homes and other infrastructure, loss of business profit from lost irrigation, and direct threat to life and human health due to contact with new flood waters, contamination of drinking water supply, or the inability to escape new flooding. Most of these threats are exacerbated by the unknown volume of water that changes annually due to natural variations (i.e. snowmelt), or the threat of a new flood.

The conditions which are creating the greatest threats include:

- Dangerous proximity of post-flood creek alignment to infrastructure.
- Unstable and eroding condition of creek channels, compounded by braiding and split-flow paths.
- Elevation changes to creek bed and water surface.
- Linearized and hardened channels with increased velocity.
- Missing or damaged bridges and roads.
- Missing or damaged ditch diversions, headgates and water supply line.

b. Post-Flood Repairs

In the last two years, numerous projects led by various entities have been undertaken within the project area. Emergency debris removal, which was funded by FEMA, removed debris within the post-flood channel below the 5-year flow event. This occurred primarily near the Andesite Bridge, the Old St. Vrain Bridge, and along the southern high flow channel where it was constrained within existing vegetation. Some grading was completed post-flood on private property to protect homes along Highway 7. To minimize the risk to these homes and others, BCPOS removed some sediment within a post-flood channel, and constructed a rock vane to split high flows into two newly created post-flood channels. The northern channel is the main stem, while the southern channel alignment receives some water during high spring flows. Two years of high spring flows following the September 2013 flood have continued to shape the stream channels, but have not led to any new avulsions or severe erosion, however areas of instability remain.

During the spring of 2015, the City of Longmont rebuilt its water pipeline and diversion infrastructure, and restored the stream channel to its pre-flood alignment immediately downstream. Additionally, BCPOS, working with the St. Vrain Chapter of Trout Unlimited, Colorado Parks and Wildlife, the US Fish & Wildlife Service and the Colorado Water Conservation Board, rebuilt the South Ledge and Meadows ditches into a shared diversion structure that chases grade upstream so as to preclude the need for a diversion dam that would inhibit fish passage.

In addition to these repairs, a number of other projects are anticipated throughout the corridor over the next several years, many of which will be funded by FEMA, including:

- Reconstruction of the Otto, Carl Holcomb, and Mathews ditches
- Repairs to the Andesite Quarry access road on the County's Hall Ranch 2 property

- Replacement of the Andesite Bridge at the west end of Old St. Vrain Road by Boulder County Transportation

Some of these existing and proposed projects are discussed in more depth in the following sections.

4. Project Goals and Objectives

a. Existing Goal Statements

A Project goals statement was generated as one of the first tasks of this Project. The Project goals statement was developed from information gathered from the Request for Proposal (RFP), the Colorado Resilience Planning Grant Program Application, the St. Vrain Creek Master Plan, and Public Comments. The aspects the Project Goals Statement was developed upon are compiled below.

i. Requests for Proposals

The requested services are needed to provide a 30% design that provides mitigation measures to reduce the impact of future flooding, provide public safety, protect public and private infrastructure, maintain or re-establish floodplain connectivity, and restore the creek channel and surrounding areas to stable, resilient, and ecologically rich habitats.

ii. Grant Request

The goal of the Project is to create a stream channel that will be sustainable and benefit ecological values while minimizing future flood risks to surrounding homes and roads.

The resiliency objectives of the Project are to restore the stream channel in a way that both protects and increases the ability of critical infrastructure and environmental and cultural resources to withstand future disaster, while reducing future recovery time by mitigating risk and assisting in local community disaster preparedness. Sustainability objectives will focus on reconstructing the channel in a way that protects the existing homes and built environment, while also improving the local economic, social and natural environments.

iii. Master Plan

The purpose of this alternative is to implement a channel alignment that will optimize the interaction with completed, ongoing, and funded projects while being sensitive to the constraints presented by the presence of numerous private residences throughout this river corridor. The implementation of this alternative will expedite the maturation of this reach by re-establishing a natural channel, repairing erosion scars, re-establishing floodplain benches, building point-bars and excavating pools, re-vegetating denuded areas, and stabilizing channel banks.

iv. Public Comments

Public comments have been collected and compiled over the past 2.5 years following the September 2013 flood. Comments were received prior to the project and were compiled by the BCPOS project manager. All of the comments received prior to the initiation of this project have been reviewed and taken into consideration by the Design Team to aid in the development of the alternatives, selection of the preferred alternative and final design. All comments have been compiled into Appendix I - Public Comments.

b. Project Goals Statement

Once a Project goals Statement was developed and vetted internally by the Design Team BCPOS reviewed the letter and provided their final edits. Below is the final Project goals statement

Provide a conceptual design for the entire South Saint Vrain Creek project area that restores and improves the channel and surrounding floodplain areas to a safe, natural, resilient, functioning, and ecologically rich habitat. This Project will use qualitative research, quantitative data, and community input to inform resilient design that shall utilize natural system principles and onsite materials to expedite recovery from the 2013 floods and set up for better performance in future flood events. Components to meet goals include incorporating natural channel diversity and character, re-establishing floodplain benches for lateral connectivity, reducing longitudinal connectivity constraints, improving flow conveyance and sediment transport to maintain environmental values, promote naturally functioning stream processes, protect public and private infrastructure, improve public safety, repair unstable erosion scars in high-risk areas, and revegetate denuded areas.

c. Project Objectives

The objective of this Project was extracted directly from the Request for Proposals and is presented below:

The objective of this Project is to provide a 30% design that is based on the Consultant's evaluation of the baseline site conditions, hydrology, hydraulics, geomorphic processes, sediment transport, habitat requirements, and alternatives analyses. The 30% design will establish mitigation measures to reduce the impact of future flooding, protect public and private infrastructure, offer public safety, provide for channel stabilization, protect and restore aquatic, wetland, riparian, and upland habitats, and assign a detailed cost estimate for the preferred alternative. In addition, the Consultant will prioritize by sub-reach each mitigation and restoration activity based on need and desire.

The 30% designs are to supply a sufficient level of detail to evaluate major design features prior to advancing the Project to either a design-build phase or complete construction drawings. CDBG-DR dictates that 30% designs will provide clear direction so that detailed Project engineering and specifications can be developed in the future. The planning and design work should incorporate information for low flows, average high flows and flood flows to promote a resilient and naturally stable river.

d. Emergency Watershed Protection Program

While the design of the 3.2 mile reach is funded under DOLA, EWP has allocated funding for actual construction along two reaches in this Project. Since EWP will be funding actual construction their objectives and criteria must also be met. The Colorado EWP Program provides funding to implement emergency recovery measures to address hazards to life and property in watersheds impaired by the 2013 Colorado flood event. The program provides financial and technical assistance to local project sponsors to reduce erosion and threats from future flooding, protect streambanks, repair conservation practices, remove debris, and more. The Colorado EWP program is funded and administered by the USDA Natural Resources Conservation Service and managed by the Colorado Water Conservation Board on behalf of the State (EWP Website).

Colorado EWP Vision: To implement watershed recovery projects that reduce risk to life and property, enhance riparian ecosystems, and generate long-term stream system resilience through a collaborative, watershed-based approach that incorporates the needs of diverse stakeholders.

5. Summary of Relevant Background Information

Relevant background information was evaluated from multiple sources in various forms. Review of existing plans and studies along with interviews of stakeholders and County officials took place and are discussed here. Meeting minutes for these meetings can be found in Appendix A - Public Meeting Minutes

Excerpts and pertinent information from the documents have been compiled in this document. Some of the documents are supplied in the appendices also for further information.

a. Meeting with BCPOS

A kick-off meeting with BCPOS took place to provide introductions and discuss the purpose and goals of this Project. This meeting took place on May 11th at the BCPOS. This meeting was the basis of the initial project development. Multiple topics were discussed at this meeting including available resources, recently completed, ongoing and proposed projects throughout the corridor, available staff at BCPOS and provided background information. The majority of the information discussed at this meeting related to concurrent or ongoing projects along with the goals of BCPOS.

b. LiDAR Mapping (2011 and 2014)

Light Detection and Ranging (LiDAR) mapping from both 2011 and 2014 was provided by BCPOS to facilitate setting up a base map with pre-and post-flood contours. The LiDAR was acquired from the Colorado GeoData Cache. This information was used to compile an existing grade surface that could be supplemented with on the ground survey performed by Matrix. The 2011 LiDAR mapping available was only 2 foot contours, while the 2014 LiDAR could be used to generate 1 foot contours. Both data sets were used to determine the changes throughout the project reach and determine various aggradation and degradation zones.

- 2011 LiDAR: The project area was produced from LiDAR flown over portions of the County of Boulder, CO and surrounding areas. Data was produced in Colorado State Plane North (NAD 1983 HARN US Survey Feet), WKID 2876 NAVD 88. The LiDAR collection vendor (under separate contract – Colorado LiDAR Task Order AERO-PTS-003-attached) collected and delivered calibrated and initially processed LiDAR Data to Boulder County. The final accuracy assessment from the Vendor indicated a Final RMSEz of 0.243 ft. Based on the accuracy in the supplied LiDAR data the contours were compiled to meet 2-foot contour accuracy, however in areas of extreme slope as indicated by USGS TM11-B4 Vertical Accuracy “Slopes that exceed 10% should be avoided” as part of the overall accuracy LiDAR base testing. The contours were “smoothed” appropriately to maintain an acceptable level of accuracy and cartographic quality. As part of the pilot data review the County and McKim & Creed agreed to produce the 2 foot contours in the areas of extreme relief in order to provide more topographic detail and visualization than would normally be available for only Index contours to provide detailed contour data at 2-foot interval.
- 2014 LiDAR: Merrick acquired accurate, high-resolution LiDAR data for flood damaged areas in Colorado. Note that the shape files used in the processing represented a combination of a 1,500 ft. buffer on each side of the stream and the 500-year floodplain, whichever is larger. The LiDAR data was processed to produce a classified point cloud, bare earth elevation models and related products, necessary to support flood recovery efforts. The Project produced LiDAR data and elevation products for approximately 458 square miles over damage areas in several Colorado counties. The contours were downloaded from State of Colorado data repository and processed for the Boulder County environment. To provide detailed contour data at 1-foot interval for watersheds in Boulder County. Derived from LiDAR data captured in 2014 was to

support disaster response, recovery, long term recovery, and other future disaster loss reduction efforts.

c. Post Flood Hydrology

Post flood hydrology was developed from the “Hydrologic Evaluation of the St. Vrain Watershed” and “St. Vrain Creek Channel Flood Recovery Design-Build Services” reports. The first report was used to set the less frequent recurrence interval flows including the 100-Year hydrology that will be used for the floodplain development permit. The latter report was used to set the more frequent recurrence interval flows including the bankfull hydrology. Further in-depth discussion of the hydrology is presented further in this report.

d. St. Vrain Creek Watershed Master Plan

Following the flood, a number of agencies and groups along the St. Vrain Creek formed the St. Vrain Creek Coalition (SVCC). The forming of this group first facilitated developing the St. Vrain Creek Watershed Master Plan (Master Plan) (Michael Baker, et al 2014). The Master Plan “articulates the vision for the future of the watershed and guides future planning and development activity by highlighting recommended projects that align with diverse community priorities” and provides a “road-map for long-term recovery” along St. Vrain Creek. Boulder County adopted the Master Plan on February 26, 2015.

The Master Plan was first evaluated to determine existing recommendations already developed since the 2013 flood. The Master Plan had specific information relating to the South St. Vrain Creek corridor through the project area. The Master Plan had high level project recommendations that were evaluated more in-depth as part of this Project. Below is an excerpt from the Master Plan related to Reach 4B (the project area).

The purpose of this alternative is to implement a channel alignment that will optimize the interaction with completed, ongoing, and funded projects while being sensitive to the constraints presented by the presence of numerous private residences throughout this river corridor. The implementation of this alternative will expedite the maturation of this reach by re-establishing a natural channel, repairing erosion scars, re-establishing floodplain benches, building point-bars and excavating pools, re-vegetating denuded areas, and stabilizing channel banks.

The Master Plan also called out the following restoration strategies for this reach:

- Incorporate/stabilize a low flow channel section with lower width-to-depth ratio
- Increase in-stream habitat complexity by incorporating pools, boulders, rock clusters, and large woody vegetation (LWD)
- Revegetate riparian corridor with native species where needed

The information from this Master Plan was used as the starting point to determine various alternatives to be applied through the Project reach. Applicable sections from the Master Plan have been in included in Appendix B - Applicable Sections of St. Vrain Creek Master Plan.

e. Emergency Watershed Protection Program

The Colorado EWP Program is funded through the USDA Natural Resources Conservation Service and managed by the Colorado Water Conservation Board to implement emergency recovery measures to address hazards to life and property in watersheds impaired by the 2013 flood. The EWP program will be one of the funding sources to provide actual construction funding throughout two reaches of the Project. Members of the EWP were consulted as the Project progressed and were allowed opportunities to comment on the Draft and 30%

Design Plans. Furthermore, BCPOS met with the EWP technical team multiple times throughout this Project to help direct designs. The Colorado EWP team developed multiple guidance documents for all flood impaired creeks and reach specific reports. Below is a synopsis of a few of the important documents.

i. Damage Survey Report

A Damage Survey Report (DSR) (USDA NRCS, 2015) was developed as part of the EWP process. The DSR evaluates damage received from the event along with the eligibility of each site to received funding. The DSR was developed for multiple reaches along the South St. Vrain Creek corridor including two through the project area, but was not broken out in the DSR, although it was in the Scope of Work which is discussed later. The preferred alternatives developed from evaluation of the site by EWP personnel is stated below:

Preferred Alternative: Restore river to pre flood measures to withstand a 100-Year event contingent upon completion of CR investigation and in compliance with requirements of F&WS emergency consultation and all applicable categorical exclusions.

An environment evaluation was conducted and environmental concerns were developed in the DSR which compared the preferred alternative proposed action to the no action alternative. The economic benefits of the proposed action also evaluated the number of properties to protect, including private homes, bridges and business. The total near term damage reduction by implementing the preferred alternative was estimated at $4,500,000. Also provided in the DSR was an engineering cost estimate that determined it would cost $2,409,099 to implement recovery measures. An EWP funding priority was also completed that determined the Project site had serious, but not immediate threat to human life and would protect or conserve federally-listed threatened and endangered species or critical habitat and maintain or improve current water quality conditions. A copy of the DSR is located in Appendix C - EWP Damage Survey Report and Scope of Work

ii. Project Engineering Guidance

Project Engineering Guidance documents were also supplied by the EWP Program. These documents outlined design objectives, standards and approaches that should be used as part of flood recovery work. It also included supplemental information on sediment and debris removal, permitting aspects and other environmental concerns. Information regarding permitting and design documents that must be submitted as part of the NRCS funding was included.

iii. Preliminary Scope of Work

Along with the DSR and the Project Engineering Guidance, a Preliminary Scope of work was evaluated. The preliminary scope of work included three different project areas. The two most upstream project areas are included as part of this Project.

Proposed Work: All project areas have one or more of the following treatments: Sediment removal to establish a floodplain, bioengineering to stabilize stream banks, armored resiliency to stabilize stream banks, critical area treatment (CAT) including willow planting, seeding, mulching and topsoil placement.

The Scope of Work was broken into three different sites for the South St. Vrain Reach 4b. The project area encompasses two of these sites. Project Site 1 is the most upstream of the three projects in an area referred to as the Hall Meadow. This site has a construction budget of $1,573,189. The proposed recovery measures at this site location are armored resiliency, streambank shaping, sediment removal, seeding and mulching, and topsoil. The second site is Project Site 2 which is located just upstream of the bridge near the intersection of Highway 7 and the Old St. Vrain Road, which has a construction budget of $161,630. The proposed recovery measures along this site include streambank shaping, sediment removal, seeding and mulching and topsoil. A copy of the Scope of Work is included in Appendix C - EWP Damage Survey Report and Scope of Work.

f. St. Vrain Creek Channel Flood Recovery Design-Build Services

Data and recommendations from the report titled "St. Vrain Creek Channel Flood Recovery Design-Build Services" (Otak, 2016) provided initial guidance on stream geomorphic trajectory. The purpose of the St. Vrain Creek Channel Flood Recovery Design-Build Project was to repair flood damage and increase resiliency in the system for reduced damage during future flood events. The project included three phases:

- Design-Build Construction along North St. Vrain Creek and mainstem St. Vrain Creek in the vicinity of the Town;
- Preliminary evaluation of numerous design alternatives, including those not constructible under this grant award due to previous and conflicting funding awards; and
- Expanded Area Study on North, South, and mainstem of St. Vrain Creek to characterize geomorphic- and sediment-specific longitudinal trajectories.

Key conclusions and recommendations resulting from the modeling and analysis performed as part of the Expanded Area Study provided resource managers and Design Teams with reach-scale hydraulic, geomorphic and restoration guidance to help inform the planning of future projects. The discussion of the results of the study provides interpretations for three geographic subsets of the project area – Apple Valley, Hall Meadows, and the Town. The discussion provides linkages between analysis results and recommended flood mitigation and restoration actions.

The primary tools used to develop these recommendations are the River Styles characterizations, Stream Evolution Model (SEM) (Cluer and Thorne, 2013), and the sediment balance and stream power calculations. From the analysis of the results, three project-wide recommendations became apparent:

- The need for long-term monitoring. Results of the geomorphic analysis show that the reaches covered in the expanded modeling footprint are in various stages of geomorphic response to the flood. Perhaps most dramatically, the South St. Vrain Creek can be expected to undergo substantial adjustment as the stream seeks equilibrium geometries, responding to fluctuating sediment loads. Monitoring the response will provide much needed information that can be used to more thoroughly plan for future flood events.
- Floodplain benches are critical for stream recovery and flood mitigation. Many of the reaches in the study area are incised requiring substantial flows before floodplains are accessed. Under this incised configuration, stream power is concentrated in the channel, enhancing the geomorphic impact of more frequently occurring flows.

- Buyout properties provide opportunities to reconnect the floodplain where the stream was previously disconnected and options for re-purposing them as effective floodplain should be evaluated from hydraulic, geomorphic, and ecologic contexts.

Specific to South St. Vrain, reaches in the project area were found to have highly degradational tendencies, but results depend on the flow used in the calculation, indicating widespread imbalances. Sediment has aggraded in the alluvial valley, suggesting the creek will work to export sediment from the valley. Channel base elevations will likely drop, as the channel abandons its former floodplain. This inset channel is likely to then cycle through sequences of incision and widening as the channel seeks an equilibrium slope, creating instability in the system. Therefore, restoration through the project area should focus on re-connecting the channel and floodplain and a coordinated establishment of equilibrium channel dimensions (slope and cross section) throughout the valley. Re-connecting the floodplain will restore a number of functions, perhaps most importantly flood energy reduction and sediment storage.

g. St. Vrain Pipeline 2013 Flood Repair

The 2013 flood caused damage to the existing City of Longmont Diversion pipeline. The cross channel diversion intercepts flow in the South St. Vrain Creek near the downstream extents of the Project. During the flood, the existing diversion abutment was scoured away along the south bank of the creek. This erosion caused the piping at the abutment to fail. The overall diversion itself remained intact during the flood and required minimal repairs along the southern abutment, beyond replacement of a 27” concrete encased pipe. Grading repairs downstream of the diversion along the southern bank also occurred to re-establish the bank slopes. A sloping grouted drop structure was designed to be installed as part of this Project, but had to be removed due to permitting issues. A manhole and flow control structure were also installed as part of this Project in the adjacent floodplain to the diversion. The piping then makes it way north east where it crosses the South St. Vrain Creek at a bridge along the Old St. Vrain Road. The pipe crossing the creek is encased in concrete.

h. Meadow and South Ledge Diversion Reconstruction and Fish Passage Demonstration

During the 2013 flood, the Meadows and the South Ledge diversion headgates were destroyed. Since the flood, the diversions have been combined and moved upstream. The points of diversion were moved upstream so that a cross channel diversion was not necessary. The newly designed diversion includes an at grade diversion with a trash rack and sediment sluice constructed in a concrete inlet structure. Minimal instream work took place near the proposed location. Furthermore, rootwads, boulders and vegetation along both banks of the creek were installed to provide additional bank stabilization. The diversion then conveyed water towards the Old St. Vrain Road to a splitter box where the flows for the Meadow and South Ledge were spilt and diverted to their appropriate ditches. The diversion pipeline had design issues, resulting in silt being trapped during the first season of operation.

i. County’s Management Plans

A number of County-adopted management plans were evaluated as part of this design. These management plans direct current and future use of the County’s open space lands within the project area. These management plans generally direct the BCPOS to manage the properties for their natural resources values, including riparian areas and species of concerns. Currently, the project area is closed to the public and there is no access allowed. Access to the creek itself is also not allowed by boaters and other recreationalists.

Below is a list of documents supplied by BCPOS for review as part of this design process.

- Boulder County Comprehensive Plan – Environmental Resources Element (2014)
- St. Vrain Creek Corridor Open Space Management Plan (2004
- St. Vrain Trail Master Plan (2004)
- North Foothills Management Plan - Hall Ranch and Heil Valley Ranch (1998)
- Hall Ranch Meadows Natural Resource Assessment (2005)
- Environmental Assessment – South St. Vrain Creek (2000)
- Resource Assessment Report – Custode Property (2000)

j. Public Engagement

The goals of the public engagement for this project were to work with the community and stakeholders to understand the site conditions for the project area, address the specific concerns of each property owner, collaboratively develop design alternatives through the consideration of public comments as well as foster a public consensus.

Between September 2013 and May 2016, prior to the initiation of this project, public comments were received and compiled by Boulder County Parks and Open Space (BCPOS). Additional comments were also received and compiled by the Design Team via public meetings, personal homeowner site visits, St. Vrain Creek Working 4B Group Meetings and online submissions. The comments have been compiled into Appendix I - Public Comments.

In total the Design Team participated in the following Public Engagement:

- Six public meetings (one that was conducted prior to contract for the South St. Vrain Working Group)
- One site visit to gather public input about the project goals; background information and existing conditions; issues and concerns; project alternatives and the preferred alternative.
- Individual meetings with private property owners in June 2016 to hear the interests, ideas and concerns regarding individual properties.
- Attended a Saint Vrain Creek Coalition meeting supported working group meeting (May 11, 2016)
- Presented to the Saint Vrain Creek Coalition (May 25, 2016 and June 29, 2016)
- Presented to the Boulder County Parks and Open Space Advisory Committee (September 22, 2016)
- Facilitated two presentations to the public (May 24, 2016 and June 30, 2016). Detailed meeting minutes for the two presentations to the public can be found in Appendix A - Public Meeting Minutes

Almost two hundred comments were collected during this process.

6. Watershed Site Assessment Information

a. Review of Existing Documentation

The aforementioned relevant background information was reviewed and pertinent information was compiled and developed as part of this planning process.

b. Survey

Topographic information for the purposes of the Project was developed from multiple sources. The base information was supplied using Light Detection and Ranging (LiDAR) data collected in October 2014 by the Colorado Water Conservation Board. Ground survey as part of this Project was conducted by Matrix, but was supplemented with ground survey from CivilArts and AECOM.

Matrix's in house survey team was responsible for acquiring new ground survey for the Project. Existing conditions for this Project were gathered using a combination of existing LiDAR data supplemented with conventional GPS surveying. The GPS survey data is based on the Boulder County control network. Bearings for the survey data are grid bearings of the Colorado state plane north zone as measured between control point T3NR70WS19N and control point LL1431_LYONS, as described by Boulder County records, having a bearing of North 17°18'14" East. The elevations are based on Boulder County control point LL1431_Lyons having a published NAVD88 elevation of 5485.20 feet.

The Project GPS data was collected during the third week of May, 2016 and consists of a sampling of the 3.2 mile project area as directed by project engineers. The data acquired consists of profile data for the existing river, 115 cross sections spread throughout the project area, water surface elevations and various critical locations as specified by the project engineers.

Ground survey topography was also developed from two outside sources. The first source was from CivilArts, who was contracted through the St. Vrain Creek Channel Flood Recovery Design-Build Services for Lyons. Ground survey included bathymetric cross sections collected in March and November 2015 and March and April 2016. The second outside source of ground survey was acquired in 2015 and developed by AECOM as part of the CHAMP and RiskMap study being performed by CWCB.

For the project area a surface was generated from the ground survey information acquired from all three sources. Ground survey information was developed into breaklines that were used to interpolate the bathymetric information between the cross sections. This information was then pasted into the LiDAR surface that was developed to develop a complete topographic model. The ground survey information was used for data within the channel banks and overflow channels while the LiDAR supplemented that survey outside of the banks.

LiDAR survey was also developed from 2011 as pre-flood data to evaluate overall changes in the ground surface from pre-flood to post-flood.

c. Riparian Assessment and Wetland Delineation

This section of the South St. Vrain was heavily impacted by the 2013 floods. The floods overtopped the creek banks creating new channels, scouring the land and removing large swaths of existing vegetation throughout. The channel incised in places cutting off the water supply for existing wetland and riparian plant species. Additional aggradation deposited large loads of sediments resulting in large sandy areas that are void of vegetation.

Despite all of the devastation, some healthy ecosystems survived this flood and have rebounded successfully. Other areas remain scared by the floods and are in need of restoration in order for the system to reach equilibrium. The Riparian Assessment and Wetland Delineation discovered historic locations of healthy plant communities. The report outlined the species that previously existed in these areas and delineated areas where successful secondary succession occurred.

The Riparian Assessment and Wetland Delineation used onsite and aerial observations, as well as state and national resources to determine riparian health, ecologic diversity, wetland locations, invasive species concerns and the ecosystem character of the Project reach.

Objectives:

- Determine how the 2013 floods modified the environment and affected ecosystem health
- Document existing wetland, riparian and upland plant communities
- Document denuded areas that are void of vegetation due to the 2013 flooding
- Document and assess pockets of unique vegetation and micro-climates related to secondary channels and groundwater seeps
- Document extent and location of revegetation opportunities
- Identify individual plant species to determine ecosystem character and biodiversity
- Develop a comprehensive plant list for the project reach
- Document native, non-native and invasive or noxious plant species
- Assess any measures that the County has taken to deter or eliminate invasive or noxious plants
- Assess onsite soil conditions
- Develop revegetation strategies for specific onsite conditions
- Identify erosion issues and areas with bank instability
- Document public and stakeholder concerns
- Assess terrestrial species presence
- Assess habitat within riparian and wetland areas
- Develop opportunities for native revegetation within denuded areas

i. Existing Restoration Data

National and state resources that have inventoried pre 2013 flood wetland and riparian ecosystems were used to gather background information and guide the revegetation process. These resources include former studies and data providing information on the historical presence of onsite wetland areas. This information was used to identify the location of wetlands and determine historical plant and habitat species.

ii. National Resources

The National Wetland Inventory Wetlands Mapper (*FWS, 2009*) indicates five different classifications of wetlands present within the project extents along the South St. Vrain. These wetland types are historically found in specific locations along the channel. Below is an excerpt from The National Wetland Inventory Wetlands Mapper website outlining the five wetland types found within the project reach.

1. *Wetland Type: Freshwater Pond*

   PUSC – Palustrine Unconsolidated Shore Seasonally Flooded

   P – Palustrine (System): Includes all non-tidal wetlands dominated by trees, shrubs, persistent emergent, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 ppt. It also includes wetlands lacking such vegetation, but with all of the following four characteristics: (1) areas less than 8 ha (2o acres); (2) active wave-formed or bedrock shoreline features lacking; (3) water depth in the deepest part of basin less than 2.5 m (8.2 ft.) at low water, and (4) salinity due to ocean-derived salts less than 0.5 ppt.

   US - Unconsolidated Shore (Class): Includes all wetland habitats having two characteristics: (1) unconsolidated substrates with less than 75 percent areal cover of stones, boulders or bedrock and; (2) less than 30 percent areal cover of vegetation. Landforms such as beaches, bars, and flats are included in the Unconsolidated Shore class.

   C - Seasonally Flooded (Water Regime): Surface water is present for extended periods especially early in the growing season, but is absent by the end of the growing season in most years. The water table after flooding ceases is variable, extending from saturated to the surface to a water table well below the ground surface. (FWS, 2009)

2. *Wetland Type: Riverine*

   R5UBH – Riverine Unknown Perennial Unconsolidated Bottom Permanently Flooded

   R – Riverine (System): Includes all wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts of 0.5 ppt or greater. A channel is an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water.

   5 – Unknown Perennial (SubSystem): This Subsystem designation was created specifically for use when the distinction between lower perennial, upper perennial, and tidal cannot be made from aerial photography and no data is available.

   UB-Unconsolidated Bottom (Class): Includes all wetlands and deepwater habitats with at least 25% cover of particles smaller than stones (less than 6-7 cm), and a vegetative cover less than 30%.

   H – Permanently Flooded (Water Regime): Water covers the substrate throughout the year in all years. (FWS, 2009)

3. *Wetland Type: Freshwater Forested / Shrub Wetland*

   PFOA – Palustrine Forested Temporary Flooded

P – Palustrine (System): Includes all non-tidal wetlands dominated by trees, shrubs, persistent emergent, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 ppt. It also includes wetlands lacking such vegetation, but with all of the following four characteristics: (1) areas less than 8 ha (2o acres); (2) active wave-formed or bedrock shoreline features lacking; (3) water depth in the deepest part of basin less than 2.5 m (8.2 ft) at low water, and (4) salinity due to ocean-derived salts less than 0.5 ppt.

FO-Forested (Class): Characterized by woody vegetation that is 6 m tall or taller.

A-Temporary Flooded (Water Regime): Surface water is present for brief periods (from a few days to a few weeks) during the growing season, but the water table usually lies well below the ground surface for the most of the season. (FWS, 2009)

4. *Wetland Type: Freshwater Forested / Shrub Wetland*

R3USA – Riverine Upper Perennial Unconsolidated Shore Temporary Flooded

R – Riverine (System): Includes all wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts of 0.5 ppt or greater. A channel is an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water.

3 – Upper Perennial (Subsystem): This Subsystem is characterized by a high gradient. There is no tidal influence, and some water flows all year, except during years of extreme drought. The substrate consists of rock, cobbles, or gravel with occasional patches of sand. The natural dissolved oxygen concentration is normally near saturation. The fauna is characteristic of running water, and there are few or no planktonic forms. The gradient is high compared with that of the Lower Perennial Subsystem, and there is very little floodplain development.

US – Unconsolidated Shore (Class): Includes all wetland habitats having two characteristics: (1) unconsolidated substrates with less than 75 percent areal cover of stones, boulders or bedrock and; (2) less than 30 percent areal cover of vegetation. Landforms such as beaches, bars, and flats are included in the Unconsolidated Shore class.

A-Temporary Flooded (Water Regime): Surface water is present for brief periods (from a few days to a few weeks) during the growing season, but the water table usually lies well below the ground surface for the most of the season. (FWS, 2009)

5. *Wetland Type: Freshwater Forested / Shrub Wetland*

PSSC – Palustrine Scrub-Shrub Seasonally Flooded

P – Palustrine (System): Includes all nontidal wetlands dominated by trees, shrubs, persistent emergent, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 ppt. It also includes wetlands lacking such vegetation, but with all of the following four characteristics: (1) areas less than 8 ha (2o acres); (2) active wave-formed or bedrock shoreline features lacking; (3) water depth in the deepest part of basin less than

2.5 m (8.2 ft) at low water, and (4) salinity due to ocean-derived salts less than 0.5 ppt.

SS – Scrub-Shrub (Class): Includes areas dominated by woody vegetation less than 6 m (20 feet) tall. The species include tree shrubs, young trees (saplings), and trees or shrubs that are small or stunted because of environmental conditions.

C - Seasonally Flooded (Water Regime): Surface water is present for extended periods especially early in the growing season, but is absent by the end of the growing season in most years. The water table after flooding ceases is variable, extending from saturated to the surface to a water table well below the ground surface. (FWS, 2009)

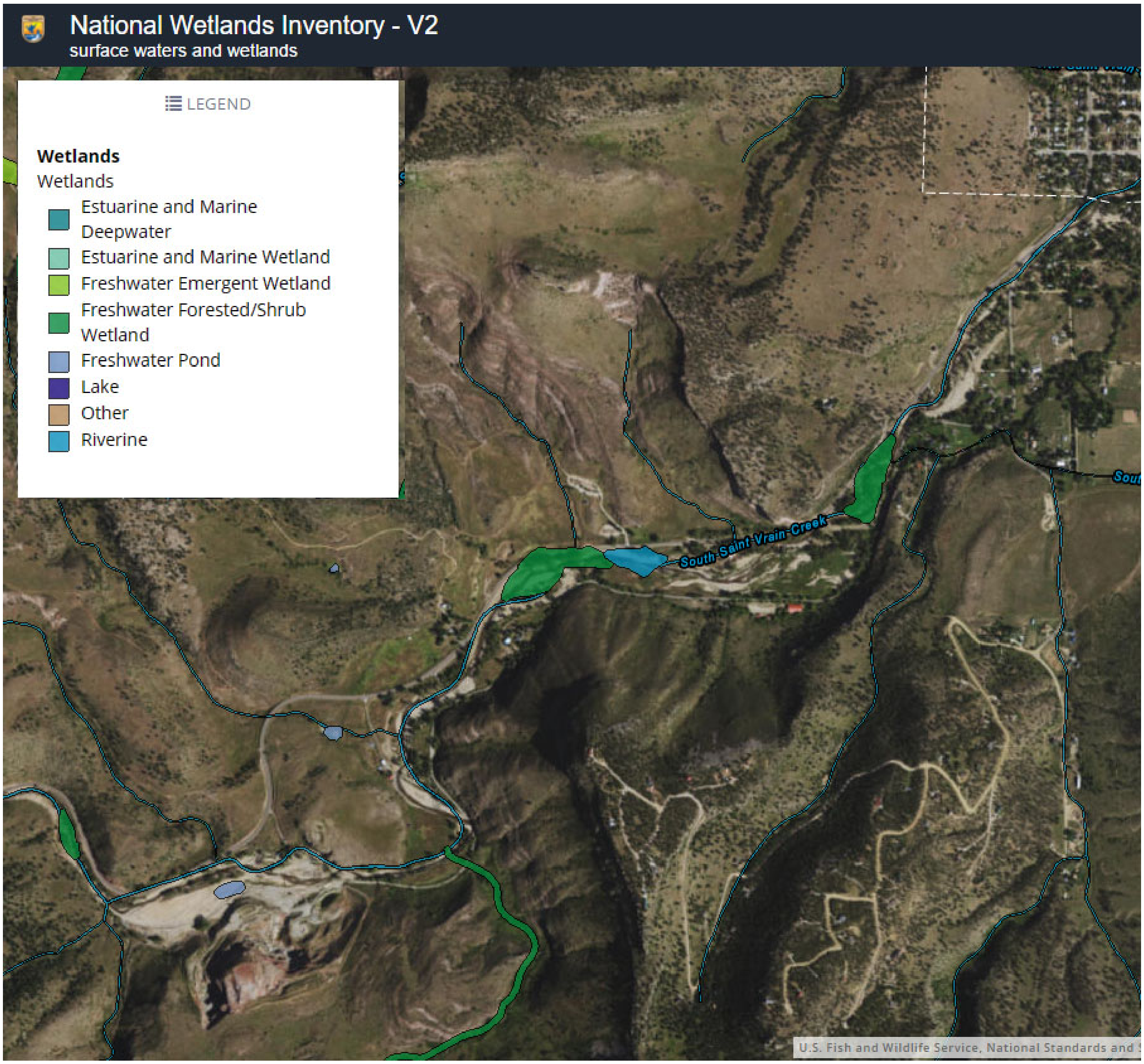


Figure 4. National Wetlands Inventory Map of existing Wetlands found on site, 2009

iii. State Resources

The Colorado National Heritage Program (CNHP) and the Colorado Wetland Inventory (NWI) Mapping tool (*CHNP, 2009*) was used to determine the location and composition of onsite wetlands. This data identifies five major riparian plant communities within the site including:

- Forested Deciduous – Cottonwood
- Herbaceous – Sedges / Rushes / Mesic Grasses (Moist Soils)
- Herbaceous - General
- Shrub – General
- Upland – Grasses

Additional information provided by CNHP shows riparian plant communities which occur alongside existing wetlands as seen in Figure *5*, and provides locations of plant community sub categories which include:

- Rp1FO – Riparian Lotic Forested
- Rp1EM – Riparian Lotic Emergent
- PEMA - Palustrine, Emergent / Herbaceous, Temporarily Flooded

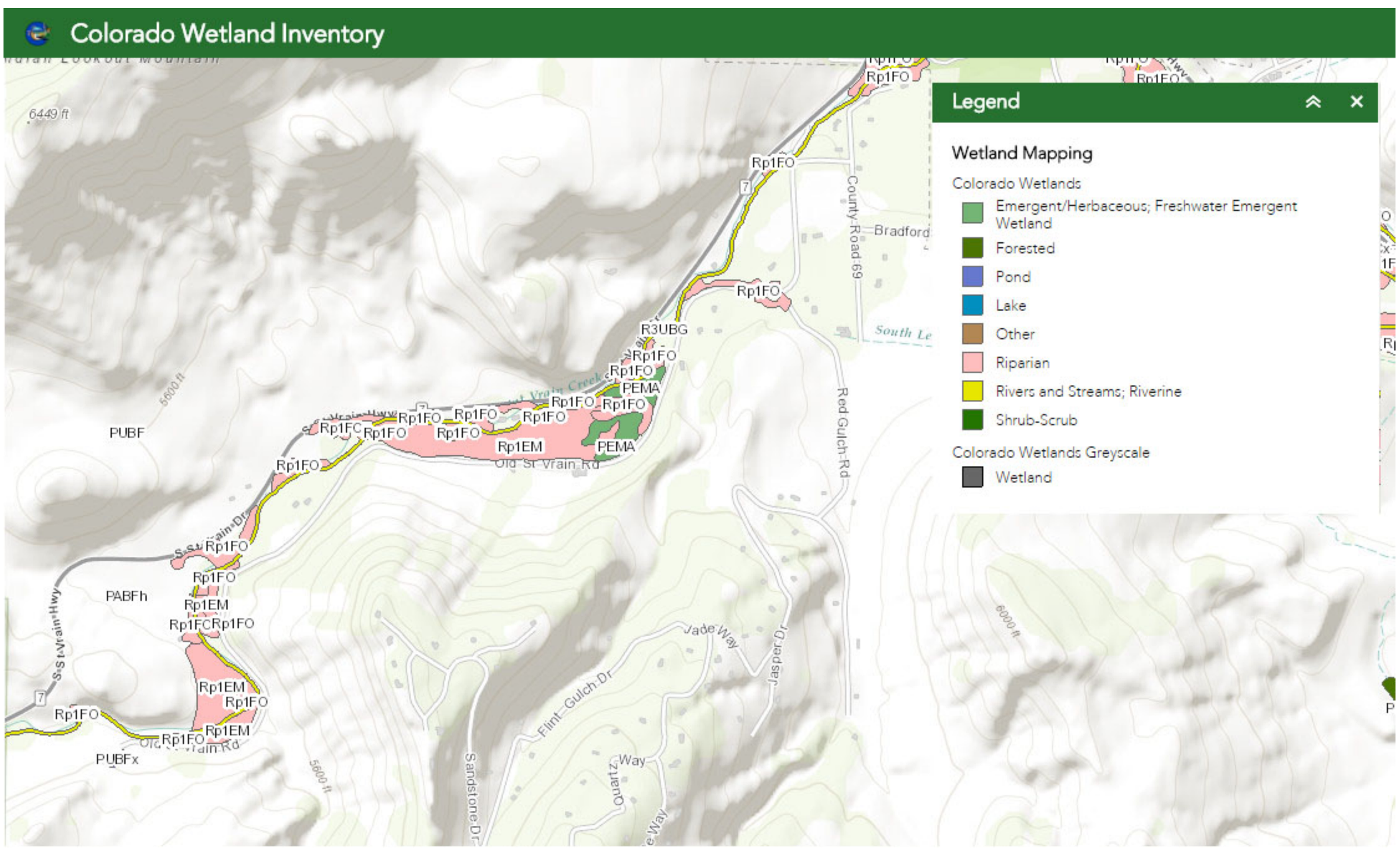


Figure 5. CNHP Colorado Wetland Inventory Map of existing Riparian Communities within the wetland area, 2009.

The CNHP Field Guide to Wetland and Riparian Plant Associates (*CNHP, 2003*) provides more specific information about the plant communities in the project extents. The CNHP field guide brakes these plant communities down into distinct groups based upon the dominate species within them.

The plant communities found on the site are most closely associated with *Group C – Deciduous Dominated Forests and Wetlands*. The specific plant associations in the area fall under the Narrowleaf cottonwood / Sandbar willow Woodland, due to the elevation range and dominate species found during the onsite assessment. Plants of this group are commonly found at an elevation between 5,200 – 8,500 feet along point bars, gravel bars and riparian benches very near or within the active stream channel and do not occur more than 3-6 feet above the high-water mark. This group represents an early, successional stage of this community consisting of primarily young Narrowleaf Cottonwoods trees with interspersed older, transitional stands of more mature trees and a dense Sandbar (also known as Coyote) willow understory. Due to frequent annual flooding in this area, the herbaceous undergrowth is sparse and a significant portion of undergrowth plant material is made up of non-native, invasive species. *(CNHP, 2003)*

The Environmental Protection Agency Level IV ecoregion data shows the project extents to be located in the Southern Rockies Crystalline Mid-Elevation Forests. This forest vegetation is generally characterized by the existence of Aspen, Ponderosa Pine, Douglas-fir and areas of Lodgepole and Limber Pine with a diverse understory of shrubs, grasses and wildflowers *(EPA, 2016).*

The Colorado Natural Areas Program Native Plant Revegetation Guide for Colorado (CNAP) further categorizes the plant communities within the Project extents as an Eastern Plains and Foothills Region Riparian Community and Cottonwood / Willow Shrublands and Forests. According to the CNAP, this project extent represents a foothill riparian forest and shrubland that contains groupings of cottonwoods that form the canopy layer. Sandbar willows occur along the meandering stream edge and grasses such as switchgrass and prairie cordgrass occur between clumps of shrubs and alongside streambanks, forming wide stands of thick, tall grass. Nebraska sedge, Baltic rush and Three-Square are a few examples of plants that are found along the edge of permanent streams and at the bottom of recurrent drainages. Dense shrub layers composed of willows, currants, plums, chokecherries and hawthorns dominate the understory with more willows, red-osier dogwood and twinberry growing along the cool, moist streambank. Cottonwood / Willow Shrublands and Forests include a vast mixture of vegetation types, with wetland areas occurring along the stream edge, in backwater areas with upland / transitional vegetation communities, interspersed with the wetland and riparian vegetation. *(CNAP, 1988)*

iv. Onsite Assessment

On July 22, 2016, members of the Project team and Boulder County conducted a comprehensive site walk of the project area to assess and discuss vegetation and ecologic concerns in the project area. This assessment addressed the entire reach and successfully identified:

- Plant communities that survived the 2013 floods
- Areas that remain denuded
- Areas that show successful secondary colonization
- Extents of prominent wetland areas
- Plant communities that have rebounded successfully from the 2013 floods
- Invasive plant communities

This assessment outlines existing conditions and compiles a comprehensive plant list that identifies varieties of native and invasive plants within the project area. The plant list that was developed as part of the onsite assessment is shown in Figure 6.

South St. Vrain Creek Restoration at Hall Ranch - Existing Plant List				
Flood-Planning & Preliminary Design Services				
On-site Plant Material - Identified July 22, 2016				
Scientific Name	**Common Name**	**National Wetland Indicator**	**Plant Type**	**Native Status**
Panicum virgatum	Switchgrass	FACW	grass	Native
Asclepias syriaca	Milkweed	FACU	forb	Non-native
Toxicodendron rydbergii	Poison Ivy	FACU	shrub	Native
Carduus nutans	Musk Thistle	FACU	forb	Introduced
Cirsium arvense	Canadian Thistle	FACU	forb	Introduced
Festuca arundinacea	Tall fescue	FACU	graminoid	Introduced
Arctium minus	Common Burdock (noxious weed)	FACU	forb	Introduced
Equisetum avense	Common Horsetail	FAC	forb	Native
Ambrosia artemisiifolia	Common Ragweed	FACU	forb	Non-native
Heterotheca villosa	Hairy Golden Aster		forb	Native
Liatris punctata	Blazing Star		forb	Native
Solidago canaensis	Goldenrod	FACU	forb	Native
Dactylis glomerata	Orchard grass	FACU	graminoid	Introduced
Hesperis matronalis	Dame's Rocket	FACU	forb	Non-native
Juncus torreyi	Torrey's Rush	FACW	graminoid	Native
Eleocharis palustris	Spike Rush	OBL	graminoid	Native
Juncus dudleyi	Dudley's Rush	FAC	graminoid	Native
Juncus ensifolius	Swordleaf rush	FACW	graminoid	Native
Epilobium ciliatum	Fringed willowherb	FACW	forb	Native
Scirpus microcarpus	Panicled bulrush	OBL	graminoid	Native
Carex emoryi	Emory's sedge	OBL	sedge	Native
Vitis riparia	Wild grape	FAC		Native
Verbascum thapsus	Mullein	FACU	forb	Introduced
Bromus inermis	Smooth Brome	FACU	grass	Non-native
Lactuca serriola	Prickly lettuce	FACU	forb	Introduced
Melilotus officinalis	Sweet Clover	FACU	forb	Non-native
Elymus lanceolatus	Thickspike wheatgrass	UPL	grass	Native
Elymus trachycaulus	Slender wheatgrass	FACU	grass	Native
Elymus dahuricus	Wildrye wheatgrass		grass	Non-native
Amorpha canescens	Leadplant amorpha		shrub	Native
Astragalus glycyphyllos	Wild liquorice		forb	Non-native
Ratibida pinnata	Yellow coneflower		forb	Non-native
Nepeta cataria	Catnip	FACU	forb	Introduced
Helianthus annuus	Sunflower	FACU	forb	Native
Thermopsis divaricarpa	Goldenbanner	FAC	forb	Native
Veronica anagallis	Speedwell	OBL	forb	Native
Glyceria grandis	American mannagrass	OBL	graminoid	Native
Hypericum perforatum	St. John's-wort	FACU	forb	Introduced
Rumex crispus	Curly dock	FAC	forb	Introduced
Verbena officinalis	Blue verbena	FACU	forb	Introduced
Primula vulgaris	Primrose		forb	Native
Carex nebrascensis	Nebraska Sedge	OBL	graminoid	Native
Leucanthemum vulgare	Oxeye daisy	UPL	forb	Introduced
Salsola tragus	Russian thistle	FACU	forb	Introduced
Juncus arcticus	Arctic rush	FACW	graminoid	Native
Hippuris vulgaris	Mare's tail	OBL	forb	Native
Grindelia squarrose	Gum weed	FACU	forb	Native
Apocynum cannabinum	Dogbane	FAC	forb	Native
Ericameria nauseosa	Rabbitbrush		shrub	Native
Prunus virginiana	Chokecherry	FACU	shrub	Native
Salix exigua	Coyote Willow	FACW	shrub	Native
Rosa woodsii	Woods rose	FACU	shrub	Native
Asparagus officinalis	Wild asparagus	FACU	forb	Introduced
Populus angustifolia	Narrow leaf cotton woods	FACW	tree	Native
Populus deltoides	Plains cottonwoods	FAC	tree	Native
Rhus trilobata	Three leaf sumac	FAC	shrub	Native
Malus domestica	Apple tree		tree	Introduced
Physocarpus monogynus	ninebark	UPL	shrub	Native
Prunus americana	Wild plum	FACU	shrub	Native
Acer negundo	Boxelder	FACW	tree	Native
Alnus incana	Alders	FACW	tree	Native
Salix amygdaloides	Peach leaf willow	FACW	tree	Native
Salvia argentea	Silver sage		forb	Non-native
Gleditsia triacanthos	Honey locust	FAC	tree	Native
Symphoricarpos albus	Snowberry	FACU	shrub	Native
Phalaris arundinacea	Canary reed grass	FACW	graminoid	Native

Figure 6. Existing Plant List

A variety of healthy ecosystems remain onsite. Upland areas have remained established, due to steep banks and an incised channel in many areas. These areas are characterized by upland vegetation including cottonwood galleries and upland meadows. Wild grape was heavily present throughout the upland areas and form dense clusters at the base of the Cottonwood trees. Woody shrubs and grasses such as Woods Rose, Snowberry, Rabbitbush, Ninebark, Thickspike Wheatgrass, Slender Wheatgrass and Wild Rye are also present in upland areas. The assessment could not determine which of the grass species recolonized naturally or were introduced through re-seeding measures.

The riparian areas throughout the site consist of a variety of woody and perennial plants including Coyote Willow, Dogbane, Alders, Wild Plum, Wild Asparagus, Common Horsetail, Torrey's Rush and Switchgrass. In areas where the channel was incised, Willow and Dogbane, along with a variety of grasses, could be found along the river banks. These species grew out of alluvial soils and cobble banks and provided a good case study for potential bioengineering measures related to bank stabilization.

Wetland vegetation exists in depressed areas, including secondary channels that were formed during the 2013 flood as well as historic wetland areas. These wetland areas support a variety of native wetland plant material including Spike Rush, Dudley's Rush, Emory's Sedge and Nebraska Sedge. Reed Canarygrass dominates the largest wetland to the south of the Longmont Diversion. This grass has spread throughout this individual wetland area and has provided erosion control and habitat benefits. However, its spread and density has likely also reduced the spread of other native species, reducing the overall biodiversity in this particular area. Overall, the existing wetland areas within the Project limits are healthy but there is great potential for further revegetation measures and localized planting with the system.

A wetland delineation was conducted for portions of the project area on August 1, 2016. Wetlands consist of palustrine emergent wetland dominated largely by sedges and grasses. Wetland delineation data has been provided to the County. Mapping on the following two pages represent the results of the onsite assessment. Additional information is in Appendix M – Wetland Delineation.

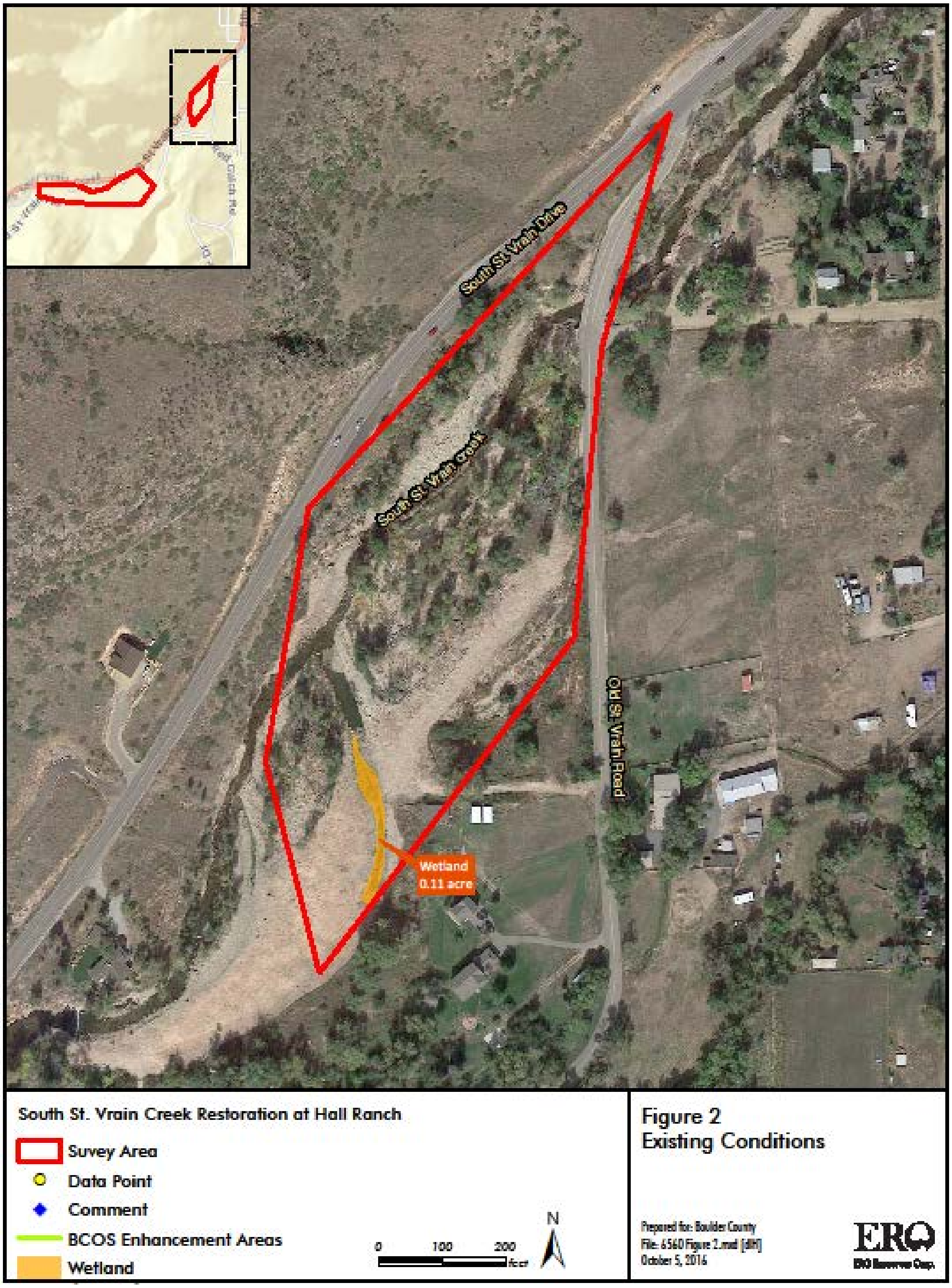


Figure 7. Wetland Delineation: EWP #2

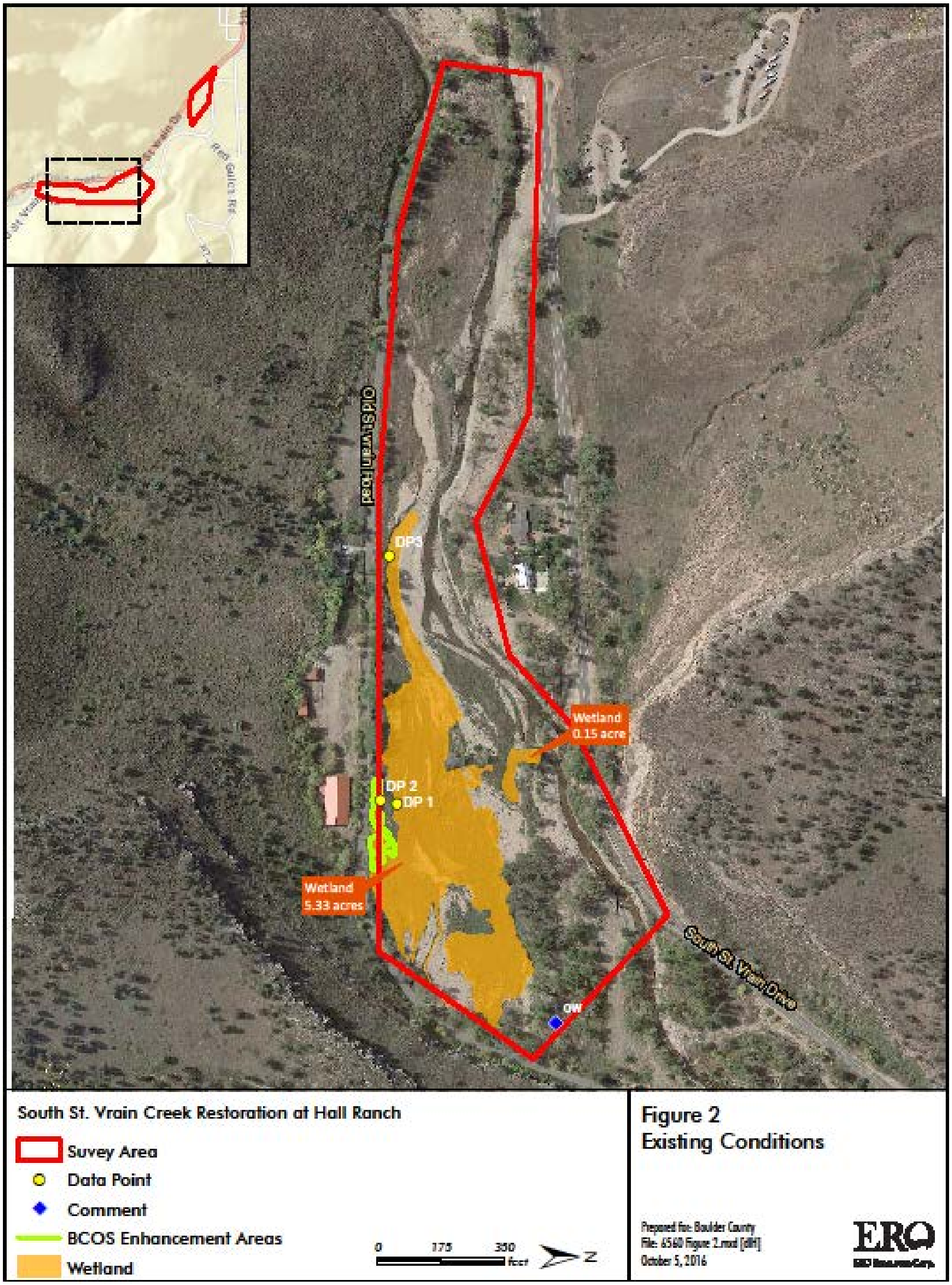


Figure 8. Wetland Delineation: EWP #1

d. Photo Documentation

Photo documentation of the entire 3.2 mile Project extents was very thorough with over 400 photos being taken on site. The majority of these photos were geo-tagged in a KMZ file so that they could be viewed spatially with a map viewer such as Google Earth. Due to the sheer volume of photos and the digital aspect of a KMZ files, these will be included in a digital submittal as part of this report. Below are a few pictures of pertinent locations throughout the corridor moving from upstream to downstream. Pre-flood aerials dating back to 1940 were also acquired to evaluate changes in the historical alignments.

Figure 9. Upstream in Canyon

Figure 10. Downstream of Canyon

Figure 11. Upstream Overflow Channel

Figure 12. Andesite Quarry

Figure 13. Damaged Old St. Vrain Road

Figure 14. NRCS Work on Hall Property

Figure 15. Post Flood Work at the "Plug"

Figure 16. Existing Rootwad Protection at Hwy 7

Figure 17. Meadows/S. Ledge Diversion

Figure 18. Overflow Channel

Figure 19. Longmont Diversion Post-Flood Work

Figure 20. Downstream Extents of Project

e. Base Map Development

The base map developed as part of this Project included combining drawings and designs along with topography and utilities from multiple sources. The base map is in NAD 83 State Plane North Coordinate System. Topographic aspects were compiled with the use of ground survey from multiple sources and pasted into a LiDAR aerial survey performed in 2014. Areas of existing vegetation and wetland areas were also mapped in the EWP areas and added to the base mapping. Base mapping also included aerials for 1940, 2004, 2005, 2006, 2009, and 2011.

All design aspects from previous or existing projects were on NAD83 State Plane North except for the Old St. Vrain Road Bridge drawing that was Modified State Plane, but was scaled back to State Plane for this Project. Aspects from the St. Vrain Creek Master Plan were also included with the base mapping to holistically move from high level planning to more refined designs and recommendations. Below are the design drawings that were compiled as part of the base mapping.

- South St. Vrain Pipeline 2013 Flood Repair
- Hall Ranch 2 Road Repair and Hazard Mitigation
- Meadows & South Ledge Ditch Final Reconstruction Plan
- Old St. Vrain Road Bridge

The base maps also included features supplied by BCPOS thought Boulder County GIS Department. The elements supplied from BCPOS were:

- Vegetation Outlines
- Bridge Locations
- Culvert Locations
- Ditch and Irrigation Features
- Fence Lines

- Parcel Information
- Preble's Meadow Jumping Mouse Conservation Areas
- Raptor Nest Locations

All base mapping and design information will be available digitally on a CD or USB.

f. Site Inspection and Documentation

i. Existing and Proposed Flood-Related Projects

Throughout the 3.2 mile Project extent there are two existing flood recovery projects and two proposed flood recovery projects. The existing flood-related projects are the Meadow and South Ledge Ditch Diversion Reconstruction / Fish Passage Demonstration Project and the City of Longmont's South St. Vrain Pipeline 2013 Repair Project. The proposed flood-related projects are the Old St. Vrain Road Bridge (Andesite Bridge) Project and the Hall Ranch 2 Road Repair and Hazard Mitigation Project.

Meadow and South Ledge Ditch Diversion Reconstruction / Fish Passage Demonstration Project

The Meadows and South Ledge Diversion Project was developed to combine two diversion structures that were damaged in the flood at one location, including providing fish passage beyond these diversions. This Project was completed by Crane Associates in the spring of 2015 with a design report released in the fall of 2015. Coordination with both the engineer and the ditch companies have taken place as part of this Project. Understanding that the main channel alignment through this section of the reach must stay in its current configuration in order to allow the ditch companies to divert water is paramount.

Coordination efforts with the ditch company and other residents in the area have noted that sediment aggradation in the diversion structure itself is currently taking place and is of concern. Recommendations should be provided to alleviate or reduce the sediment being trapped in this diversion. The trapped sediment in this diversion cannot easily be removed from the diversion structure due to the fact the sediment sluice is located at the upstream end of the diversion structure so that the sediment cannot be removed with use of the sluice. The diversion then leads to a pipeline that has an engineered sag where it crosses an overflow channel near Old St. Vrain Road. There is concern that the sediment is accumulating in this sag location and could cause the pipeline to become clogged.

South St. Vrain Pipeline 2013 Repair

The City of Longmont has a cross channel diversion structure located near the downstream extents of the project area that was damaged. During the flood, the right abutment of the diversion was scoured and damaged the pipeline that conveys water away from the diversion. The diversion itself was not damaged. The post flood repairs consisted of repairing the damaged section of pipeline and installing sections of new pipeline from the diversion toward the northwest to tie into existing undamaged sections of pipeline along the Old St. Vrain Road. The installation of the new pipeline also included installing a couple of new manholes and also a flow control structure with another small pipeline that could convey flow back to the river. The existing pipeline was also repaired where it crosses underneath the South St. Vrain Creek, and at the bridge on the Old St. Vrain Road where it connects back into Highway 7.

From interviews with the City of Longmont and the residents it was determined that a grouted sloping drop structure was planned for the downstream area of this diversion. The sloping drop structure would have provided additional safety from the low head dam while also increasing fish passage along this reach. The sloping drop was required to be removed at the 50% complete stage by the Corp of Engineers due to a permitting issue.

Hall Ranch 2 Road Repair and Hazard Mitigation

Downstream of the Andesite Quarry and the Old St. Vrain Road, a small section of the road was washed away during the 2013 flood. This road is the only access point to the quarry and is currently being designed by BCPOS. The road is directly up against bedrock at this location and the South St. Vrain Creek has a tight bend against the road. In the flood the creek washed out the road until it hit the bedrock control.

The plans for this area include rebuilding the road in the same location. Grading for the embankment of the road will cause a minor realignment of the creek back to its pre-flood location. Bank stabilization measures including soil riprap, willow staking and boulder toe protection will be emplaced along the road embankment. A floodplain bench will be graded in along the inside of the bend as allowable by existing vegetation.

Old St. Vrain Road Bridge (Andesite Bridge)

Downstream of the Hall Ranch 2 Road Repairs and the Andesite Quarry is a location where a bridge was washed out during the 2013 flood. This bridge is known as the Andesite Bridge. This bridge connects Old St. Vrain Road back to Highway 7. BCPOS is currently in the process of designing a new bridge with JUB and Anderson Consulting Engineers. The new bridge will be a single span bridge and increase the conveyance capacity compared to the previous bridge. The proposed bridge will pass the new 50-year storm event, but be overtopped during the 100-year event.

Project coordination has taken place between the Design Team and the bridge consultants to ensure a holistic design between the two projects. Design elements including potential floodplain culverts, bank shaping, bank toe protection and revegetation were provided to the bridge consultants based upon the Team’s evaluations. It was determined that floodplain culverts at this location provided little added relief to the bridge during the 100-year storm event. Proposed channel dimensions developed by the Design Team have been included in the bridge design.

ii. Existing and Proposed Non-Flood Related Projects

Andesite Quarry

The Andesite Quarry is currently in the process of submitting their revised reclamation plans to the state for review. Coordination with the Andesite Quarry owners, Aggregate Industries, has taken place to inform them of the proposed design developed through this area. For the purposes of this design it is assumed that the toe of the mining area will remain at the same location with modifications to the existing quarry slopes along with cleanup and revegetation of the floodplain area in vicinity of the quarry.

g. Soils Mapping

The NRCS Web Soil Survey was used to determine various soil types and hydrologic groups. The majority of the area within the river corridor for the Project is composed of Niwot soils. Niwot soils are a hydrologic soil group B with a wet meadow ecological site condition. The depth to the water table for the Niwot soils group is about 18 to 36 inches. The NRCS soils information should be evaluated cautiously since the flood deposited large amounts of new sediment through this reach after the soils mapping was developed.

h. Field Sediment Sampling

Field sediment sampling took place in two different forms. The first sample was taken in-situ bedload and suspended sediment at the downstream end of the Project during average bankfull flows. The second source of field sediment sampling took place with bed and bank sampling and pebble counts throughout multiple locations of the Project.

i. In-situ Bedload and Suspended Sediment Sampling

Sampling

On June 14, 2016 sediment transport and discharge measurements were made on South St. Vrain Creek near the Old St. Vrain Road Bridge to estimate the bedload and suspended sediment transport rates near bankfull flow conditions. Two bedload measurements were taken; one from 6:00 to 7:00 am and the other from 8:00 to 9:00 am, by using a six-inch Helly-Smith sampler suspended from a truck mounted crane off the bridge. Each sample consisted of 10 equally spaced verticals across the bridge span, sampling at two minutes per vertical. Samples from the ten verticals were aggregated in a heavy-duty plastic bag, labeled, and taken back to the laboratory for analysis. A suspended sediment sample was taken after each bedload sample using a depth-integrating DH-59 sampler to collect approximately 300 ml of water from 3 verticals (100 ml/vertical). Standard laboratory methods were used to analyze both the bedload (organics removal, oven drying and sieving) and suspended sediment (filtration, oven drying and sand/wash load fraction determination). A summary of the laboratory analysis is presented in Appendix K - In-situ Sediment Analysis.

A single discharge measurement was taken between 10:00 am and 10:50 am on June 14, 2016 just upstream from the bridge at a location that was conducive to wading. Stretching a tape perpendicular to the flow from the left to right bank, measurements were made at 24 verticals using a top-setting wading rod, a Price AA current meter and Model 3000 Swoffer data logger. Using the standard USGS incremental width methodology to calculate flow, the measured discharge was 355 ft^3/s. A summary of the discharge measurement is presented in Appendix K - In-situ Sediment Analysis.

Analysis

Figure 21 shows the June 2016 hydrographs for 3 stream gages in the St. Vrain system, as well as the timing for the measured sediment and discharge samples on June 14, 2016. Bankfull discharge is estimated to be 450 ft^3/s and based on the Design Team's discharge measurement, the lag to the St. Vrain stream gage in Lyons (SVCLYOCO) and the North St. Vrain gage below Button Rock Reservoir (NSVBBRCO). The discharges at the bridge during the sediment samples were estimated to be 437 ft^3/s and 411 ft^3/s, respectively. It is assumed that these measurements were taken at bankfull discharge, and sediment transport is an average of the two samples, understanding the natural variability in sediment transport rates. The estimated bankfull bedload transport rate was calculated to be 0.5813 kg/s, and the estimated bankfull suspended sediment concentration is 122.28 mg/l (sand fraction, only).

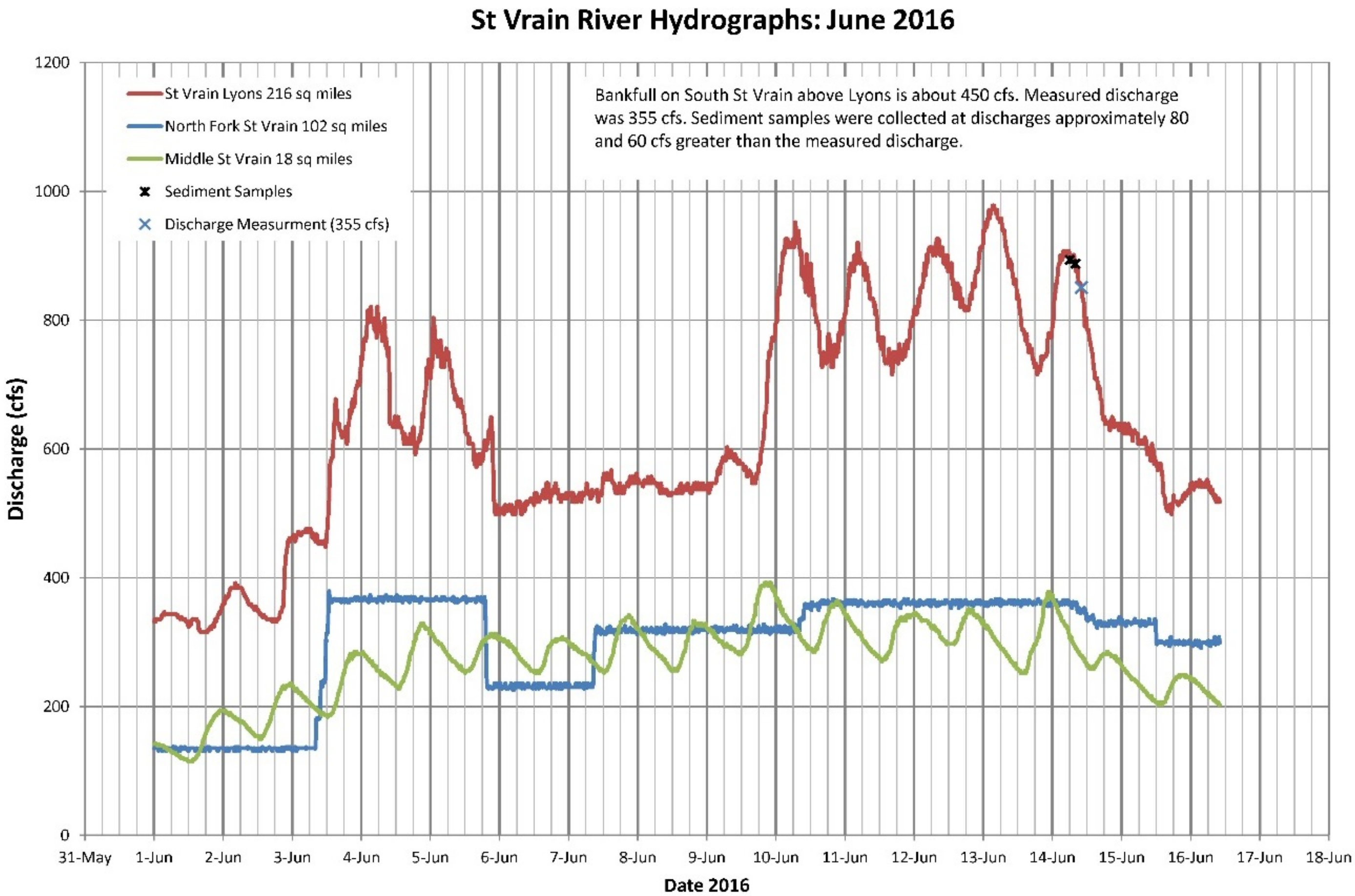


Figure 21. Hydrographs for Three Gages

To get an estimate of average annual sediment yield, the dimensionless sediment transport rating curves developed by Rosgen (2006) were used along with the bankfull sediment transport estimates. The results were applied to a hydrograph or flow duration curve.

While there is no current stream gage on South St. Vrain Creek in the vicinity of this study, the USGS did operate a stream gage for four water years (1977-1980: USGS Gage No. 06723400) that was located within a few hundred feet of the location of the June 14, 2016 discharge measurement (Figure 22). Though the gage was operated for only a short period of the time, the flows it measured represent a reasonable range of discharges from wet and dry years (Figure 23). The measured flows at that location are considered more accurate compared to scaling flows from other nearby gages that perhaps would not reflect the operational hydrology and flow regulation that influences the South St. Vrain Creek hydrograph.

Figure 22. Location of Historic Gage

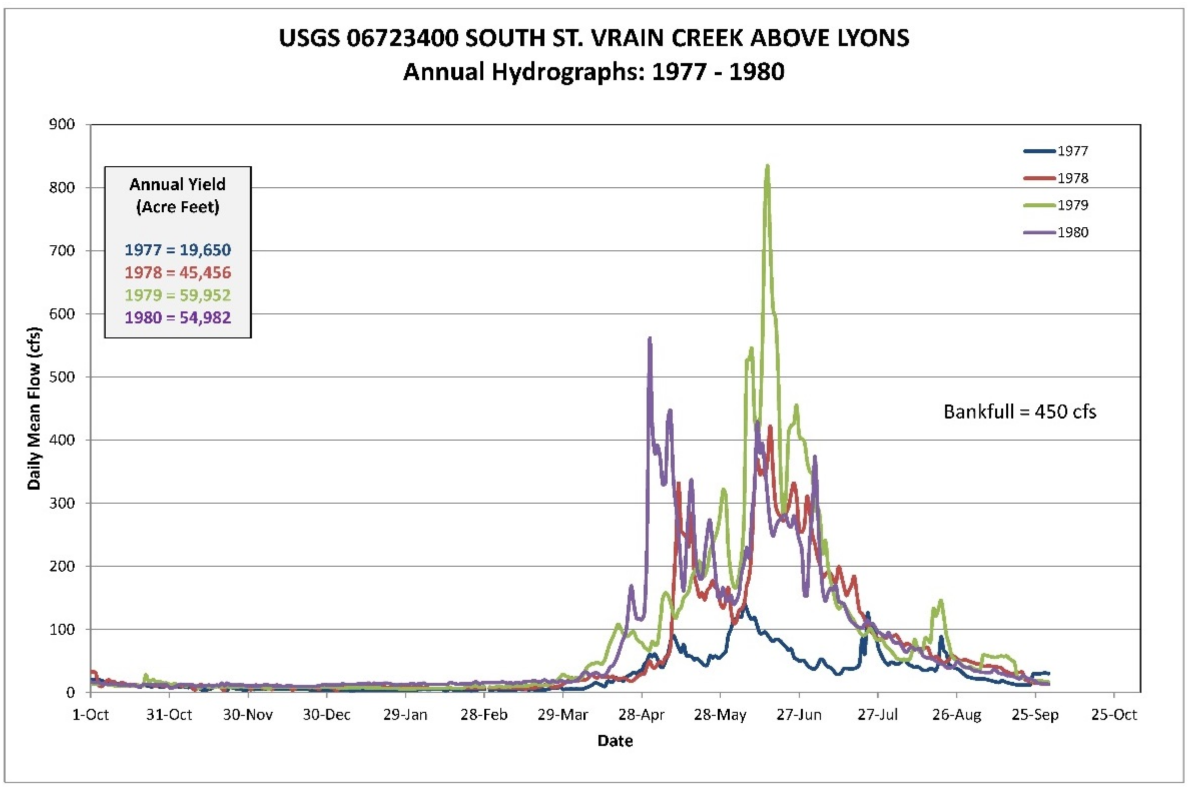


Figure 23. South St. Vrain Creek Above Lyons Hydrograph

To estimate sediment yield using the four years of South St. Vrain Gage data, seasonal daily mean flow (Q) values (April 1 to September 30) were divided by the bankfull value 450 ft3/s (Qb). Seasonal flow values were used because very little if any sediment is being transported by the low flows from October 1 to March 31 (Figure 23). Using four dimensionless sediment transport equations (Rosgen 2006), the dimensionless sediment transport value was calculated for each seasonal daily mean flow in the period of record based on sediment type and stream channel stability. Multiplying each dimensionless sediment transport value by the bankfull estimate, converting units from kg/s or mg/l to tons/day, summing all dates and dividing by 4 (4 years in the period of record) provides an estimate of average annual sediment in South St. Vrain Creek (Table 1).

- Equation 1. Dimensionless Bedload (Good/Fair) = -0.0113+1.0139(Q/Qb)2.1929
- Equation 2. Dimensionless Bedload (Poor) = 0.0718+1.0218(Q/Qb)2.3772
- Equation 3. Dimensionless Suspended (Good/Fair) = 0.0636+0.9326(Q/Qb)2.4085
- Equation 4. Dimensionless Suspended (Poor) = 0.0989+0.9213(Q/Qb)3.659

The Good/Fair and Poor designations refer to stream channel stability ratings; which pre-flood would have been Good/Fair for the majority of the reach while post-flood is dominated by Poor sections. Comparing sediment transport by channel stability is both an indication of how much more sediment is being transported post-disturbance but also of the potential to reduce downstream sediment delivery by properly stabilizing and restoring sections of the river generating the excess sediment from bed and banks. Because the dimensionless sediment transport equations are based on measured data, as are the South St. Vrain Creek bankfull sediment values, the resulting estimates of sediment yield are considered to be reasonable values. Additional information is presented in Appendix K - In-situ Sediment Analysis

Table 1. Summary of Average Annual Sediment Yield

	Average Annual Sediment Yield (Tons)		
	Bedload	Suspended (Sand) Load	Total
Good/Fair	1185	3045	4230
Poor	1935	3677	5613
Difference	750	632	1383
Percent Difference	63.3%	20.8%	32.7%

ii. Bed and Bank Sediment Sampling

During the geomorphic site assessments, reach- representative locations were determined for pebble counts in all eight reaches, including several overflow channel locations. These pebble count data provide quantitative comparisons of bed material size longitudinally through a reach as well as among reaches. They are also used as inputs for the sediment transport capacity modeling and design calculations discussed below.

The sediment sampling location map is included in Figure 24 and shows the locations of the pebble counts, and the sediment gradation results are presented in Table 2 and Figure 24. The median bed material size found along the project reach ranges from coarse gravel to small cobble. The shape of the sediment gradation curves are fairly similar for most of the main channel locations, with the exception of the sediment sample collected in Reach 5 (PB5), where there is a lack of the smaller material (D10 is 41 mm, compared to the other reaches with D10 of less than 10 mm), and the sediment samples collected in Reach 2 (PB2-2) and Reach 7 (PB7) where the upper range of the gradation includes smaller material than other reaches.

Table 2. South St. Vrain Sediment Gradation Summary

SSVCR Reach (Expanded Study Reach #)	**R1** (SSV-03)	**R2** (SSV-04)			**R3** (SSV-05)	**R4** (SSV-06)	**R5** (SSV-07)	**R6** (SSV-08)	**R7** (SSV-09)		**R8** (SSV-10)
		dstrm	upstrm	ofc					current	alt align	
Sample ID	**PB1**	**PB2-1**	**PB2-2**	**PB2-ofc**	**PB3**	**PB4**	**PB5**	**PB6**	**PB7**	**PB-ofc**	**PB8**
D10	8.9	5.6	3.1	2.0	5.8	6.9	41	5.3	5.1	2.3	2.0
D16	19	17	13	2.0	23	11	61	18	24	3.9	4.4
D25	56	25	30	21	49	19	79	39	35	7.9	35
D50	101	44	64	81	85	64	115	86	54	78	80
D75	153	81	115	119	141	109	167	129	84	167	132
D84	185	101	149	139	171	133	207	174	105	271	153
D90	218	121	176	162	252	189	250	221	124	344	168
D_{MAX}	1024	250	370	370	730	350	660	600	300	650	500

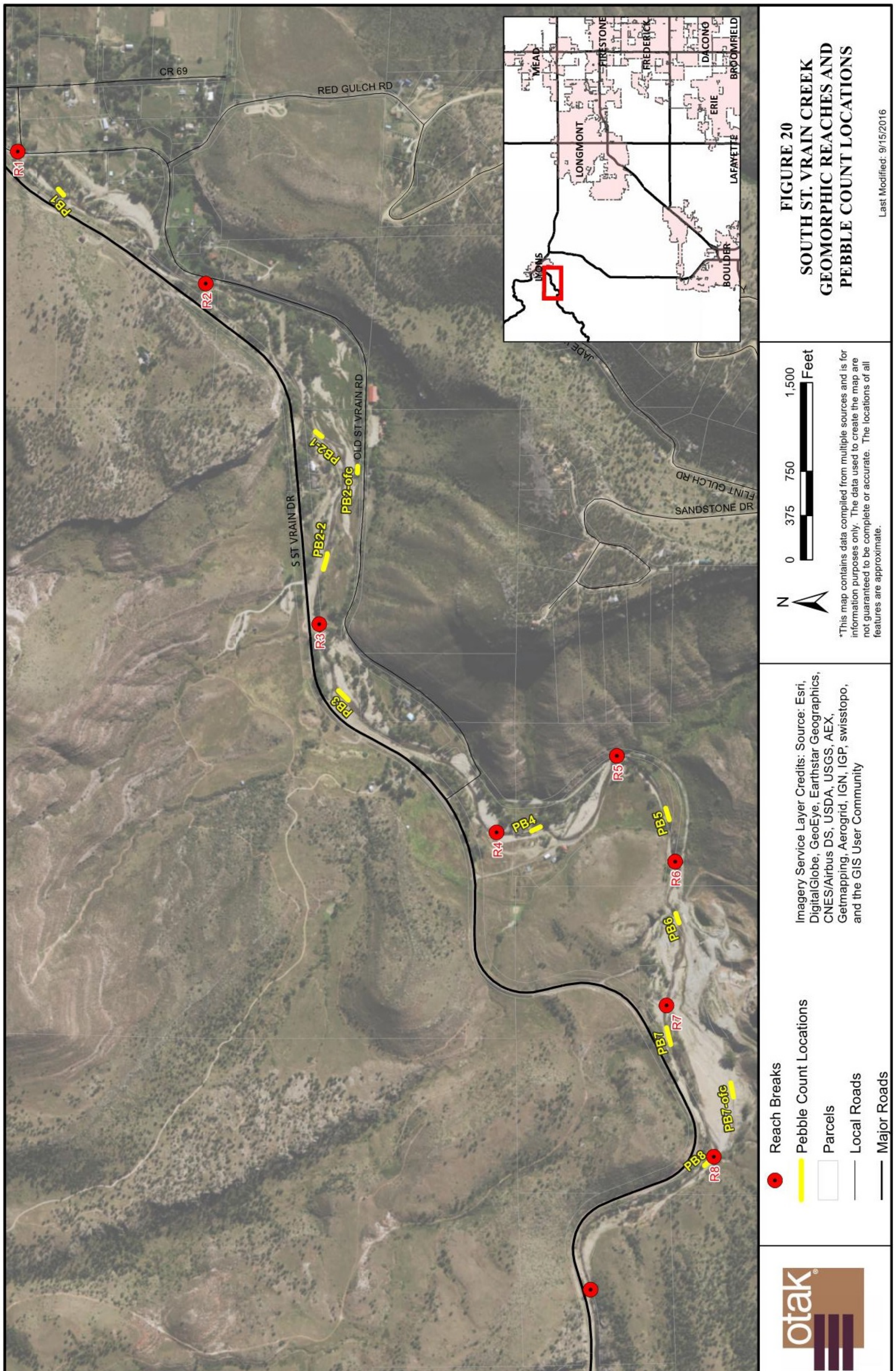


Figure 24. Geomorphic Reach Breaks

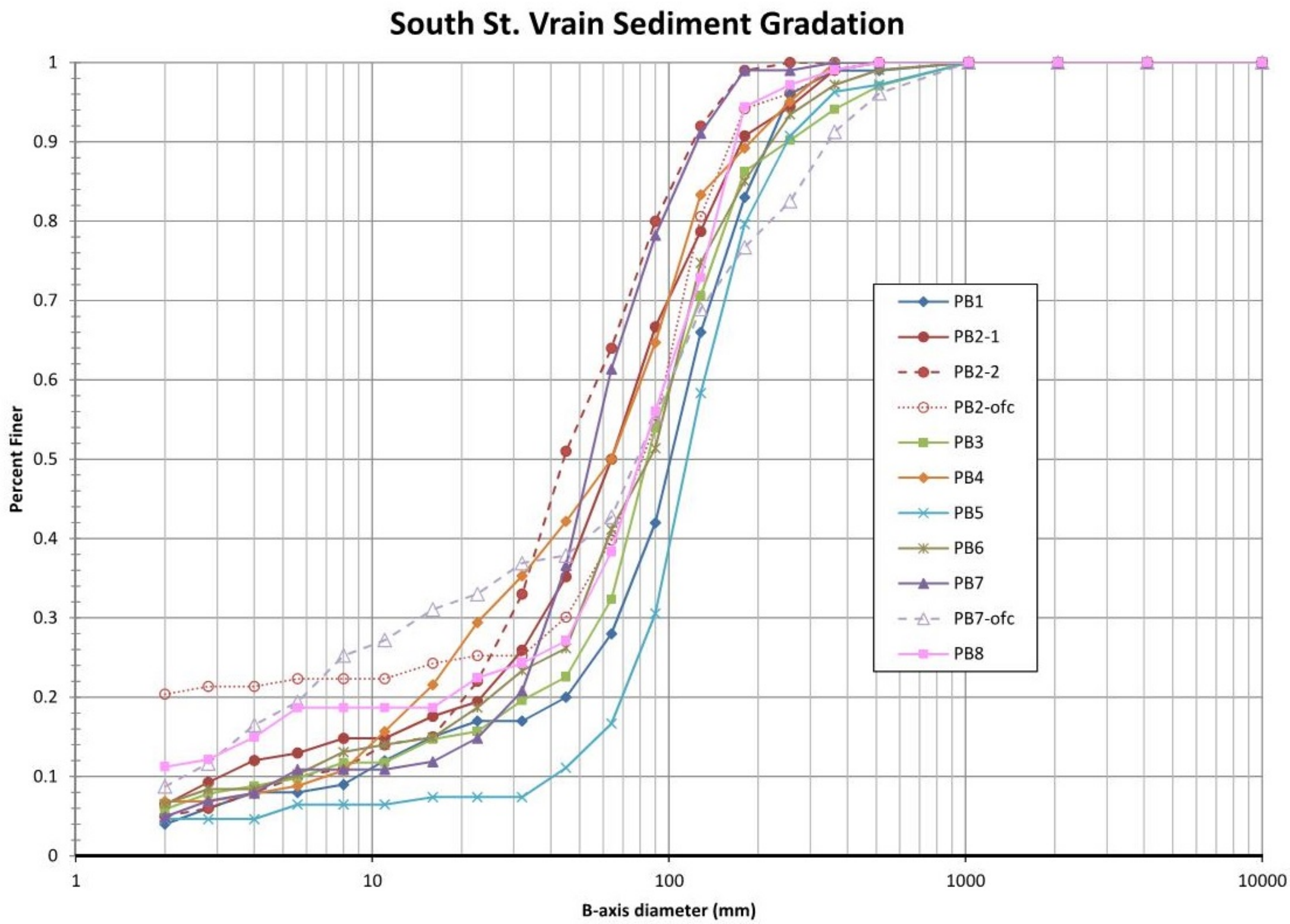


Figure 25. South St. Vrain Sediment Gradation

7. Hydrology/Hydraulics Data

a. Hydrology

Hydrology was evaluated from multiple different sources. Hydrology for the project area was validated to verify accurateness of channel forming hydrology and ascertain flood hydrology for this project area. In this section, the data sources will be discussed and recommendations for channel forming and flood hydrology are developed.

Several floods have been noted in the project area. In Crane Associates design report for the Meadows and South Ledge Diversion Project it noted that 10 notable floods have occurred in the past 150 years on St. Vrain Creek (Crane, 2015). The largest peak discharge on record prior to the September 2013 flood was 10,500 cfs in June 1941, which mainly originated on South St. Vrain Creek with a very rapid rising and falling of floodwaters. It is assumed that a very localized cloudburst occurring over South St. Vrain Creek just upstream of Lyons caused this event (FEMA, 2012). The preliminary peak discharges estimated on the South St. Vrain Creek as a result of the September 2013 flood is 8,886 cfs above the confluence with the North St. Vrain Creek (Jacobs, 2014)

i. FEMA: Flood Insurance Study

The effective Flood Insurance Study (FIS) for Boulder County was revised and made effective on December 18, 2012. This FIS data was found in the *CDOT Hydrologic Evaluation of the St. Vrain Watershed, Post September 2013 Flood Event* (Jacobs, 2014). The hydrologic and hydraulic analyses for the unincorporated areas of Boulder County, including the South St. Vrain Creek watershed, were completed by the U.S. Soil Conservation Service (SCS) in August 1974. These records were analyzed using a Log-Pearson Type II analysis of peak runoff recoded at gages on St. Vrain Creek near Lyons in accordance with U.S. Water Resources Council Bulletin 15. Subsequent hydrologic and hydraulic analyses were prepared for the Town of Lyons by Howard, Needles, Tammen & Bergendorff in October 1977. These updated discharge-frequency relationships in the St. Vrain Creek basin were generated with data from the June 1972 and September 1972 Floodplain Information Reports, by the U.S. Army Corps of Engineers. This report was based on an updated statistical analysis of gages on the St. Vrain Creek at Lyons. Synthetic unit hydrographs were developed for the South St. Vrain Creek, as a sub-basin of the St. Vrain Creek basin.

Table 3. FIS Study

Design Point	Drainage Area	Design Storm Hydrology			
		10 Year	50 Year	100 Year	500 Year
		10%	2%	1%	0.2%
	[sq mi]	[cfs]	[cfs]	[cfs]	[cfs]
FEMA FIS	92	1,400	3,750	5,430	11,900

ii. Blue Mountain Consultants: Geomorphic Indicators Paired with Discharges

Blue Mountain Consultants conducted a study to establish bankfull conveyance of the South St. Vrain Creek using geomorphic indicators surveyed by the United States Forest Service (USFS) in 1988. By pairing the survey data with flow conditions taken by the USFS in 1990, bankfull capacity can be calculated. Table 4 summarizes the calculated flow for a return period of 1.5 years.

Table 4. BMC LLC./USFS Bankfull Hydrology

Design Point	Drainage Area	Design Storm
		1.5 Year
		66.6%
	[sq mi]	[cfs]
BMC LLC. - USFS	83	450

iii. CDOT Hydrologic Evaluation of the St. Vrain Creek Watershed

A study on the St. Vrain Creek watershed was prepared by Jacobs in 2014 for Colorado Department of Transportation (CDOT) to ascertain the approximate magnitude of the September 2013 flood event and to prepare estimates of peak discharges associated with various return periods. The St. Vrain Creek is the receiving body of the South St. Vrain Creek. South St. Vrain Creek is considered part of the St. Vrain Creek watershed; therefore, hydrology calculations were performed on the South St. Vrain Creek sub basin.

The total watershed was divided into 59 basins, ranging in size from 0.25 square miles to 10 square miles. In order to compare the peak discharge estimates at investigation sites to the calibrated model, basins were manually subdivided. There were two investigation sites on the South St. Vrain Creek: below Middle St. Vrain Creek and above the Town of Lyons.

This study was performed using the HEC-GeoHMS and HEC-HMS software platforms. Spatial data was acquired from USGS and used to delineate and characterize watersheds. Runoff parameters and lag times were computed and applied to the Snyder Unit Hydrograph to determine peak flow measurements.

Once the watersheds physical characteristics were initially modeled, they were calibrated based upon observed flows from high water marks. Initially, Button Rock Dam was modeled as a simple junction with no runoff storage or attenuation. During the calibration process the stage-storage-discharge relationship for Button Rock Dam was incorporated.

Calibration efforts were being conducted concurrently in the Big Thompson River Watershed, adjacent and to the north of the St. Vrain Creek Watershed. U.S. Bureau of Reclamation provided a stage-storage relationship for Lake Estes, along with stage-storage-discharge time-series data during the 2013 Flood Event. This allowed for better calibration and optimization routines based upon the Lake Estes inflow hydrograph.

South St. Vrain Creek experienced significant rainfall totals and intensities within the study area. The average 24-hour rainfall depth experienced during the September event was greater than a 100-year storm. The graphic on the following page produced by NOAA displays the annual exceedance probabilities for the heaviest rainfall over a 7-day period.

Table 5 outlines the estimated September event and several design storms for South St. Vrain Creek watershed developed for the CDOT study. The estimated September event flow was based upon the maximum rainfall that occurred over the ten-day event. This value was then used to calibrate the hydrological model to develop a typical 24 hour NOAA storm. An area rainfall reduction was not performed on South St. Vrain Creek in this study due to the relative magnitude of the event that happened.

Table 5. CDOT Design Hydrology

Design Point	Drainage Area	Design Storm Hydrology			
		10 year	25 Year	50 Year	100 Year
		10%	4%	2%	1%
	[sq mi]	[cfs]	[cfs]	[cfs]	[cfs]
South St. Vrain Creek above confluence with North St Vrain Creek	91.27	1,605	3,168	4,933	7,234

iv. St. Vrain Creek Channel Flood Recovery Design-Build Services

The St. Vrain Creek Channel Flood Recovery Design-Build Services report was developed by Otak, S20 Design and Engineering and others for the Town of Lyons following the September 2013 flood. The purpose of this study was to repair flood damage and increase resiliency for reduced damage during future flood events (Otak 2016). This report was determined to be the most in-depth report for determining channel forming hydrology including base flow, Q1, Q1.5, Q2, and Q5 recurrence interval hydrology.

Since adequate gage date is not available on the South St. Vrain Creek base flows were scaled based upon drainage area from the St. Vrain Creek calculated discharges (Otak, 2016). The equation below used A as the watershed area and C as a constant to determine Q_P the peak discharge. The constant, C, was calculated from the mainstem results for each return period and the base flow. The corresponding discharge for the North and South St. Vrain creeks was then calculated using the watershed area and the constant.

$$Q_p = C\sqrt{A}$$

Peak discharges on the mainstem of the St. Vrain Creek were calculated using Log-Pearson Type III distribution (USGS, 1982) to statistically asses the annual instantaneous peak discharges from 1895 to 2013 (Otak, 2016). The assessment evaluated Q1, Q1.5, Q2, and Q5 return period flows. For this analysis the three highest discharges (2013- 23,800 cfs; 1941- 10,500 cfs; 1919- 9,400 cfs) were removed from the dataset since they were produced by rainstorm events rather than the annual peak snowmelts and are therefore part of different hydrologic datasets. The data was then statistically fit to the Log-Pearson Type III distribution and the return period discharges were calculated. The results of the Log-Pearson Type III analysis were compared to StreamStats (USGS, 2016) results to provide an order-of-magnitude verification of the results. Below are the results of the analysis from this report.

Table 6. St. Vrain Creek Channel Flood Recovery Design-Build Services Hydrology

Design Point	Design Storm Hydrology				
	Q Base [cfs]	1 Year [cfs]	1.5 Year [cfs]	2 Year [cfs]	5 Year [cfs]
South St Vrain Creek at the Confluence	25	232	470	681	1,063

v. Hydrology Summary

In summary the hydrology for this study will be used from the CDOT Hydrologic Evaluation of the St. Vrain Creek Watershed for the less frequent recurrence intervals along with floodplain analysis, while the St. Vrain Creek Channel Flood Recovery Design-Build Services will be used to set the channel forming hydrology along with the more frequent recurrence interval flows.

Design Point	Design Storm Hydrology (Years)								
	Base [cfs]	1 [cfs]	1.5 [cfs]	2 [cfs]	5 [cfs]	10 [cfs]	25 [cfs]	50 [cfs]	100 [cfs]
South St Vrain Creek at the Confluence	25	232	470	681	1,063	1,605	3,168	4,933	7,234

b. Preliminary Models

i. 1D HEC-RAS Models

A preliminary existing and proposed conditions hydraulic analysis was completed using HEC-RAS v4.1.0 computer software to determine flow depths and velocities across the range of flow rates established by the hydrologic analysis. This evaluation was also completed to determine variations in the base flood elevation when comparing existing and proposed conditions. Water surfaces generated from these analyses were generated in AutoCAD to define design parameters and overflow channel inverts.

While this planning Project is for the entire 3.2 mile reach of the South St. Vrain is considered a 30% level design, further refinement of the HEC-RAS models for the EWP specific reaches will take place as the design is progressed to 80%.

Evaluation Parameters

Discussions with the floodplain management department at Boulder County help to set the base evaluation parameters for comparison of existing conditions to proposed conditions. The effective FIS study is no longer inaccurate due to the widespread changes in the channel topography from the 2013 flood, coupled with the increase in hydrologic evaluations. Existing topography from post-flood evaluations was used for the existing conditions cross sections. Hydrology developed as part of the CDOT *Hydrologic Evaluation of the St. Vrain Creek Watershed* was used for the 100-year hydrology of 7,234 cfs. This approach is in line with the direction provided by the CWCB in the *Guidance for Hydrology and Hydraulic Modeling* memo (CWCB, 2014).

Existing Conditions Model

The existing conditions model developed for the St. Vrain Creek Channel Flood Recovery Design-Build Services Project was built upon to ensure coordination with downstream projects. Newly acquired surveyed cross section topography from this Project was used to supplement existing information in the HEC-RAS model to better represent the creek corridor. These new cross sections were used to define the channel parameters more accurately in the existing topography surface as discussed in the previous Base Map section.

The existing model was extended further upstream to include the entire 3.2 mile reach with an addition of nine new cross sections. Additionally, a few of the existing cross sections from the model were reevaluated or lengthened to better represent the hydraulic conditions and encompass the entire floodplain extents.

Cross-sections were developed from existing conditions topography at critical points along the alignment and approximately every 250 feet. 145 cross sections were generated along the 3.2 miles to represent and evaluate the hydraulic conditions. Channel roughness coefficients (Manning's n) were initially estimated based upon the river channel bed material for comparison to published USGS verified roughness characteristics of natural channels. In multiple locations ineffective flow areas were assigned due to the numerous overflow channels still existing in the corridor.

A final range of estimated Manning's n values were used in the hydraulic analysis. A Manning's of 0.045 was used to for the channel to reflect the gravel and cobble channel bed, steep gradient of the study and meandering planform. A Manning's of 0.06 was used for the overbank areas to reflect scattered trees and brush. A Manning's of 0.02 was used in locations were Highway 7 is inundated to represent the asphalt road.

The reach currently only has one structure located at the downstream extent of the Project, which is a bridge for the Old St. Vrain Road where it connects to Highway 7. Due to the fact there are two proposed projects to take place between the writing of this report and the construction of proposed elements under this plan, these Project aspects were included in the existing conditions model. These two projects included reconstruction of the Old St. Vrain Road as part of the Hall Ranch 2 Road Repair and Hazard Mitigation and the reconstruction of a bridge through the Old St. Vrain Road Bridge Project. Design plans from each of these projects were evaluated and developed into the existing conditions model.

The downstream hydraulic control for the HEC-RAS model was determined by a normal depth calculation with an average channel slope of 1.2%.

Proposed Conditions Model

A preliminary proposed conditions model was developed as part of this Project and built off of the existing conditions model. This model was used to evaluate the change in base flood elevations based upon proposed conditions. Existing channel cross sections were replaced with proposed channel cross section and analyzed in HEC-RAS. Further refinement of the proposed conditions model will occur as the design progresses into an 80% design.

Comparison of Models

Once both the existing and proposed conditions models were developed, proposed conditions were evaluated to determine changes in the base flood elevations. Comparison of the models were made via profiles, cross sections and tables output from HEC-RAS. The preliminary proposed design of the entire 3.2 mile reach shows a rise at 9 of the 60 cross sections developed as part of this evaluation. The average rise of the 9 cross sections showing a rise is about 0.3 feet with no rise greater than one foot. Further refinement of the proposed design could be implemented to avoid a rise at any cross section. Multiple iterations of design and hydraulic modeling would be necessary to remove these rises. The preliminary design of the 3.2 mile reach could be implemented if a Conditional Letter of Map Revision (CLOMR) is prepared and submitted to FEMA.

Further refinement of the design throughout the EWP reaches will take place as this Project moves from 30% to 80%. It is the intent of the Design Team to show no rise for the construction eligible EWP project areas so that funding deadlines can be met. A floodplain development permit will be applied for the EWP reaches as the design is progressed to 80%.

Output from HEC-RAS in the form of cross-sections, profiles, and table along with a floodplain work map are included in Appendix D - HEC-RAS Hydraulic Model Output and Floodplain Work Map. At this preliminary stage, the proposed and existing conditions floodplain map should only be evaluated for informational purposes. New regulatory floodplain mapping is being conducted by CWCB through CHAMP.

ii. Colorado Hazard Mapping Program (CHAMP)

Following the 2013 flood, the Colorado Water Conservation Board (CWCB) initiated a program to re-map the predicted 1% chance regulatory floodplain (100-year flood zone) of the most affected waterways. The program was named the "Colorado Hazard Mapping Program" or "CHAMP." The CWCB draft floodplain maps will reflect changes to waterways caused by the 2013 flood and the recovery work since that flood. They will also utilize more accurate data and advanced technology than was available when the effective maps were created. As a result, the CWCB draft maps will be a more accurate representation of the anticipated 1% annual flood elevation and therefore more precisely reflect the flood risk for residents than the existing regulatory floodplain maps.

The CHAMP mapping for the South St. Vrain Creek is currently underway and is scheduled to be completed this fall. This mapping effort will not include the proposed design elements proposed under this 3.2 mile planning study or the EWP eligible areas. Therefore, further coordination with the consultants performing the CHAMP mapping will need to take place to determine steps that need to performed to ensure the updates mapping is reflective of the proposed elements actually constructed under this Project.

iii. 2D SRH Models

South St. Vrain Creek has many areas where overbank flows, at high discharges, can have many complex flow paths across the floodplain. Understanding the flow complexities through modeling is crucial, as the design relies on floodplain conveyance to reduce stream energy in the main channel and to moderate the incoming sediment load. Considering the inability of one-dimensional (1-D) hydraulic models to capture complex overbank flow characteristics, two-dimensional (2-D) models were developed. 2-D models compute transverse variations in water-surface elevations (WSE), velocities and momentum that are not captured in 1-D models. The results from a 2-D model are therefore much more comprehensive at defining hydraulic conditions in a complex hydraulic setting such as South St. Vrain Creek.

The Sedimentation and River Hydraulics – Two-Dimensional hydraulic model (SRH-2D) produced by Yong G. Lai of the Bureau of Reclamation in SMS 12.1.6 (Lai, 2008) was selected for the 2-D modeling of the project area. This program was selected for the powerful mesh creation capabilities of SMS and the stable computational engine that has been developed over three versions of the SRH-2D model.

Model Set-Up

Existing Conditions Model

A terrain model of the South St. Vrain Project Area was imported into SMS to develop the 2-D hydraulic model. All elevation data was extracted from this terrain to produce the mesh and for flow computations. Mesh generation began by defining the boundaries or breaklines of important features in the terrain. A combination of the hillshade terrain model and overlaid aerial imagery was utilized to delineate channel/side channel boundaries, floodplains, and roads. The mesh was developed using the paving mesh type in combination with the merged triangles feature. This builds the mesh using triangular elements between nodes and merges triangular features into quadrilateral elements where possible. This technique can help maximize the efficiency of the model computations while retaining a high level of detail with mesh elements. The mesh was inspected to meet details needed to capture in-channel variations and have quality non-irregular shaped mesh elements. The entire South St. Vrain model was broken into two sections (upper and lower) for computational efficiency purposes as shown below in Figure 26. An example of the mesh overlaying the terrain model is presented in Figure 27.

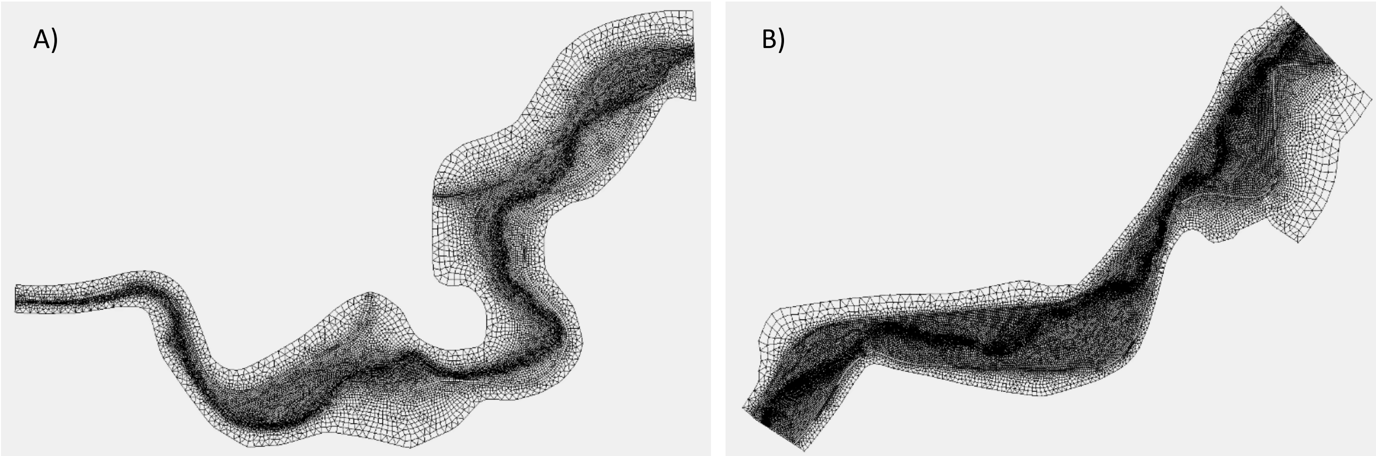


Figure 26. Screenshots of the mesh for A) upper and B) lower sections of the South St. Vrain.

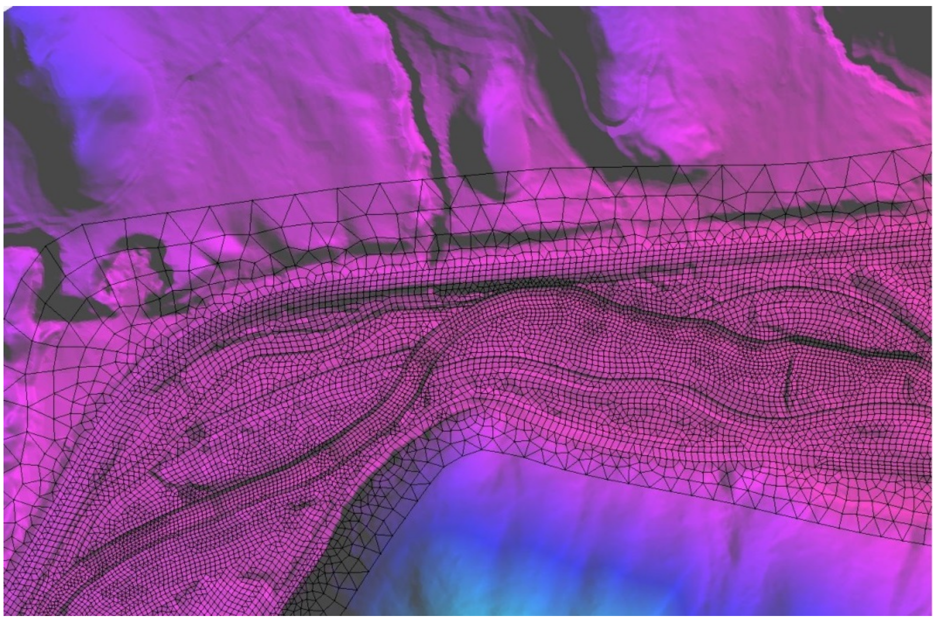


Figure 27. Example screenshot of lower mesh zoomed-in overlaying terrain model.

The boundary conditions for the 2-D model were set for the upstream and downstream edge of the mesh. An inlet-discharge time series curve was generated for the upstream boundary condition. The discharge is ramped up by doubling every half an hour of simulation until it reaches the design discharge of interest, and is then held constant (Figure 28). A rating curve of water surface elevation (WSE) versus discharge was chosen for the downstream boundary condition (Figure 29). The rating curve was derived from a pre-existing 1-D HEC-RAS (Otak, 2016) model that had WSE information for each design discharge tested in the model. The cross section that aligned with the downstream boundary was selected to extract the rating curve.

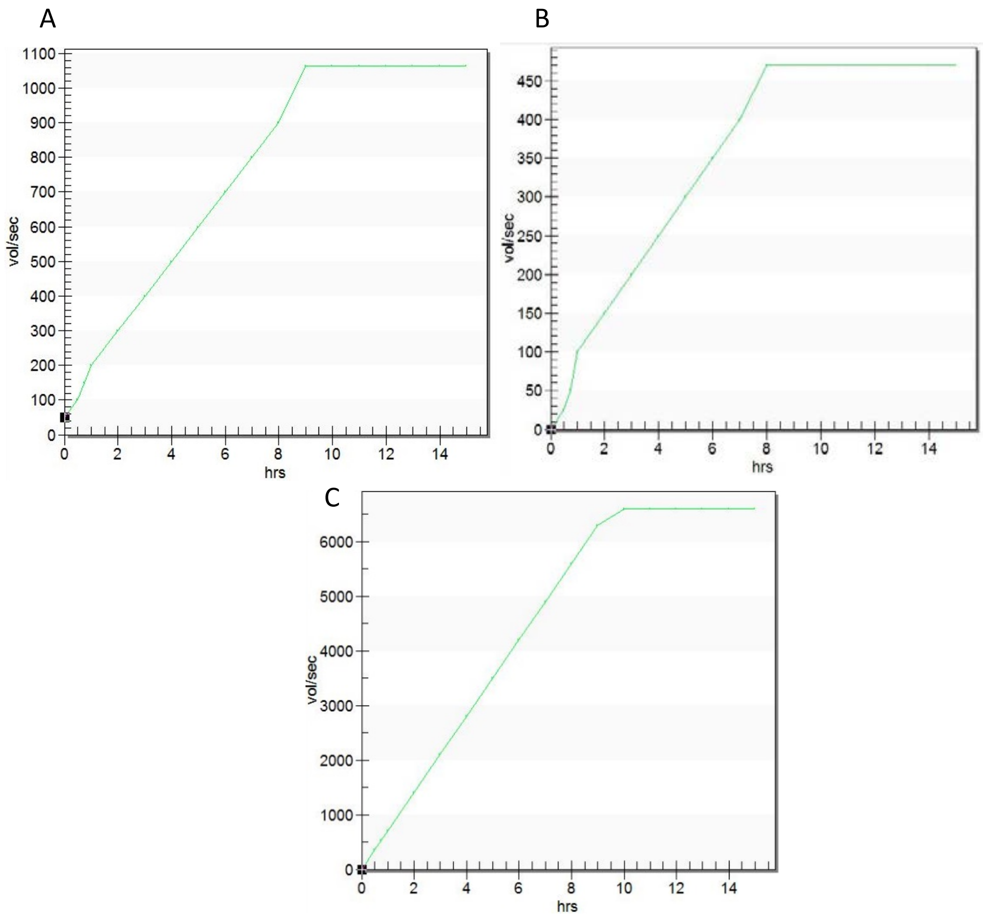


Figure 28. Upstream inlet discharge boundary condition for both the upper and lower sections for A) Q1.5, B) Q5, and C) Q100

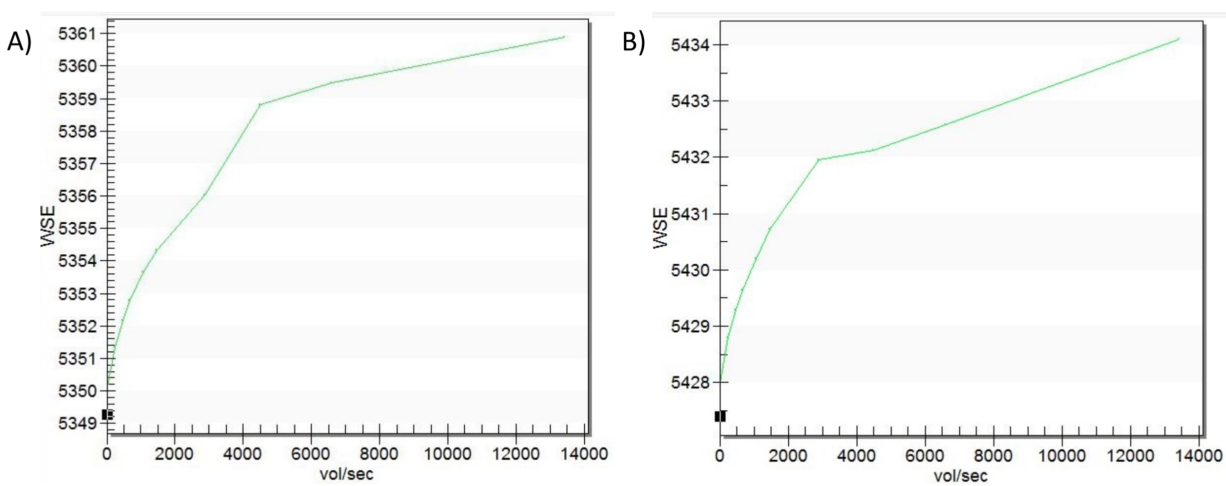
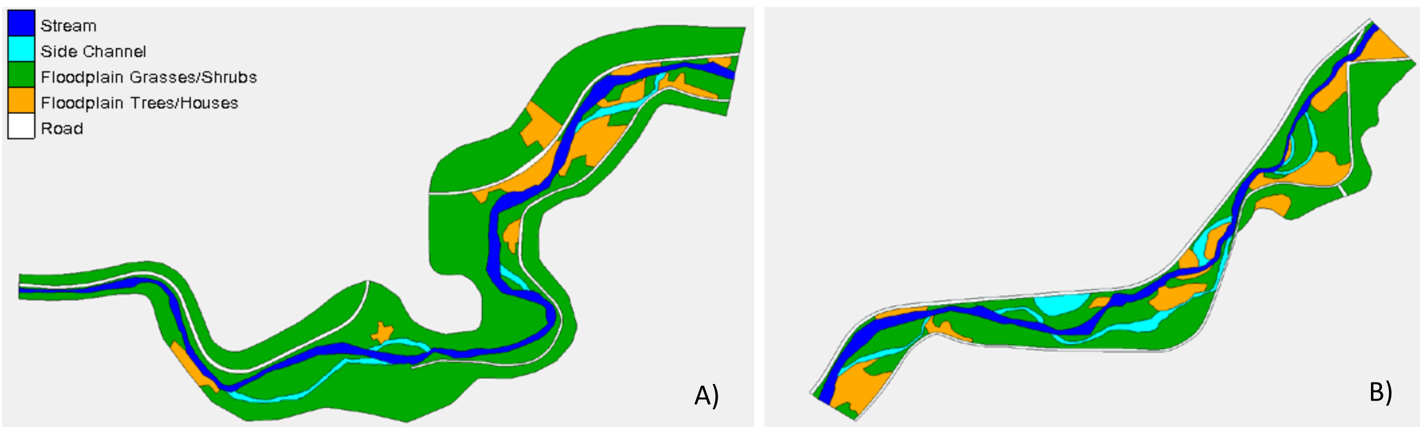


Figure 29. Downstream WSE rating curve boundary conditions from 1D HEC-RAS model for A) upper section and B) lower section.

The areas delineated in the mesh generation process for the stream boundary, floodplain, and roads were used to assign roughness characteristics to be used in the 2-D computations. In addition, areas of high roughness, such as patches of trees and houses, were delineated using aerial imagery and assigned a separate roughness value. A Manning's n value of 0.035, 0.045, 0.06, 0.08, and 0.025 were selected for the stream, side channels, floodplain (grasses and shrubs), floodplain (trees and houses), and road roughness characteristics, respectively. The spatial reference for these categories for the upper and lower sections of the model is shown in Figure 30. These values were selected based on field observations, aerial photography, previous models, and engineering judgment in conjunction with calculations based on (Bathurst, 1985; Hey, 1979; Chow, 1959). The (Bathurst, 1985) and (Hey, 1979) equations along with previous models were used to select the in-channel roughness value. This value also took into account the increased ability of 2D models to account for bed forms and roughness at meander bends. The chosen values were held static and not vertically varied with increasing flows.

Figure 30. Roughness categories for A) upper and B) lower sections of South St. Vrain model.



Existing conditions model results have been computed for the $Q_{1.5}$, Q_2, Q_5, Q_{50}, and Q_{100} design discharges for at least 15 hours of simulation to reach a steady state solution for analysis.

Proposed Conditions Model

An updated proposed terrain model for South St. Vrain Creek was imported into SMS to develop the proposed conditions 2-D model. The same mesh generation process, boundary conditions methodology, and roughness values were used to set up the model for simulation.

Model results for the proposed conditions were computed for the $Q_{1.5}$, Q_5, and Q_{100} design discharges for at least 15 hours of simulation to reach a steady state solution for analysis and for comparison to the existing conditions output. The output WSE profiles for each design discharge are shown below in Figure 31 and Figure 32.

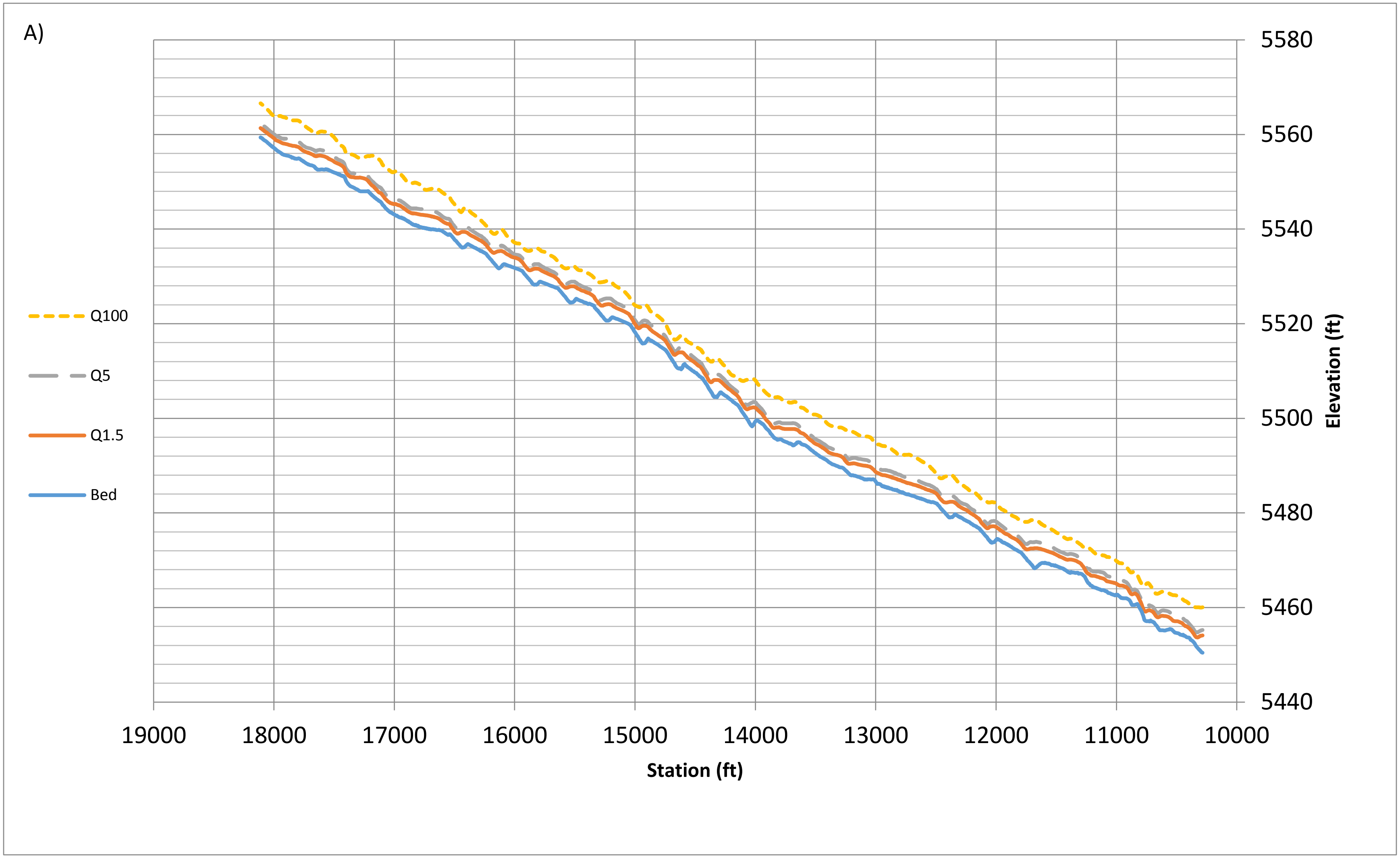


Figure 31. WSE profiles of Q1.5, Q5, and Q100 proposed conditions from SRH-2D model for upper sections of model.

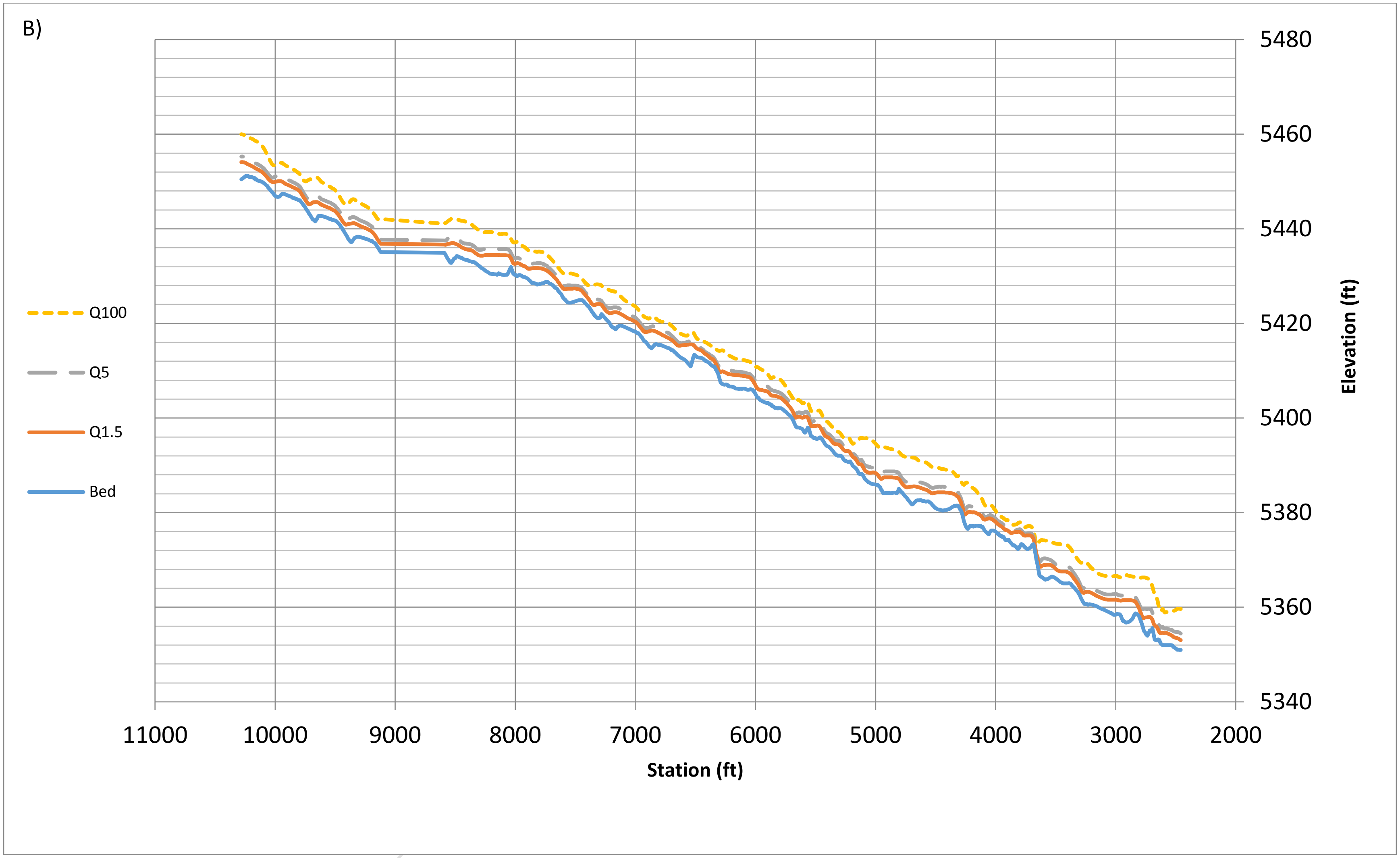


Figure 32. WSE profiles of Q1.5, Q5, and Q100 proposed conditions from SRH-2D model for lower sections of model.

Comparison of Existing vs. Proposed Models

The set-up process and simulations were matched for the existing and proposed models, with the only difference being the terrain models. The upland and floodplain regions of the terrain models were extracted from existing 1-meter LiDAR data, and in-channel detail is extracted from survey data for the existing condition model and through grading of design specifications for the proposed condition. The terrain models were inspected to meet the details necessary to capture in-channel flow variations and minimize irregular surface areas that can collect water in the model.

The outputs for the existing and proposed conditions model can be directly compared for each of the design discharges run in the simulations. The screenshots in Figure 33 show example outputs of SRH-2D for the Q1.5 flow in a lower section of South St. Vrain Creek for existing and proposed conditions (additional SRH-2D results can be found in Appendix E – SRH 2D Hydraulic Model Output). The proposed design output shows greater floodplain connection and the initiation of several side channel flow paths compared to the existing conditions model. The reconnection to the floodplain was a goal of the design which can help mitigate the concentration of flood flows and reduce overall velocities in the channel that can help bring the sediment transport balance closer to an equilibrium state as discussed in Section 8c of this report. These results are consistent with the other model outputs for the remainder of the South St. Vrain and for the Q_5 and Q_{100} design discharges as well.

Stream Power

Stream power is a measure of the stream's ability to work the bed and banks. Calculation of this metric (product of the specific weight of water, discharge, and slope, per unit channel length) provides relative information about the magnitude of work a particular flow is capable of exerting on the channel and floodplain. Unit stream power (stream power per unit channel width) was calculated using raster math within SRH-2D to find the potential unit stream power across the spatial extent of the study area. The stream power was calculated for the existing and proposed conditions models for the $Q_{1.5}$, Q_5, and Q_{100} design discharges. The results were imported into ArcGIS and converted into a continuous raster to create stream power maps for each scenario (Appendix F – Stream Power Maps).

The stream power maps for the existing and proposed conditions (as illustrated by Figure 34) show clear differences in the distribution of stream power along the channel. The proposed condition stream power is higher in certain concentrated areas but more consistently distributed along the channel. These areas of concentrated stream power are at the crest of riffle features in the proposed design. This higher stream power can help maintain riffle features and sequentially scour pools below the feature. The existing condition model displays stream power over longer stretches of river length and more sporadically placed along the channel length. This can potentially lead to discontinuity in sediment transport capacity which is evident in the sediment transport balance results for the existing conditions model.

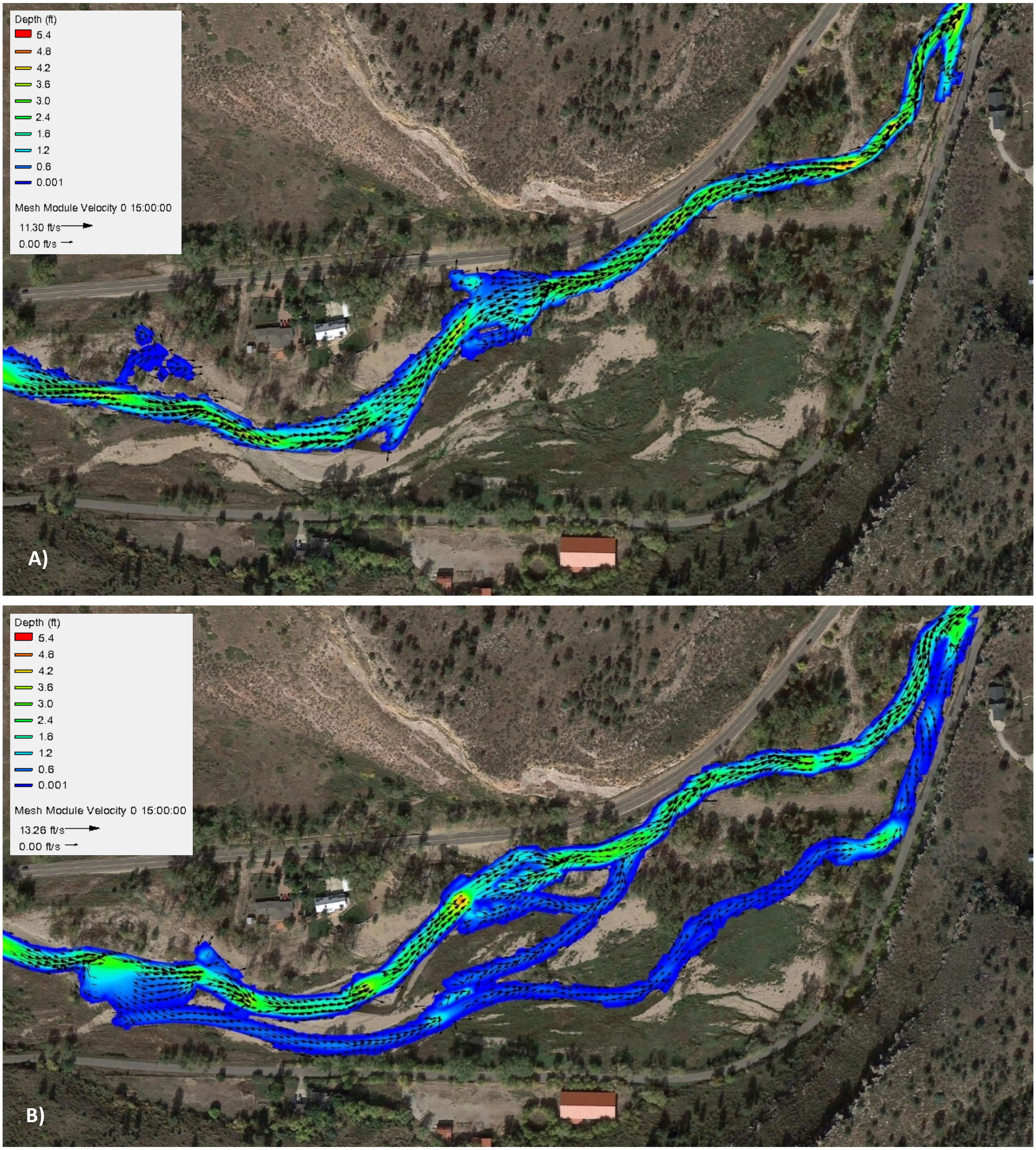


Figure 33. $Q_{1.5}$ depth contour maps with velocity vectors for A) existing and B) proposed conditions.

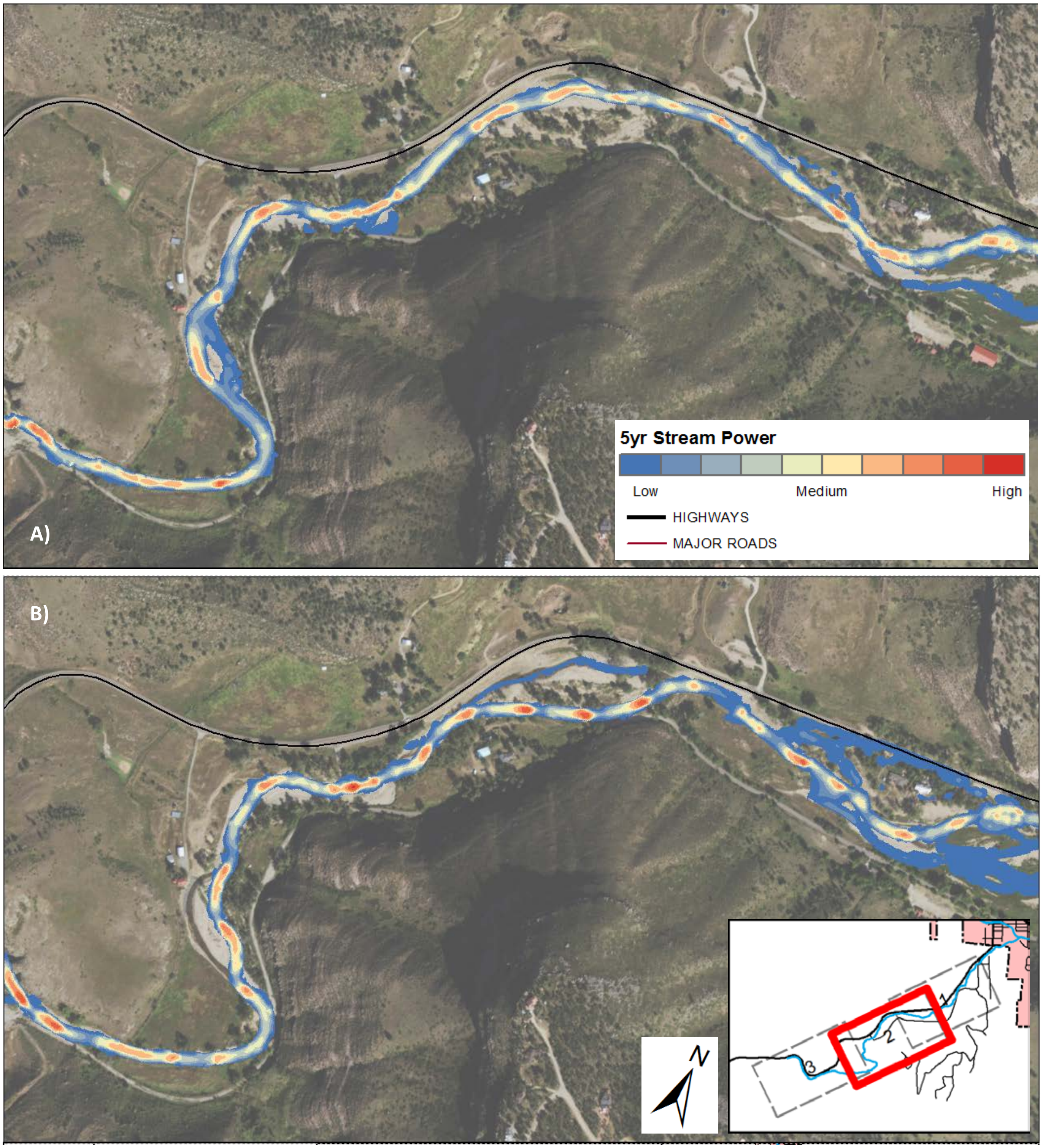


Figure 34. Example Q_5 Stream Power maps for middle section of South St. Vrain for A) existing and B) proposed conditions.

c. Supporting Electronic Files

Supporting electronic files in the form of CAD drawings along with HEC-RAS project files have been included in a CD or USB for further use.

8. Geomorphology

The geomorphic assessment is based on the River Styles stream classification methodology (Brierley and Fryirs, 2005). The goal of the method is to identify the dominant controls and spatial extent of behavior of the stream channel and floodplain in response to floods and over time following the 2013 flood. The primary product from this task was a reach-specific Stream Evolution Model (SEM) that was used to guide field sampling and provide context for the sediment transport study. Bed mobility and sediment transport modeling were also conducted in conjunction with the geomorphic assessment and classification. Results from this analysis helped to inform reach-scale geomorphic stability and trajectories, as well as site-specific restoration strategies.

a. Available Data

Planform and profile analysis and a planning-level channel migration zone (pCMZ) delineation were performed as part of the St. Vrain Creek Watershed Master Plan (Baker, 2014). South St. Vrain Creek displayed some variations in planform between 1949 and 2013 (pre-flood) for the majority of the project area, but between pre- and post-flood, large-scale variations in planform were witnessed, specifically the numerous avulsions that occurred throughout the project reach. Brief descriptions of the rapid geomorphic assessment and pCMZ mapping for the reaches applicable to this project are presented below.

The process diagram presented in Figure 35 (Otak, 2016) is a useful tool to align reach and landscape scale geomorphic variables. The diagram shows the longitudinal (i.e., downstream) progression of dominant channel process variables. At the landscape scale, the portion of the South St. Vrain covered in this project is located in alluvial valleys, with the Town of Lyons at the downstream end of the project sitting on an alluvial fan (Reach 1, SSV-02 and SSV-01 in the process diagram). Alluvial valleys and fans are areas where rapid reduction in downstream channel gradient causes the channel to deposit its sediment load and frequently shift its alignment. Over time, the position of the channel will vary vertically and horizontally across the valley, without preference for any particular location – the channel is merely adjusting to the incoming discharge and sediment load. These landforms, in more natural states, serve the function of moderating the sediment loads to downstream reaches (Cluer and Thorne, 2013). As the high energy canyon environment transitions to lower gradient alluvial valleys, South St. Vrain creek deposits its bedload, building the floodplains upon which the Town of Lyons was constructed. Much of South St. Vrain Creek has been pushed into a simplified single thread channel, with limited floodplain connection, in order to armor property and re-purpose floodplain for various land uses. The unfortunate side effect is that sediment loads transmitted downstream are increased, translating the disturbance downstream and overwhelming the capacity of the lower gradient floodplains and channels. The natural behavior of this environment was observed throughout the 2013 flood by rapid channel expansion, avulsion, and significant sediment deposition.

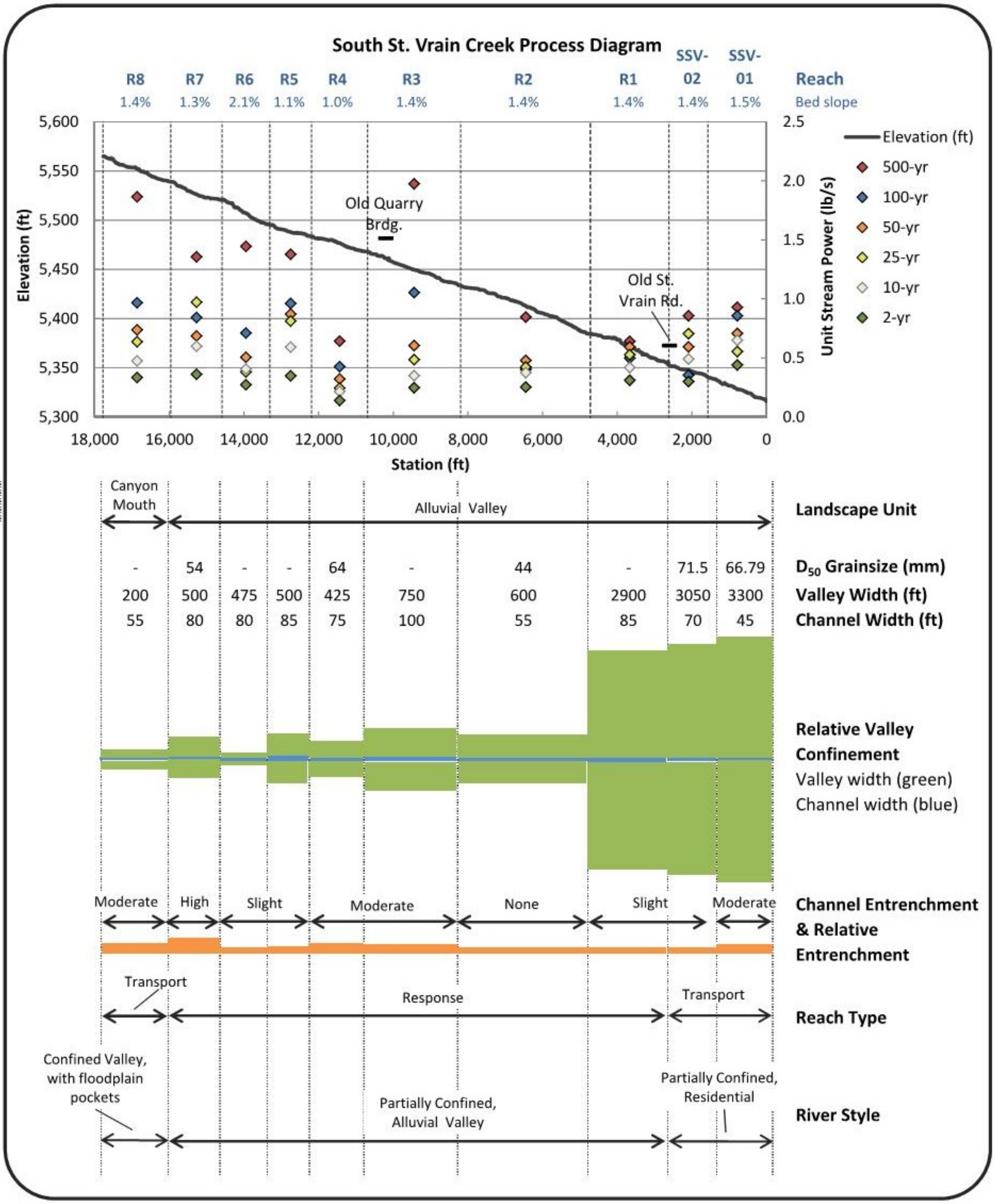


Figure 35. South St. Vrain Creek Geomorphic Process Diagram (Otak, 2016)

At the mouth of the canyon just upstream of the Andesite Quarry the valley slope significantly flattens, the channel becomes unconfined and the South St. Vrain becomes a highly depositional gravel- and cobble-dominated, pool-riffle channel. During the flood, this segment demonstrated a propensity for braiding and lateral meander migration during floods. Alteration of the corridor and response to these depositional features has resulted in channel dredging, straightening, and berming into and through the Town of Lyons where South St. Vrain joins with the North St. Vrain Creek. However, many of these channel alterations were eliminated or substantially altered as a result of the flood.

The pCMZ mapping included a much wider modern valley bottom (MVB) at the mouth of the South St. Vrain Canyon, compared to the canyon reaches upstream, to encompass the large depositional area (also identified as an avulsion hazard zone [AVZ]) which runs through the Town of Lyons, where historical and recent channel braiding is common.

In general, the South St. Vrain Creek flows from the southwest to the northeast, and passed through the more gently sloping sandstone escarpments of the South St. Vrain foothills. Development within the floodplain includes numerous diversions, irrigated pastures, low density residential structures, roads, bridges, and a rock quarry. The historic (pre-flood) morphology of South St. Vrain Creek in the project area was a meandering, single-thread channel with alternating pool/riffle sequences and occasional bedrock outcrops. The river channel had a wide, relatively flat, floodplain through the majority of this reach, and the river banks were composed of coarse alluvium, had dense riparian vegetation, and experienced relatively infrequent encroachment from engineered structures.

The post-flood channel morphology of South St. Vrain Creek in the project area is quasi-braided due to the formation of numerous islands and bars during the flood. Pool/riffle sequences are still present, but their spacing and arrangements have been minimized. The sinuosity of the channel remained unchanged but the meander planform had changed drastically at several locations throughout the reach. Channel avulsions were common, and numerous secondary and tertiary channels were established, sometimes abandoning the primary channel all together. The active channel and floodplain are both considerably wider than before, and many of the dense riparian zones have been completely eliminated.

Extensive in-channel work was performed following the flood, primarily in an effort to stabilize and repair State Highway 7 (CO-7) and to restore the previous channel form and stability, land use, and infrastructure. This work included in-channel and bank grading activities (including moving main channel flow back to pre-flood alignment in many locations), installation of bank armoring using blasted angular riprap, filling of eroded banks using native channel materials, construction of cabled large woody debris structures, and construction of a fish passage diversion structure.

b. Geomorphic Assessment

In general, the application of the River Styles framework to this Project involved a desktop analysis of available GIS data including digital elevation models of pre- and post-flood topography, geomorphic field measurements and observations, identification of River Styles, and summary and mapping of the field data.

i. Desktop Analysis

As part of the Expanded Study (Otak, 2016), a desktop analysis of the GIS data for the geomorphic assessment focused on mapping the current channel alignment, calculating channel slopes, assessing valley and channel confinement, and breaking the study area into reaches. Reach breaks were identified using the LiDAR terrain model and digital elevation model (DEM) with a difference calculation (i.e., difference between the pre-flood terrain [2011] and post-flood terrain [2013]) to identify changes in slope, valley confinement, and flood response. The junctions of major tributaries and prominent infrastructure were also used to define reach breaks.

In all, the study identified 8 reaches on the South St. Vrain Creek, within the project area (Figure 24).

ii. Field Assessment

To inform and confirm the results of the desktop analysis, a reach-scale geomorphic field assessment was conducted as part of the Expanded Study (Otak, 2016) and a site- specific assessment was conducted as part of this study during the alternative analysis phase. The assessments included an investigation of key geomorphic characteristics, such as channel geometry, channel confinement and entrenchment, bank condition and failure modes, sediment dynamics (e.g., sediment sources, bar types), and stage of stream evolution.

iii. River Styles

Based on the desktop analysis and field assessment, the reaches were classified into River Styles. This classification structure allows for the assessment and evaluation of multiple reaches that are similar in geomorphic traits, but may be geographically dispersed throughout the study area. A large emphasis is placed on valley confinement because it is a key control over the channel's ability to adjust. In addition to overall valley confinement, position within the landscape, confinement ratio (valley bottom width/channel top width), geomorphic characteristics, stage of stream evolution, and flood/stream stage behavior were used to group each of the reaches reach into appropriate River Styles.

As part of the Expanded Study (Otak, 2016), the reaches within the South St. Vrain project area were classified into two different River Styles. The key properties of each River Style are summarized below and presented in detail in Figure 36 and Figure 37.

- Confined Valley with Floodplain Pockets (CFP) *[Reach 8]*
    - Relatively steep, single thread channel with secondary channels in floodplain pockets
    - Mostly confined by valley
    - Contains some pockets of floodplain
    - Step-pool morphology (potential for pool-riffle), large wood stored in reach
- Partly-confined, Alluvial Valley (PCAV) *[Reaches 1 through 7]*
    - Moderate gradient, slightly meandering, single-thread and braided channel
    - Partly confined by valley
    - Located within the transition from the canyons through the hogbacks to the alluvial plains
    - Well-developed floodplain in places
    - Pool-riffle morphology, bar complexes, large wood jams

Confined Valley with Floodplain Pockets (CFP)

Properties:
Generally, found along meander bends in canyon settings, these reaches contain "floodplain pockets" or limited areas of less confinement where sediment may be temporarily stored and where the channel may be more alluvial in nature. Where these reaches share the valley with a road, stream banks are often heavily armored. Because this reach type tends to have a milder slope (observed average slope 1.4%) and has areas with wider valley bottoms than the confined reaches that bracket them, some upstream sediment supply may fall out of transport here aiding in channel avulsion and braiding during floods, resulting in these styles being more geomorphically sensitive and potentially hazardous. Substrate in these reaches ranges from gravel to small boulder.

Reach: 8

RIVER CHARACTERISTICS	
Valley Setting	Confined. Observed confinement ratio of 4
Channel Planform	Channel is generally single thread and straight, but floodplain pockets may contain overflow, secondary, and chute channels.
Bed Morphology	Typical: step-pool, with potential pool-riffle at lower gradient pockets; Large wood is stored in these reaches, providing channel structure, floodplain roughness and jams. Observed: step-pool and plane bed
RIVER BEHAVIOR	
Current Stream Evolution Stage	N/A
Flood Response	Confined areas generally experienced channel degradation and expansion. Floodplain pockets experienced substantial aggradation and loss of established vegetation, with lateral channel migration and avulsions.
Stage Behavior	Low flows are generally single thread, storing sediments in pools and channel margins in confined sections. In the floodplain pocket areas, sediments are stored in bar complexes, along channel margins and in pools. At bankfull flows, pool-riffle sequences and pool structures are flushed of fine sediments. At flood stage, these steep, armored reaches have excess transport capacity for all but the largest sediment (boulders), but the pocket areas are able to store flood energy and debris. Overflow channels activate and chute cutoff channels form in response to vertical accretion in the floodplain.

Figure 36. Confined Valley with Floodplain Pockets

Partially Confined, Alluvial Valley (PCAV)	
Properties: The majority of the reaches in the study area are classified under this stream style. They occupy the transition from the canyons through the hogbacks to the alluvial plain landscape units. Slopes are steep, but milder than the confined reaches (observed slopes ranged from 0.3% to 2.1%). As a result of this relative steepness, relative lack of confinement, and position downstream of confined reaches directly coupled with hillslope sediment supplies, these reaches exhibit the most geomorphic response to floods. Because these reaches experienced the most geomorphic change, many channels of this style are still evolving in response to the floods. In some cases, channels are beginning to narrow and some side channels are slowly filling in with sediment. Nevertheless, a large amount of unstable sediment ranging from sand to cobble material exists in the banks and floodplains of these reaches and will continue to be a net sediment supply to downstream reaches for some time.	
Reaches: 1 through 7	
RIVER CHARACTERISTICS	
Valley Setting	Partially confined. Observed confinement ratio ranging from 6 to 35
Channel Planform	Meandering channel with low sinuosity, braided in some areas after flood. High flow, side channels are present.
Bed Morphology	Typical: pool-riffle, boulder clusters, large wood jams and roughness elements; lateral and mid-channel bars. Observed: pool-riffle, plane bed, riffle-run, mid-channel/point/lateral bars, instream large wood.
RIVER BEHAVIOR	
Current Stream Evolution Stage	Three of the reaches in this River Style are in the Aggradation and Widening stage, three are in the Degradation and Widening stage and one is Degradational stage.
Flood Response	Flood response ranged from channel widening throughout, downstream lateral migration of meander bends, channel avulsion, and braiding.
Stage Behavior	Low flows are generally single thread with splits around mid-channel bars. Sediment is stored in bar complexes at the channel margin. Bankfull flows activate side channels and re-work in-channel bars. Large wood has significant influence on bank erosion and sediment accumulation. At flood stages, extremely high stream power values are generated before flows can spill into extensive floodplains, dissipating stream energy. Side channels are activated through inundation and channel avulsions will likely occur. Large wood is recruited into the channel as banks and terraces become undercut and may have significant influence over channel behavior as additional wood is racked up.

Figure 37. Partially Confined Alluvial Valley (PCAV)

Figure 35 illustrates the reaches of South St. Vrain Creek in the context of the surrounding reaches and the larger system. The profile of the creek is shown along with stream power values, valley and channel width measurements, valley setting characteristics, entrenchment, and river style.

c. Sediment Transport Analysis

The sediment transport analysis performed for this Project consisted of two main approaches – transport rates measured in the field and capacity-supply balance calculations based on field samples and the hydraulic models. The field measured transport rates are discussed above, Section 6.h.i. The capacity-supply balance calculations build off of the analysis and results discussed in Otak; (2016). Key points that pertain to this Project and design are summarized below as they provide the basis from which to evaluate the geomorphic effectiveness of the design developed for this Project.

i. Bed Mobility

As discussed in Otak (2016), bed mobility was calculated for all reaches of South St. Vrain Creek from the canyon mouth to the Town of Lyons. Bed mobility refers to the ability of a given flow rate and associated shear stress to mobilize sediment. Results show that reaches in South St. Vrain Creek are more readily mobilized. Figure 38 shows that through the South St. Vrain (green line, circled in red), mobile grain sizes are relatively larger than the North St. Vrain and main stem (A) and are mobilized by more frequent flows (B). This behavior is largely a response to the relatively steeper slopes finer bed observed in the South St. Vrain. This also suggests that South St. Vrain Creek is likely to undergo further adjustment.

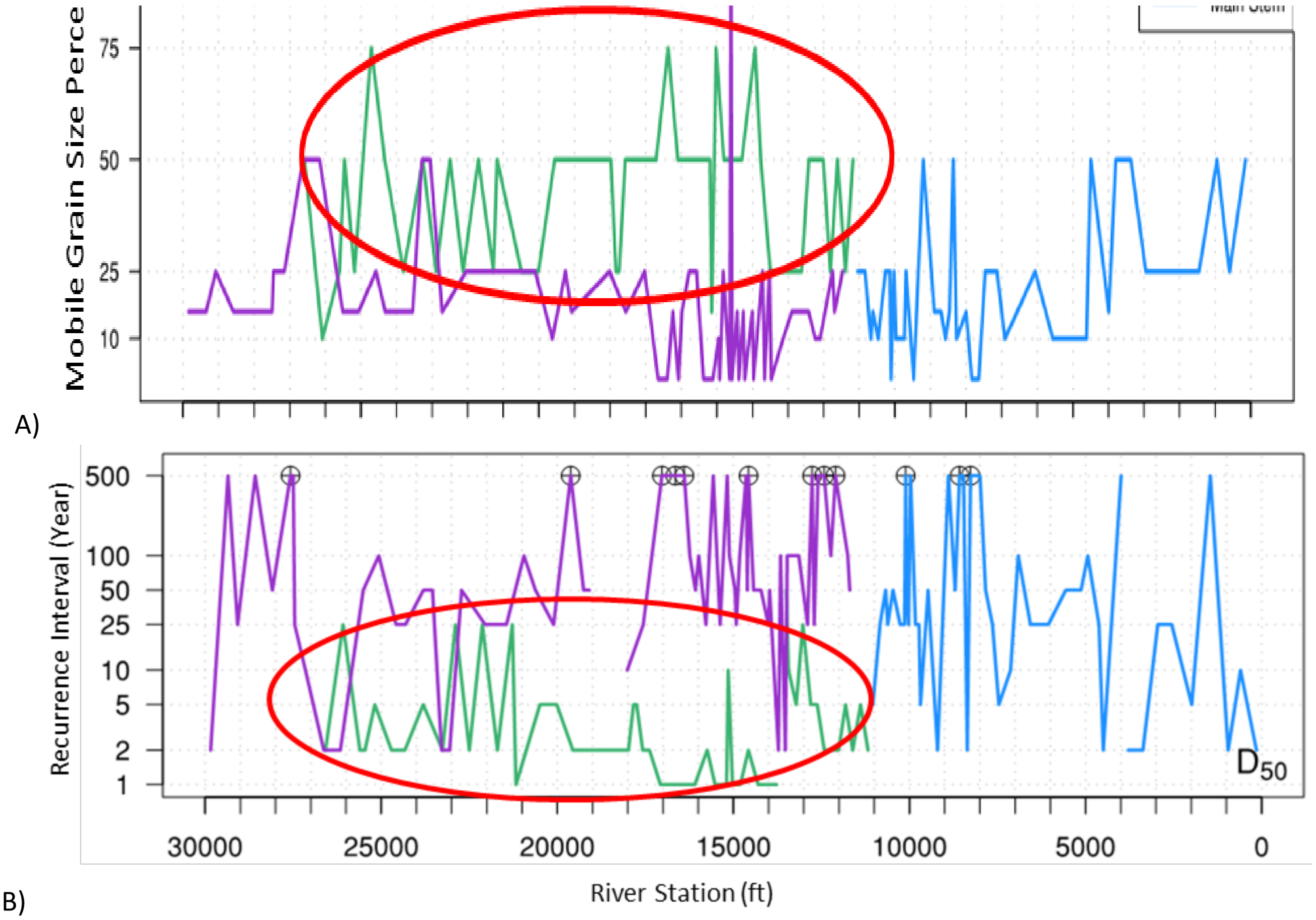


Figure 38. Bed mobility, reproduced from Otak, 2016. South St. Vrain Creek is represented by the green line.

Bed mobility calculations were not updated as part of the 30% design effort. In later stages of design, these calculations should be updated to verify the stability of various features of the design, such as riffle gradations.

ii. Sediment Transport Capacity and Balance

Sediment Transport Capacity

Sediment transport capacity is defined as the quantity and rate of sediment that a river is able to transport at a given flow. It is a function of the shear stress on the river bed and the range and relative quantities of sediment grain sizes on the bed surface available to transport downstream. Sediment transport capacity calculations rely on grain size distribution data collected by pebble counts, as described above. Grain size distributions from pebble count locations are associated with ranges of nearby modeled cross sections. Sediment transport capacity at each model cross section is then scaled based on the relative quantities of grain sizes on the bed (coarse sand, gravel, cobble, and up to small boulders). Using hydraulic modeling results and grain size distribution data, transport capacity is estimated using the Parker (1990) surface-based, bed material load equation for coarse bed rivers as described by Pitlick et al. (2009). Transport capacity is calculated for a given discharge for each grain size interval and then scaled based on the fraction of each grain size interval represented in the bed. The bed shear stress was partitioned based on the approach outlined in Pitlick et al. (2009).

Sediment transport in rivers occurs over different time frames with sand and fine gravel-sized material able to travel longer distances and more frequently over the course of a year and larger gravel and cobble-sized material travelling shorter distances more episodically. Sediment yield in a river (sediment mass exported from a reach) is driven by the entire range of competent flows. Here, transport capacity at individual design floods is considered. Coarse bed rivers such as St. Vrain Creek tend to mobilize their bed during flood flows such as the annual flood and larger. Therefore, considering sediment continuity during these flood events allows one to consider the relative rate and quantity of sediment moving in each reach. In addition to calculating sediment transport capacity at each modeled cross section, transport capacity is averaged over a reach comprised of several cross sections.

Field estimates of bedload and suspended load sediment transport rates were taken on June 14, 2016 near the Old St. Vrain Road Bridge on South St. Vrain Creek. As discussed in the Field Sediment Sampling section of this report (Section 6.h), the bedload transport rate was estimated twice using a six-inch Helley-Smith sampler for flows near bankfull discharge. The measured bedload value was compared with the sediment rating curve of bedload transport rate for three cross sections closest to the bridge, which were also produced using the existing 1-D hydraulic model (Otak, 2016). The comparison of field measurements and the sediment rating curves produced from the existing conditions model is shown below (Figure 36).

The orange line in Figure 39 is the cross section closest to the Old St. Vrain Road Bridge on the downstream side. The field measurements were sampled off of the bridge and align well with the predicted transport from the hydraulic model for this cross section. This result seems to support the validity of the transport and hydraulic models, but this comparison is recognized only to be a snapshot representation of the sediment transport at one particular flow, in a stream undergoing significant adjustment to a large disturbance event.

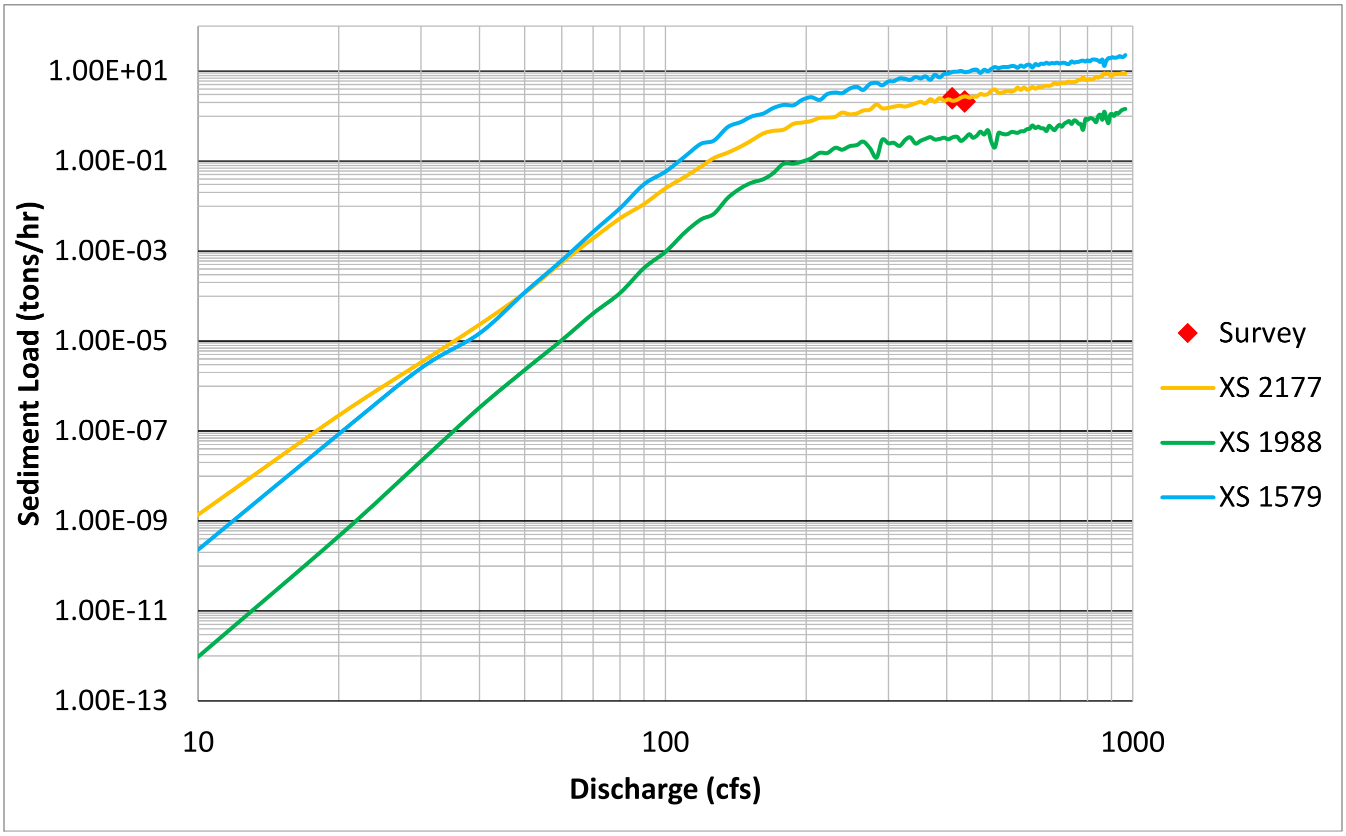


Figure 39. Sediment rating curves for three cross sections of existing conditions and field measurements of sediment transport rates.

Sediment Transport Capacity Balance

Sediment transport capacity balance is estimated as the difference between the transport capacity of an upstream reach and a downstream reach, where the upstream transport capacity is assumed to be the bed material supply to downstream. Positive transport capacity balance values in a given reach indicate that more sediment transport capacity (and more sediment) is coming from upstream than there is capacity to transport in the reach of interest. This means that this particular area may be subject to aggradation. Negative transport capacity balance values indicate degradational tendencies for a particular reach. However, some of the modeled sediment deficit will be in finer sediment classes (gravel to coarse sand), which may be supply limited. This means that the actual sediment deficit will be smaller than the modeled deficit. The large grain sizes (large gravel and cobble) encountered in the beds of South St. Vrain Creek indicates that many of these reaches are supply limited of finer sediment and have armored beds. Bed armoring tends to mitigate channel degradation.

A further simplification of this evaluation is through the use of the Capacity-Supply Ratio (CSR) presented in Soar and Thorne (2001). The CSR is calculated by dividing the bed material load transported through a reach (by a natural sequence of flow events over an extended time period) by the bed material load transported into the reach (by the same flow events over the same time period). Values greater than 1.0 indicate potential for degradation, and values below 1.0 indicate potential for aggradation. This simple metric can be used to estimate the geomorphic stability of proposed restoration designs.

Existing vs. Proposed Conditions Model Results

The sediment transport capacity and balance was calculated for the existing conditions as part of Otak (2016), and the 1-D HEC-RAS model was updated by importing the new proposed design surface using HEC-GeoRAS. The model was re-run for the Q_2 design flow to estimate the new sediment transport potential of the design to compare with existing conditions (resulting maps are presented in Appendix G – Sediment Transport Capacity and Balance Maps). Results from the SRH-2D model were used to confirm the performance of the 1D model. The existing grain size distributions and same sediment transport modeling techniques, using the Parker (1990) bedload transport equation, were utilized to estimate the reach-averaged sediment transport capacity for proposed conditions. The sediment balance was also calculated between reaches using the CSR methodology described above, and results are presented in Table 7 .

Table 7. South St. Vrain Existing vs. Proposed Capacity Supply Ratio at 2-yr Recurrence Interval Flow

Reach #	Expanded Area Reach ID	Existing CSR at Q_2	Proposed CSR at Q_2
R8	SSV-10	N/A	N/A
R7	SSV-09	N/A	N/A
R6	SSV-08	2.8	1.5
R5	SSV-07	0.4	0.4
R4	SSV-06	0.6	1.0
R3	SSV-05	1.9	1.2
R2	SSV-04	2.3	1.3
R1	SSV-03	1.2	1.2
-	SSV-02	0.2	0.4
-	SSV-01	3.4	3.1

Table 7 shows the comparison of CSR outputs for the existing and proposed conditions models for each reach. The existing condition shows great disparity of CSR values and the sediment balance oscillating widely, with reaches that tend towards aggradation and reaches that tend towards degradation due to longitudinal discontinuities in sediment transport capacity. This indicates that the channel is still adjusting to the flood impacts more so than the other segments. At larger flood events, this oscillation from oversupply and undersupply is more evident, and is to be expected as very large, infrequent flood events tend to reform channel geometry to account for this inter-reach transport capacity imbalance. As recommended in Otak (2016), restoration designs should therefore seek to achieve continuity in CSR values from reach to reach, with values close to 1. The proposed conditions output continues to display oscillation around unity; however, the CSR is closer to unity for every reach in comparison to the existing condition with the exception of Reaches 1 and 5, where the values stayed the same. This suggests that the proposed channel design can provide a more geomorphically stable configuration than the existing channel, near the effective discharge. Although the results also suggest that further refinement of the design is possible (i.e., moving all reaches closer to unity), as the watershed, as a whole, adjusts to the flood. A key aspect of the proposed design is floodplain connection, which may facilitate further adjustment of the project area without destabilizing implemented portions of the proposed design. This concept is elaborated upon further in Section 8.e Stream Evolution Model.

d. Effective Discharge

Design discharges used to size bankfull channel dimensions often rely on regional hydraulic geometry relations and/or flood frequency estimates such as the 1.5- or 2-year flood peaks. Consideration of the range of geomorphically-effective flows as well as the relationship between discharge and sediment movement can better inform channel design, especially in systems adjusting to a disturbance, such as post flood St. Vrain Creek (Doyle et al., 2007). The effective discharge, Q_{eff}, is that which transport the most sediment on average over time. It is calculated from a flow frequency distribution representing a long-term flow record (e.g., a flow duration curve) and a relationship between the flow rate and sediment transport rate for a given reach and bed material size distribution (Figure 40a; Biedenharn et al., 2000). In gravel and cobble bed rivers such as St. Vrain Creek, Q_{eff} tends to predict bankfull discharge well (Sholtes and Bledsoe, 2016). The half-yield discharge, Q_h, is the discharge associated with a cumulative 50% of sediment transport on the sorted flow (and sediment yield) record (Figure 40b). Its calculation relies on the same data as Q_{eff}. It is also a good predictor of bankfull discharge in most river types and often corresponds with Q_{eff} in coarse bed rivers.

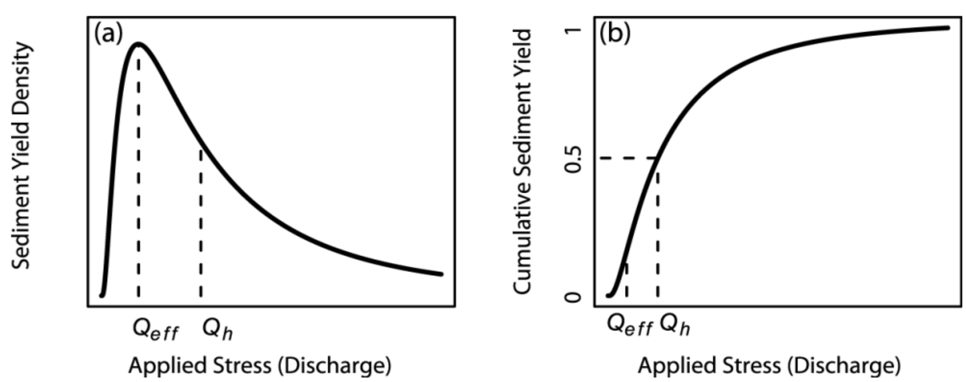


Figure 40. a) Conceptual diagram of sediment yield effectiveness curve used to calculate the effective discharge. (b) Cumulative sediment yield curve used to calculate the half-yield discharge (Otak, 2016)

These sediment yield-based design discharge metrics provide additional information about a river beyond flood frequency-based design discharges. By combining information from the entire flow regime and characteristics of the local sediment supply, these design metrics highlight other flows or a range of flows that are important to consider for sediment continuity and ultimately geomorphic stability. The effective and half-yield discharges were calculated for reaches on South St. Vrain Creek as part of the Otak; (2016).

Resulting values of Q_{eff} and Q_h on South St. Vrain Creek are similar in magnitude to each other at approximately 230 and 280 cfs, respectively (Figure 41). These values approximate the 1-year recurrence interval flood. Both Q_{eff} and Q_h are most influenced by flow variability, bed material grain size, and channel geometry. All things being equal, Q_{eff} and Q_h decrease with decreasing grain size and increasing channel entrenchment (Sholtes et al., 2014). For this study, Q_{eff} and Q_h were calculated based on post-flood channel geometry and bed material, both of which are likely still adjusting to this disturbance. In general, the flood created larger and deeper channels and brought in finer sediment from upstream bank erosion and hillslope failure. This may have resulted in producing estimates of Q_{eff} and Q_h that are smaller than their pre-flood values. This is likely the case for the South St. Vrain, which exhibits finer sediment and the most geomorphic change relative to St. Vrain and North St. Vrain Creeks.

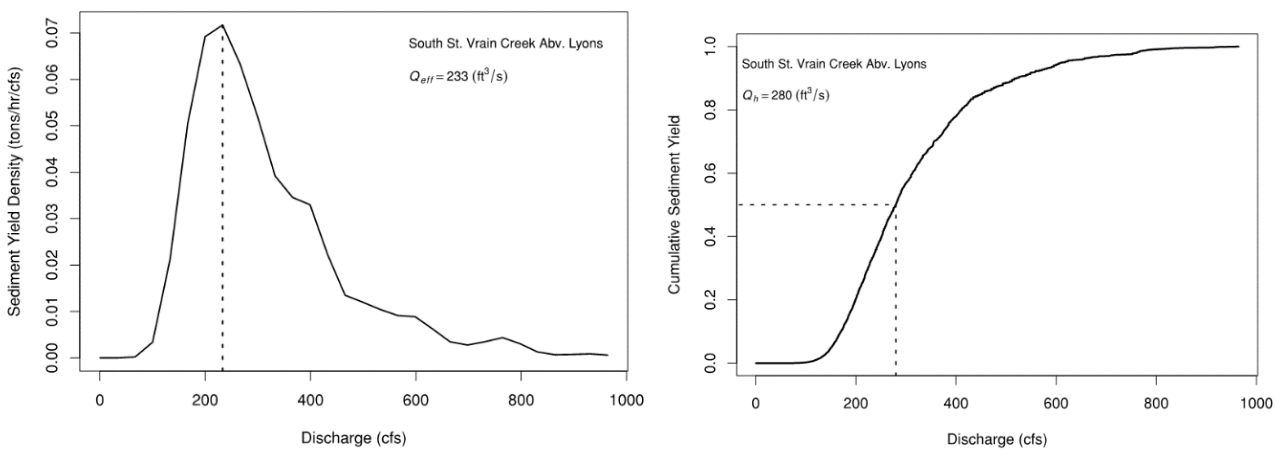


Figure 41. Effective discharge and cumulative sediment yield curves for South St. Vrain Creeks.

e. Stream Evolution Model

Otak (2016) used the stream evolution model (SEM) presented in Cluer and Thorne (2013) to define the current stage of stream evolution of each reach along the South St. Vrain. The SEM is a tool to assist with understanding morphological responses to disturbances within a stream system (e.g., base level change, channelization, alterations to the flow/sediment regimes) and can help determine channel trajectories and achievable restoration goals. A graphic showing the stages of the SEM is shown in Figure 42 below and the SEM trajectories identified in Otak (2016) are reproduced in Table 8. Additionally, the table has been updated to incorporate the projected impacts of the proposed design on the channel trajectories.

All identified stages are adjustment stages, meaning that the South St. Vrain can be expected to undergo further flood response. This table will be updated based on additional analyses of the proposed design.

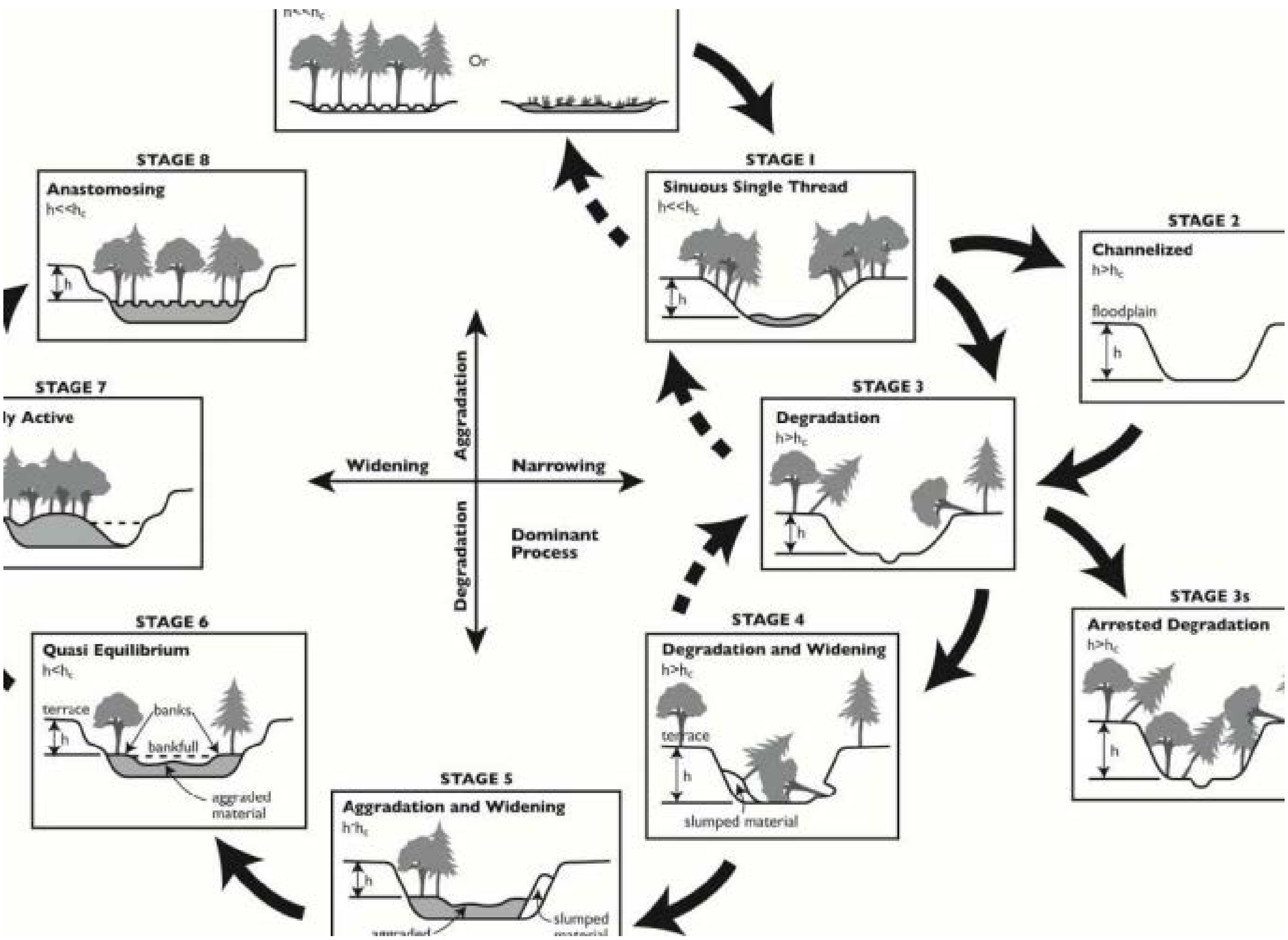


Figure 42. Stream Evolution Model (Cluer and Thorne, 2013)

Table 8. Stream evolution trajectories reproduced from Otak, 2016 and updated to reflect the proposed design.

Reach #	Expanded Study Reach ID	River Style	Current Stream Evolution Stage[a,b]	Capacity/Supply Ratio @ Q_2		Stream Evolution Trajectory[a,b]	
				Existing	Proposed	Existing	Proposed
8	SSV-10	Confined Valley w/ FP pockets	N/A	-	-	N/A	N/A
7	SSV-09	Partially Confined, Alluvial Valley	Stage 3 Degradation	-	-	Stage 4 Degradation and Widening	Stage 6 Quasi Equilibrium
6	SSV-08	Partially Confined, Alluvial Valley	Stage 5 Aggradation and Widening	2.8	1.5	Stage 3 Degradation	Stage 4 Degradation and Widening
5	SSV-07	Partially Confined, Alluvial Valley	Stage 4 Degradation and Widening	0.38	0.4	Stage 5 Aggradation and Widening	Stage 6 Quasi Equilibrium
4	SSV-06	Partially Confined, Alluvial Valley	Stage 5 Aggradation and Widening	0.59	1.0	Stage 6 Quasi Equilibrium[c]	Stage 6 Quasi Equilibrium
3	SSV-05	Partially Confined, Alluvial Valley	Stage 4 Degradation and Widening	1.9	1.2	Stage 5 Aggradation and Widening[c]	Stage 7 Laterally Active
2	SSV-04	Partially Confined, Alluvial Valley	Stage 4 Degradation and Widening	2.3	1.3	Stage 5 Aggradation and Widening[c]	Stage 7 Laterally Active
1	SSV-03	Partially Confined, Alluvial Valley	Stage 5 Aggradation and Widening	1.2	1.2	Stage 6 Quasi Equilibrium[c]	Stage 3s Arrested Degradation

Notes: [a] Based on (Cluer & Thorne, 2013)
[b] N/A=stream evolution model not applicable (e.g., step-pool reaches do not necessarily follow the same disturbance model)
[c] Potential for reach to move into Stage 3 - Degradation

The canyon opens up to the alluvial valley upstream of the Town of Lyons (R7 through R1), where alluvial valley refers to a valley bottom that has been formed over time by the river itself. This means that the channel footprint has occupied every part of these valleys during some point in the modern geologic era and is referred to as high geomorphic hazard areas with the potential for larger channel adjustments during large flood events. This concept was made evident by the river's response to the flood. A combination of relatively large slopes and a rapid reduction in stream power from the steeper and confined reaches upstream resulted in vast amounts of sediment falling out of transport along these reaches and massive lateral channel migration and avulsion. In many cases in these reaches, channels are relatively unconfined and not entrenched, and as such, they moved from one side of the valley to the other. Channels widened and developed multiple threads. As summarized on

Table 8, stream evolution trajectories for these reaches along South St. Vrain Creek vary widely from Degradation to Aggradation/Widening to Quasi Equilibrium (with the potential to move back into the Degradation stage).

The Hall Meadows reaches (R2 and R3) were evaluated as Stage 4 – Degradation and Widening of the SEM. However, the application of the SEM to these reaches is anything but straightforward – at various locations throughout the reaches, properties of several stages of the SEM (Stage 3 – Degradation, Stage 5 – Aggradation and Widening) are evident, obscuring the application of the simplifying SEM model. Ultimately, Stage 4 was chosen for both reaches because the channel remains mostly disconnected from overflow channels and the floodplain, has actively eroding banks and poorly formed hydrogeomorphic units that are likely to be re-worked or destroyed upon receipt of flows approaching the effective discharge rate (~2-year discharge, ~230 cfs) or even the annual flood event. Both reaches (R2 and R3) are likely to undergo substantial geomorphic adjustment in response to a net evacuation of sediment as the river seeks to establish equilibrium slopes and channel dimensions. However, the determination of the geomorphic trajectory is obscured by the issues noted above, wildly fluctuating balance calculation results through the range of design flows, and an uncertain sequence of flow events (meaning, while flow sequences are always uncertain, mild flow events will moderate geomorphic adjustment, while larger flow events may cause widespread destabilization). Fine sediments (i.e., sand) are prevalent throughout the reach which has the effect of increasing the geomorphic sensitivity of the reach, whereby small differences in shear stress produce large changes in transport capacity. At the effective discharge rate, CSR values suggest that both reaches are degradational. However, locations containing slackwater near the channel margins and substantial sediment supply suggest that the stream may begin to deposit material, narrowing the wetted channel, and building banks and functional geomorphic units. In light of these seemingly contradictory pieces of information and the fact that several restoration projects have been implemented and/or are forthcoming through the project reach, these reaches are assigned a trajectory of Stage 5 Aggradation and Widening with a significant chance of regressing into another round of degradation (Stage 3).

Considering the impact of the design on the re-calculated CSR values, the trajectories of many of the reaches approach more stable SEM stages. As part of the next stages of design, realignment through reach 7 should be fine-tuned to bring the channel to a more stable stage. Under the design condition, the CSR value for Reach 6 (1.5) has been moved much closer to stable (i.e., 1), but remains slightly degradational. Despite a highly degradational CSR value for Reach 5, the reach is confined and the proposed grade control (i.e., hardened riffles), combined with the proposed upstream work will limit channel incision moving the channel to a quasi-equilibrium state. The proposed grading in Reach 4 will ensure the channel moves to the more stable quasi-equilibrium stage.

Reaches 2 and 3 encompass the larger of the two EWP projects, EWP #1. In both cases, the CSR values are brought closer to 1, but remain slightly degradational at 1.2 for Reach 3 and 1.3 for Reach 2. Given the limitations of the transport method, a slight trend toward degradation is most likely acceptable. A significant supply of mobile sediment remains on the channel margins upstream of Reaches 2 and 3 (as well as the project site) and is readily mobilized during rainfall and higher runoff events. This increased supply will help limit the degradation in the project reaches. Essentially, by having a slightly degradational CSR, the design is anticipating additional watershed response to the flood.

Reach 1 contains EWP #2, and upon further study performed as part of this project, is determined to be moved to the end stage 3s – Arrested Degradation. The reach has significant anthropogenic controls from the bridge, Longmont diversion and berm along the southern channel margin. Further degradation will be limited by these anthropogenic features, along with the extensive bedrock observed in the reach.

9. Aquatic and Terrestrial Species Habitat Requirements

Aquatic and terrestrial species habitat requirements were completed by ERO, THK and Blue Mountain Consultants.

a. Aquatic Species Habitat Requirements

i. Fish Species Evaluated

Below is a list of the species of concern throughout reach.

- Brown Trout (*Salmo trutta*)
- Rainbow Trout (*Onchorhyncus mykiss*)
- Longnose Sucker (*Catastomus catastomus*)
- Longnose Dace (*Rhinichthys cataractae*)

No T&E fish species present in Project reach (per Matt Kondratieff, CP&W)

ii. Fish Passage Aspects

There are no major fish passage issues in the project reach. However, while adult salmonids can likely negotiate the Longmont Pipeline check dam, it would deter upstream movement for native non-game species (e.g. long-nose dace and long-nose sucker). Juvenile trout may also have difficulty moving upstream past this diversion structure. This effect can result in artificial concentrations of both predator and prey fish, resulting in altered rates of predation. Longitudinal movement for fishes is important (at the very least, seasonal passage). Additionally, these diversions alter sediment transport and elevate geomorphic risk. In the end, the diversion poses no barrier to adult brown and rainbow trout movement.

- Option 1 – Do nothing. Least costly, but the check dam does negatively impact sediment transport and some fish movement, as it has historically done.
- Option 2 – Install a sand sluice on left bank of the check dam. This action would improve sediment transport through reach and allow upstream passage at certain times of the year for juvenile trout and perhaps suckers and dace. Cost and feasibility are dependent on elevation of Longmont Diversion through the check dam.
- Option 3 – Move the diversion upstream and remove the check dam all together. This is the best solution for both the physical and biological function of river reach, but is the costliest.

iii. Channel Function

The flood negatively impacted the pattern, profile and dimension of the South St. Vrain Creek through the project reach. Valley width is a major factor in determining what could, or should, be done in the project reach. The highway, infrastructure and private property concerns limit the potential for restoration at certain "choke" points in the valley, while locations with ample belt width could certainly benefit, both physically and biologically, from appropriate restoration techniques.

Factors to consider when developing conceptual design are:

- Continuity – biological access up and downstream over a range of flows
- Conveyance – account for water and sediment transport including:
    - Capacity – sediment load
    - Competence – particle size
- Connectivity – a well-connected floodplain will dissipate energy at flows greater than bankfull and promote a robust riparian community that will enhance the sustainability of any restoration.

- Cover – instream cover for fish, primarily trout. Overhead and near-bank cover will improve as the riparian vegetation recovers.
- Carbon – long term and short term carbon sources. The flood turned the river corridor into a cobble field but the cottonwood/willow/alder communities are coming back strong. The project should encourage the natural recovery where possible, and assist the areas that are lagging. Where river pattern requires realignment, toewood/rootwads should be used. The wood provides an excellent long term carbon source and when installed properly should be more than sufficient to provide structural stability until the riparian recovers.

A multi-stage channel with a well-developed inner berm would be appropriate for this reach. The inner berm would enhance the biological continuity, particularly at low flows, and provides about 15% greater efficiency in bedload transport. The flood removed much of the substrate fines but subsequent flows will continue to add that component back into the system. Between the bedrock outcrops and the coarseness of the substrate, large rock grade control, outside of riffle crest, will not be necessary.

b. Terrestrial Species Habitat Requirements

ERO Resources Corporation (ERO) conducted a site visit on July 22, 2016 and assessed the project area for terrestrial species habitat. The sections below summarize terrestrial federally threatened and endangered species; state and local threatened, endangered, and species of concern; migratory birds and raptors; and other wildlife potentially found in the project area. Where applicable, recommendations for future actions are provided based on the current site conditions and federal, state, and local regulations.

i. Federally Threatened and Endangered Species

On July 22, 2016, ERO assessed the project area for suitable habitat for federally listed threatened and endangered species protected under the Endangered Species Act (ESA). The project area does not fall within U.S. Fish and Wildlife Service (Service) habitat or survey guidelines for the majority of the species listed by the Service as potentially being present in Boulder County (Table 9). Because the project area falls within survey guidelines for Preble's meadow jumping mouse (*Zapus hudsonius preblei* or Preble's) and Ute ladies'-tresses orchid (*Spiranthes diluvialis* or ULTO), ERO assessed the project area for suitable habitat for both species. ERO also assessed the project area for Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis* or CBP), a federally threatened species that has been documented in northern Colorado.

The proposed Project would not directly impact the Canada lynx, Mexican spotted owl, or greenback cutthroat trout because of the lack of potentially suitable habitat in the project area. The interior least tern, piping plover, whooping crane, pallid sturgeon, and western prairie fringed orchid occur in Nebraska within the Platte River floodplain, and are potentially affected by water depletions from the Platte River watershed. Projects that include activities that deplete water in the South Platte River, such as diverting water from a stream or developing new water supplies, could potentially affect these species and consultation with the Service may be required.

Table 9. Federally threatened and endangered species potentially found in Boulder County or potentially affected by projects in Boulder County.

Common Name	Scientific Name	Status*	Habitat	Potential Habitat Present
		Mammals		
Canada lynx	*Lynx canadensis*	T	Climax boreal forest with a dense understory of thickets and windfalls	No
Preble's meadow jumping mouse	*Zapus hudsonius preblei*	T	Shrub riparian/wet meadows	Potential
		Birds		
Interior least tern**	*Sterna antillarum athalassos*	E	Sandy/pebble beaches on lakes, reservoirs, and rivers	No habitat and no depletions anticipated
Mexican spotted owl	*Strix occidentalis*	T	Closed canopy forests in steep canyons	No
Piping plover**	*Charadrius melodus*	T	Sandy lakeshore beaches and river sandbars	No habitat and no depletions anticipated
Whooping crane**	*Grus americana*	E	Mudflats around reservoirs and in agricultural areas	No habitat and no depletions anticipated
		Fish		
Greenback cutthroat trout	*Oncorhynchus clarki stomias*	T	Cold, clear, gravel headwater streams and mountain lakes	No
Pallid sturgeon**	*Scaphirhynchus albus*	E	Large, turbid, free-flowing rivers with a strong current and gravel or sandy substrate	No habitat and no depletions anticipated
		Plants		
Colorado butterfly plant	*Gaura neomexicana* ssp. *coloradensis*	T	Subirrigated, alluvial soils on level floodplains and drainage bottoms between 5,000 and 6,400 feet in elevation	Yes
Ute ladies'-tresses orchid	*Spiranthes diluvialis*	T	Moist to wet alluvial meadows, floodplains of perennial streams, and around springs and lakes below 6,500 feet in elevation	Potential
Western prairie-fringed orchid**	*Platanthera praeclara*	T	Mesic and wet prairies, and sedge meadows	No habitat and no depletions anticipated

*T = Federally Threatened Species, E = Federally Endangered Species.
**Water depletions in the South Platte River may impact the species and/or critical habitat in downstream reaches in other counties or states.
Source: Service 2016.

Potential habitat for Preble's, CBP, and ULTO is generally more prevalent within areas across the Front Range. Because these species are more likely to be addressed by counties and regulatory agencies such as the US Army Corps of Engineers, a more detailed discussion is provided below.

Preble's Meadow Jumping Mouse

Species Background

Preble's Meadow Jumping Mouse (Preble's) was listed as a federally threatened subspecies under the ESA in May 1998 (63 FR 26517 (May 13, 1998)). On July 9, 2008, the Service issued a final ruling to amend the listing for Preble's. The amended final rule states that Preble's is a distinct subspecies and will remain listed as a federally threatened species in Colorado. The Service's amended final rule states that because of development along Colorado's Front Range, the long-term survival of the subspecies in Colorado remains threatened. The Service also announced that Preble's will not remain protected in Wyoming because threats from development and other habitat-altering practices are not prevalent. On August 5, 2011, the Service reinstated ESA protection for Preble's in Wyoming because of interpretations regarding the definition of a threatened species being "in danger of extinction throughout all or a significant portion of its range," which was invalidated by two court rulings. The Service requested that the courts remand the Preble's decision back to the Service. The court granted the request and the Service reinstated the listing of Preble's as a federally threatened species in Wyoming. Previous critical habitat designation in Wyoming was not reinstated. In 2011, two petitions to delist Preble's were filed to the Service. In May 2013, the Service completed a 12-month finding in response to the petitions and ruled that delisting was not warranted at the time. Therefore, Preble's remains protected under the ESA.

Habitat

Along Colorado's Front Range, Preble's is found below 7,600 feet in elevation, generally in lowlands with medium to high moisture along permanent or intermittent streams. Preble's typically inhabits areas characterized by well-developed plains riparian vegetation with relatively undisturbed grassland and a water source nearby. Previous studies have suggested that Preble's may have a wider ecological tolerance than initially thought, and that the requirement for diverse vegetation and well-developed cover can be met under a variety of circumstances (Meaney et al. 1997). Radio-tracking studies conducted by the Colorado Parks and Wildlife (CPW) have documented Preble's using upland habitat adjacent to wetlands and riparian areas (Shenk and Sivert 1999). Additional research by CPW has suggested that habitat quality for Preble's can be predicted by the amount of shrub cover available at a site.

Critical Habitat

In June 2003, the Service designated critical Preble's habitat (50 Code of Federal Regulations (CFR) 17). Critical habitat consists of specific areas that are designated for threatened and endangered species recovery. Critical habitat was designated along portions of the North Fork of the Cache la Poudre and Cache la Poudre Rivers in Larimer County, and along the South Platte River in portions of Douglas County. Critical habitat was also designated along portions of Ralston Creek in Jefferson County and Buckhorn Creek in Larimer County (Service 2003). In 2009, the Service proposed revision of designated Preble's critical habitat (74 FR 52102; October 8, 2009). On December 14, 2010, the Service issued a final rule for revised critical habitat designation (50 FR 78430; December 14, 2010). The newly revised critical habitat includes 8 miles of streams within the South Boulder Creek watershed south of the project area limits and along the Cache la Poudre River north of the project area in Larimer County. While there is no federal designated Critical Habitat, it should be noted that this area is designated as a Mouse Management Area under the Boulder County Comprehensive Plan - Environmental Resources Element map of Preble's Habitat Conservation Areas. This map was adapted from the federal Preble's Science Team.

Potential Habitat within the Project Area

The project area is within an area mapped as Preble's overall range by the Colorado Natural Diversity Information System (NDIS 2016). Portions of the project area contain multilayered shrub habitat consisting of sandbar willow (*Salix exigua*), American plum (*Prunus americana*), chokecherry (*Prunus virginiana*), and snowberry (*Symphoicarpos albus*), which is suitable habitat for Preble's. Trapping surveys have been conducted in previous years (1996, 2005 and 2015 BCPOS; Meaney 2005) in the project area. Trapping surveys conducted in 1996 and 2015 within the project area did not result in any Preble's captures; however, in 2005 Preble's was captured in the project area (Meaney 2005).

Recommendations

Riparian habitat within the project area provides adequate habitat for Preble's. Areas currently devoid of vegetation due to sedimentation and scour from the 2013 flooding may be enhanced through construction of secondary channels, or other areas that are low enough to provide adequate hydrology for wetland and riparian vegetation. ERO recommends that Boulder County consult with the Service prior to construction activities to discuss the level of Section 7 consultation required for the Project.

Ute ladies'-tresses Orchid

Species Background

Ute ladies'-tresses Orchid (ULTO) is federally listed as threatened. Once thought to be fairly common in low-elevation riparian areas in the interior western United States, ULTO is now rare (Service 1992a).

In Colorado, the Service requires surveys in areas of suitable habitat on the 100-year floodplain of the South Platte River, Fountain Creek, and Yampa River, and their perennial tributaries; or in any area with suitable habitat in Boulder and Jefferson Counties (Service 1992a). ULTO does not bloom until late July to early September (depending on the year) and the timing of surveys must be synchronized with blooming (Service 1992b).

Habitat

ULTO occurs at elevations below 6,500 feet in moist to wet alluvial meadows, floodplains of perennial streams, and around springs and lakes where the soil is seasonally saturated within 18 inches of the surface. Generally, the species occurs where the vegetative cover is relatively open and not overly dense or overgrazed.

Potential Habitat within the Project Area

The soils in the project area consist primarily of sand and cobble, which is typically associated with ULTO (Service 1992a). The wetland vegetation found within the project area is dominated by broadleaf cattail, common threesquare, Baltic rush, and dense stands of reed canarygrass and Emory's sedge. Many of the plants in wetland areas within the project area are likely too dense for ULTO establishment. Additionally, there is no known seed source within the South St. Vrain Creek watershed. ULTO surveys have been conducted in previous years, and no ULTO have been found during survey efforts (Hirt 2016).

Recommendations

The project area falls within the survey guidelines for potential ULTO habitat because of the presence of wetland vegetation and because the project area is in Boulder County. ERO recommends coordination with the Service prior to construction requesting the site be cleared from a presence/absence survey for ULTO due to the lack of suitable habitat and known populations. If the Service clears the site from a presence/absence survey, no further consultation would be needed for ULTO.

Colorado Butterfly Plant

Species Background

The Colorado Butterfly Plant (CBP) is federally listed as threatened and is found in small areas in southeastern Wyoming, western Nebraska, and north-central Colorado (Service 2004). The CBP flowers from June to September and produces fruit from July to October (Spackman et al. 1997). The Service has not established formal survey guidelines for CBP, but has indicated that areas similar to, and slightly drier than, ULTO habitat should be assessed.

Habitat

The CBP is a short-lived perennial herb found in moist areas of floodplains. It occurs on sub irrigated alluvial soils on level or slightly sloping floodplains and drainage bottoms at elevations from 5,000 to 6,400 feet. Colonies are often found in low depressions or along bends in wide, active, meandering stream channels that are periodically disturbed. Historically, the main cause of disturbance was probably flooding (Service 2004).

Potential Habitat within the Project Area

The project area is located outside of the known geographic range of CBP, which includes portions of Larimer and Weld Counties. While potential habitat exists within portions of the project area, no known populations or seed sources are known to occur within the South St. Vrain Creek watershed.

Recommendations

ERO recommends coordination with the Service prior to construction requesting the site be cleared from a presence/absence survey for CBP due to the lack of suitable habitat and known populations. If the Service clears the site from a presence/absence survey, no further consultation would be needed for CBP.

ii. State Threatened, Endangered, and Species of Concern

The project area contains potential habitat for threatened, endangered, and species of special concern protected under State Statute 33. Although State Statute 33 prohibits the take, possession, and sale of a state-listed species, it does not include protection of their habitat. The state lists several threatened, endangered, and species of special concern that are known to occur or have the potential to occur in Boulder County and are presented in Table 10.

Table 10. State threatened, endangered, and species of concern potentially found in Boulder County or potentially affected by projects in Boulder County.

Common Name	Scientific Name (Status*)	Status	General Colorado Range	Suitable Habitat Present
Mammals				
Black-tailed prairie dog	*Cynomys ludovicianus*	SC	Eastern plains/urban	No
Northern pocket gopher	*Thomomys talpoides* ssp. *macrotis*	SC	Eastern Colorado – Douglas/Arapahoe Counties, northern El Paso County	No
Northern river otter	*Lontra canadensis*	ST	Colorado, Gunnison, Piedra, and Dolores Rivers and possibly the Poudre River	No
Townsend's big-eared bat	*Corynorhinus townsendii pallescens*	SC	Western and mountain portions of eastern Colorado	Potential
Birds				
American peregrine falcon	*Falco peregrinus anatum*	SC	Open spaces associated with high cliffs and bluffs overlooking rivers and coasts	Potential
Bald eagle	*Haliaeetus leucocephalus*	SC	Open water and rivers; large trees for nesting and roosting	Yes
Ferruginous hawk	*Buteo regalis*	SC	Northwestern, eastern Colorado; open grasslands and shrub steppe communities	No
Long-billed curlew	*Numenius americanus*	SC	Southeastern Colorado	No
Western burrowing owl	*Athene cunicularia*	ST	Grasslands, shrublands, and deserts with ground squirrels	No
Amphibians and Reptiles				
Common garter snake	*Thamnophis sirtalis*	SC	Eastern base of the Front Range in wetlands and ponds	Yes
Northern leopard frog	*Rana pipiens*	SC	Eastern Colorado wetlands	Yes

* ST = Colorado Threatened Species, SC = Colorado Species of Special Concern.
Source: CPW 2016.

Townsend's Big-Eared Bat

Of the species listed in Table 10, the Townsend's big-eared bat (TBEB), American peregrine falcon, bald eagle, common garter snake, and northern leopard frog have potential to occur in the project area. The black-tailed prairie dog, northern pocket gopher, northern river otter, ferruginous hawk, long-billed curlew, and western burrowing owl would not be affected by the proposed Project because the project area is outside of the species' known range, suitable habitat is not present, or potential habitat would not be impacted by the Project and, therefore, these species are not discussed in the following sections.

Species Background

The TBEB is currently a species of special concern in Colorado (CPW 2016). The Colorado National Heritage Program (CNHP) ranks TBEB as S2, imperiled in the state because of rarity due to very restricted range, few populations, steep declines in population, or other factors making it vulnerable to extirpation. Threats to the species includes disturbance of roosting areas (Sherwin et al. 2000; Schmidt 2003).

The TBEB forages primarily for insects over water or along the margins of vegetation (Fitzgerald et al. 1994; Armstrong et al. 2011). The TBEB is found in the western United States, where it occurs in Idaho, Wyoming, Colorado, New Mexico, southern Kansas, Oklahoma, and Texas, with scattered populations in Arkansas, Missouri, Kentucky, Virginia, and West Virginia. In Colorado, the TBEB is found over most of the western two-thirds and the extreme southeastern parts of the state to elevations of approximately 9,500 feet (2,900 meters) (Armstrong et al. 2011). The abundance of the TBEB in Colorado is unknown.

Habitat

The TBEB uses a variety of habitats including coniferous forest, desert shrublands, piñon-juniper woodlands, and pine forests (Jones et al. 1983). Most of the accounts of this species focus on requirements of suitable roosts, which include caves, mines, rocky ledges, overhangs, buildings, and bridges (Sherwin et al. 2000; Adam and Hayes 2000; Keeley and Tuttle 1999; Jagnow 1998). Throughout this species' range, it seems to be common in mesic habitats with coniferous and deciduous forests (Humphrey and Kunz 1976) or associated with dry ponderosa pine and Douglas fir (Holroyd et al. 1994).

This species was identified in coniferous forests s within Hall Ranch in 2015 (Adams 2015). Riparian areas and rock outcrops within the project area contain potential foraging and roosting habitat for the TBEB and some rock outcrops that potentially housed this species were identified by Adams (2015) in coniferous areas. No TBEB were identified in riparian areas along the St. Vrain. An abandoned quarry and some structures in the western portion of the project area could provide potential roosting habitat for the TBEB.

Recommendations

The proposed Project is unlikely to adversely affect the TBEB given the lack of suitable roost sites in areas where Project activities would occur. The proposed Project would not affect rocky outcrops, coniferous forests, or abandoned buildings within the project area; therefore, no action is recommended for the TBEB.

American Peregrine Falcon

Species Background

The American peregrine falcon is currently a species of special concern in Colorado (CPW 2016). The peregrine falcon once ranged throughout North America (Service 1984). In 1970, after significant population declines due largely to the effects of organochloride pesticides (such as DDT) in the environment, the falcon was federally listed as endangered. In 1999, however, after a considerable population increase, the falcon was removed from listing under the ESA. Additional causes for the sharp population decline are also believed to include low breeding densities and reproductive isolation and reduced availability of foraging habitat and avian prey (Finch 1992). Peregrines remain protected under the Migratory Bird Treaty Act (MBTA) and the CPW recommends applying spatial and seasonal buffers around active nest sites.

Peregrines primarily prey on medium-size birds including jays, doves, flickers, shorebirds, and songbirds. Preferred hunting areas include cropland, meadows, river bottoms, marshes, and lakes that attract abundant bird life. Peregrines may travel up to 29 kilometers (17 miles) from nesting cliffs to hunting areas (Service 1984). Peregrine falcons can be found in downtown Denver, along the foothills, and all the way to the western border of Colorado. Peregrine falcons mate for life and usually breed in March and April.

Habitat

Peregrines use a variety of habitats for nesting, foraging, migrating, and wintering. Nest sites are usually constructed on rugged, remote cliffs generally from 60 to more than 100 meters (200 to 300 feet) in height with nearby water sources where prey is abundant (Service 1984; Craig and Enderson 2004). As peregrine populations have expanded, they have accepted cliffs as low as 30 meters (100 feet) as suitable nesting sites (Craig and Enderson 2004). In the Rocky Mountains, nests can be found at elevations up to 3,600 meters (11,811 feet) (White et al. 2002). Potential peregrine falcon habitat exists within some of the rocky outcrops located around the project area. No known nests occur in the project area.

Recommendations

No known peregrine falcon nests are known to occur in the vicinity of the project area. Additionally, proposed Project activities would not affect potential peregrine falcon habitat; therefore, no action is necessary regarding peregrine falcons.

Bald Eagle

Species Background

The bald eagle is currently a species of special concern in Colorado (CPW 2016). The bald eagle is a large North American bird with a historical distribution throughout most of the U.S. The bald eagle was listed as a federally endangered species in 1978. Population declines were attributed to habitat loss, the use of organochloride pesticides, and mortality from shooting. Since its listing, the bald eagle population has been increasing. On July 9, 2007, the Service announced the delisting of the bald eagle from the threatened and endangered species list (Service 2007). Although removed from the list of threatened and endangered species, the bald eagle continues to be protected under the MBTA and Bald and Golden Eagle Protection Act.

Habitat

Most bald eagle nesting in Colorado occurs near lakes or reservoirs or along rivers. Typical bald eagle nesting habitat consists of forests or wooded areas that contain tall, aged, dying, and dead trees (Martell 1992). Bald eagles seek aquatic habitat for foraging and typically prefer fish, although they also feed on birds, mammals, and carrion, particularly in winter (Buehler 2000; Sharps and Uresk 1990). Prairie dogs provide a major food resource for bald eagles wintering along the Colorado Front Range (Environmental Science and Engineering 1988).

CPW recommends that construction activities remain at least ½ mile from active bald eagle nests. One historical bald eagle nest occurs within ½ mile of the project area in Lyons. The status of this nest is not known according to the NDIS (2016). The project area occurs within an area mapped as bald eagle winter range (NDIS 2016). Winter range typically refers to those areas where bald eagles have been observed between November 15 and April 1 (CPW 2014).

Recommendations

For any work conducted within areas mapped as bald eagle winter range, ERO recommends contacting the local CPW district manager to request concurrence that the proposed Project would not likely affect wintering bald eagles. Because of the low level of human disturbance in the project area and surrounding area, ERO biologists conclude the Project activities would not likely disturb eagles potentially using the winter range.

Common Garter Snake

Species Background

The common garter snake is currently a species of special concern in Colorado (CPW 2016). The subspecies of the common garter snake that occurs in Colorado is the red-sided garter snake (*Thamnophis sirtalis* ssp. *parietalis*), which is characterized by black and red sides with a pale yellow to white stripe down the center of the back. In Colorado, this species is found from southern Jefferson County north through Boulder and Larimer Counties and northeast through Nebraska and Wyoming (Hammerson 1999). The common garter snake inhabits the margins of streams, irrigation ditches, natural and artificial ponds, as well as open areas that are surprisingly far from water.

Habitat

This species has been known to inhabit riparian and wetland areas in the northeastern portion of the state (Hammerson 1999). It has been noted that in previous years, the populations of this species began to decline in Colorado (Hammerson 1999). The reasons for the population declines are currently unknown. However, periodic droughts, declines in local amphibian populations, and rapid development are suspected. Furthermore, rural communities north of Denver have undergone a rapid increase in human population. Many riparian and wetland areas that once contained high numbers of this species have been developed. In 2001, the Colorado Division of Wildlife (now CPW) listed the common garter snakes as a state species of special concern and has made it illegal to collect specimens without proper permitting (CPW 2016). The project area provides suitable habitat for the common garter snake and this species likely inhabits the project area, particularly in wet years. The proposed Project could potentially affect common garter snakes if work is conducted within the wetland areas, primarily due to displacement from suitable habitat during construction.

Recommendations

ERO recommends implementing Conservation Measures (CMs) and Best Management Practices (BMPs) to avoid habitat and incidental take. Recommended CMs and BMPs include: 1) constructing the Project during the winter when common garter snakes are inactive, minimizing the risk of incidental take of any random occurrence or movement of common garter snakes in the area; 2) confining clearing to the minimal area necessary to facilitate construction activities and confine movement of heavy equipment within designated areas and minimize impacts on habitat disturbance along stream and drainage channels and wetlands; 3) planning staging areas to be within nonnative upland areas; and 4) prior to construction activities, surveying the project area for common garter snakes. If a common garter snake is encountered during construction, ERO recommends activities cease until appropriate corrective measures have been completed or it has been determined that the common garter snake will not be harmed. After completion of construction activities, any temporary fill and construction debris should be removed and, wherever feasible, disturbed areas should be restored to pre-Project conditions. Restoration work may include replanting species removed from impacted channels, banks, or wetland areas, or planting native vegetation in undisturbed areas for habitat enhancement. The listed CMs and BMPs would prevent long-term impacts on the species and minimize potential short-term impacts. If no activities would occur within the wetland areas, the proposed Project would not likely adversely affect the common garter snake because suitable habitat would not be impacted.

Northern Leopard Frog

Species Background

The northern leopard frog is listed as a Colorado species of special concern (CPW 2016). This species typically inhabits the banks and shallow portions of wetlands, ponds, lakes, streams, and other permanent water bodies. The northern leopard frog occurs at elevations from 3,500 to 11,000 feet in Colorado (Hammerson 1999).

Habitat

Permanent water bodies including wetland and backwater areas are potential habitat for the northern leopard frog. During a site visit on July 22, 2016, several tadpoles were observed in a small backwater area in the western EWP section of the project area. Although the tadpoles resembled those of northern leopard frogs, this could not be confirmed. Additionally, a northern leopard frog was documented at the pond at the Hall 2 quarry site in 2013 (pre-flood). No frogs have been detected at this site since 2013. Similar to the common garter snake, the proposed Project could have potential short-term impacts on the northern leopard frog if construction activities occur within the wetland areas.

Recommendations

In addition to following the CMs and BMPs listed in the *Common Garter Snake – Recommendations* section, ERO recommends that project workers try to minimize potential spread of disease (particularly *Batrachochytrium dendrobatidis* or bd) by spraying the souls of boots with 10% bleach before entering wetland areas and washing all equipment before entering wetland areas to minimize adverse effects on the northern leopard frog. If no activities would occur within the wetland areas, the proposed project would not likely adversely affect leopard frogs because suitable habitat would not be impacted.

iii. Locally Threatened, Endangered, and Species of Concern

Boulder County maintains a list of species of special concern (Boulder County 2013). The Boulder County Species of Special Concern List was created for the conservation and preservation of wildlife species and their habitat. Additionally, this reach of the South St. Vrain Creek has been identified as Critical Wildlife Habitat by BCPOS. Table 11 lists several species of concern that have been identified as potentially occurring within the project area. Many of these species are discussed in other sections above and below. It is likely that impacts on these species would be short-term because of the Project goal to avoid and minimize impacts or enhance high-quality habitat, including wetland and riparian areas.

Table 11. Boulder County species of special concern potentially found in the project area or potentially affected by projects in the area.

Common Name	Scientific Name	Community Type[1]
Mammals		
American Badger	*Taxidea taxus*	U
American Beaver	*Castor canadensis*	RC, U
Big-brown bat	*Eptesicus fuscus*	RC, U, W
Brazilian Free-tailed Bat	*Tadarida brasiliensis*	RC, U, W
Black-tailed Prairie Dog	*Cynomys ludovicianus*	U
Colorado Chipmunk	*Tamias quadrivittatus*	RC, U
Dwarf Shrew	*Sorex nanus*	U
Least Shrew	*Cryptotis parva*	U, RC
Little Brown Myotis	*Myotis lucifugas*	RC
Myotis, Western Small-Footed	*Myotis ciliolabrum*	RC
North American Porcupine	*Erethizon dorsatum*	RC, U
Tricolored bat	*Perimyotis subflavus*	RC, U
Uinta Chipmunk	*Neotamias umbrinus*	RC
Birds		
American Avocet	*Recurvirostra americana*	RC, W
American Bittern	*Botaurus lentiginosus*	W
American Redstart	*Setophaga ruticilla*	RC
Black-crowned Night Heron	*Nycticorax nycticorax*	RC, W
Bobolink	*Dolichonyx oryzivorus*	W, U
Bushtit	*Psatlriparus minimus*	RC, U
Cedar Waxwing	*Bombycilla cedrorum*	RC, U
Golden Eagle	*Aquila chrysaetos*	U
Great Blue Heron	*Ardea herodias*	RC, W
Great Egret	*Ardea alba*	W
Indigo Bunting	*Passerina cyanea*	RC, U
Lark Bunting	*Calamospiza melanocorys*	W, U
Lazuli Bunting	*Passerina amoena*	RC, U
Least Bittern	*Ixobrychus exilis*	W
Ling-billed Curlew	Numenius americanus	W
Long-Eared Owl	*Asio otus*	RC, U
Northern Harrier	*Circus cyaneus*	W, U
Northern Mockingbird	*Mimus polyglottos*	RC, U
Northen Pygmy Owl	*Glaucidium gnoma*	U
Ovenbird	*Seiurus aurocapilla*	RC
Prairie Falcon	*Falco mexicanus*	U
Rough-Legged Hawk	*Buteo lagopus*	RC, U, W
Yellow-Headed Blackbird	*Xanthocephalus xanthocephalus*	W, U
Insects		
Hops Feeding Azure	*Celastrina humulus*	U
Moss's elfin	*Callophrys mossii*	RC, U
Mottled Duskywing	*Erynnis martialis*	U
Reptiles		
Common Garter Snake	*Thamnophis sirtalis*	RC, U, W
Spiny Softshell Turtle	*Apalone spinifera*	W
Amphibians		
Chorus Frog	*Pseudacris triseriata*	W
Great Plains Toad	*Anaxyrus cognatus*	RC, U, W
Northern Leopard Frog	*Rana pipiens*	W
Plains Spadefoot Toad	*Spea bombifrons*	U, W
Tiger Salamander	*Ambystoma tigrinum*	RC, W

[1]U= Uplands; RC = Riparian Corridor; W = Wetlands.

iv. Raptors and Migratory Birds

Regulatory Background

Migratory birds, as well as their eggs and nests, are protected under the MBTA. While destruction of a nest by itself is not prohibited under the MBTA, nest destruction that results in the unpermitted take of migratory birds or their eggs is illegal (Service 2003). The regulatory definition of a take means to pursue, hunt, shoot, wound, kill, trap, capture, or collect; or attempt to pursue, hunt, shoot, wound, kill, trap, capture, or collect (50 CFR 10.12).

Under the MBTA, the Service may issue nest depredation permits, which allow a permittee to remove an active nest. The Service, however, issues few permits and only under specific circumstances, usually related to human health and safety. Obtaining a nest depredation permit is unlikely and involves a process that takes from four to eight weeks at a minimum. The best way to avoid a violation of the MBTA is to remove vegetation outside of the active breeding season, which typically falls between March and August, depending on the species. Public awareness of the MBTA has grown in recent years, and most MBTA enforcement actions are the result of a concerned member of the community reporting a violation.

Potential Habitat and Effects

A wide variety of bird species use different habitat types in the upland, riparian, and wetland habitat along South St. Vrain Creek for shelter, breeding, wintering, and foraging at various times during the year. Riparian vegetation, wetlands, and upland grasslands and shrublands within and adjacent to the project area are potential nesting habitat for migratory birds.

Some of the most common birds observed in the region include cliff swallow, red-winged blackbird, mallard, American robin, and mourning dove.

Wetland habitats typically support and provide nesting habitat for common yellowthroat, song sparrow, red-winged blackbird, and yellow-headed blackbird. Riparian vegetation supports several avian species including the yellow warbler, western wood-pewee, Bullock's oriole, American goldfinch, house finch, and American robin. Shorebirds and waterfowl species such as the killdeer, mallard, double-crested cormorant, and great blue heron are common around lakes and rivers.

Both prairie falcon (*Falco mexicanus*) and golden eagle (*Aquila chrysaetos*) nests have been documented near the project area. The prairie falcon nest is located on the cliff face east of the Hall Ranch Open Space parking lot. The nest was last active in 2005. Additionally a golden eagle nest occurs in Meadow Park. The buffer for the nest overlaps the Old South Bridge area. However, the nest has not been active since 2010. Other raptors potentially occurring in or adjacent to the project area include American peregrine falcon and bald eagle (described in sections above), merlin (*Falco columbarius*), American kestrel (*Falco sparverius*), sharp-shinned hawk (*Accipiter striatus*), red-tailed hawk (*Buteo jamaicensis*), Swainson's hawk (*Buteo swainsoni*), rough-legged hawk (*Buteo lagopus*), long-eared owl (*Asio otus*), great horned owl (*Bubo virginianus*), eastern screech owl (*Megascops asio*), Northern harrier (*Circus cyaneus*), and osprey (*Pandion haliaetus*) (Boulder County 2013).

Recommendations

To avoid destruction of potential migratory bird nests, vegetation including grasslands, riparian vegetation, and wetlands should be removed outside of the April 1 through August 31 breeding season. If active nests are identified within or near the project area, activities that would directly affect the nest should be restricted. Habitat-disturbing activities (e.g., tree removal, grading, scraping, and grubbing) should be conducted in the nonbreeding season to avoid disturbing active nests or to avoid a "take" of the migratory bird nests within the project area. Nests can be removed during the nonbreeding season, September 1 through March 31, to preclude future nesting and avoid violations of the MBTA. There is no process for removing nests during the nonbreeding season; however, nests may not be collected under MBTA regulations. If the construction schedule does not allow vegetation removal outside of the breeding season, a nest survey should be conducted prior to vegetation removal to determine if the nests are active and by which species.

Should an active raptor nest occur on or within ⅓ mile of the project area, ERO recommends compliance with the CPW temporal and spatial recommendations. Activities that would directly impact an active nest, or that would encroach close enough to cause adult birds to abandon the nest during the breeding season, should be restricted. Consultation with CPW or the Service may be required if construction is proposed within a buffer zone of an active raptor nest. Previously known active raptor nests should be surveyed if construction activities will occur during the breeding season. Although there is no CPW buffer designated for great horned owls, any active owl nests should be left undisturbed until the birds have left the nest.

v. Other Sensitive Species Habitat and Natural Resources

Mule Deer and Elk

Although mule deer and elk are most commonly found in upland or riparian shrublands, both species are known to occur within almost all available habitat types including open grasslands. The project area is within the overall ranges of mule deer and elk. Mule deer change their habitat use patterns. Although elk are less common than mule deer at lower elevations, they are known to occur along foothill riparian corridors.

The project area is located in mule deer overall range as well as summer range, winter range, and winter concentration areas and elk winter range (NDIS 2016). It is likely that mule deer and elk forage or migrate through the project area; however, no designated wildlife corridors were mapped in the project area (NDIS 2016). No deer or elk were observed during the July 22, 2016 site visit.

Bats

Bat surveys were conducted at Hall Ranch in 2015. A total of 18 bats comprising of six species were captured (Adams 2015). Species identified at Hall Ranch include big brown bat (*Eptesicus fuscus*), hoary bat (*Lasiurus cinereus*), small-footed myotis (*Myotis ciliolabrum*), long-eared myotis (*Myotis evotis*), little brown myotis (*Myotis lucifugus*), and fringed myotis (*Myotis thysanodes*). Additionally, Townsend's big-eared bat, and silver-haired bat (*Lasionycteris noctivagans*) calls were identified. The hoary bat and silver-haired bat are migratory bats that overwinter south of Colorado, whereas every other bat identified at Hall Ranch hibernate during the winter months.

Most of the bats at Hall Ranch were captured near ponds or pools. Disturbance from construction equipment during the summer months may disturb foraging bats and curtail foraging in areas containing a high amount of human activity due to construction activities. If possible, construction should be limited to daylight hours and end before late afternoon and early evening during the summer months. Winter construction would likely result in less adverse effects to bat species, assuming hibernacula (caves, rocky outcrops and abandoned buildings) are avoided.

Other Mammals

The project area provides habitat for a variety of small mammals such as cottontail rabbits (*Sylvilagus* sp.), deer mice, voles, and pocket gophers. Carnivores such as coyotes, raccoons (*Procyon lotor*), red and grey foxes *(Vulpes vulpes* and *Urocyon cinereoargenteus*), and striped skunks (*Mephitis mephitis*) are also likely to occur in the project area. Ringtail cats (*Bassariscus astutus*) have been observed along riparian areas in Boulder County and could occur in the project area. These species are typically observed in open grasslands and close to riparian corridors. Additionally, the project area is within the overall range of mountain lion (*Puma concolor*) and black bear (*Ursa americanus*) (NDIS 2016). It is likely that impacts on these species would be short-term because of the Project goal to avoid and minimize impacts or enhance habitat, especially in wetland and riparian areas.

10. Alternatives, Alternative Analysis and Preferred Alternative

a. Decision Making Process

To develop and analyze the initial alternatives the Design Team first synthesized the goals laid out in the RFP, Grant Request and Master Plan into a Project goals statement that can be found in Section 3.4 of this document.

Six core values were identified from this Project goals statement and first public meeting formed the categories in which the public comments were organized. The six core values for this Project are:

- Community
- Resiliency
- Safety
- Environment
- Implementation
- Schedule

b. Alternatives

The development of the alternatives for this project began with public engagement and comment evaluation. The Design Team first reviewed the public and stakeholder comments received and compiled by Boulder County Parks and Open Space (BCPOS) between September 2013 and May 2016. The comments received during this period and in the subsequent public engagement process can be found in Appendix I - Public Comments. These comments were then used to drive the formation and prioritization of the alternatives.

The magnitude of this project mandated a holistic design of the entire 3.2 miles, from above the Andesite Quarry down to the eastern Old South St. Vrain Road Bridge. Sub-reach sections of the project were delineated enabling individual elements to be evaluated in more detail.

The main issues facing the corridor are floodplain connectivity, minimal instream structures for geomorphically effective bedforms and habit, lack of vegetation to support a diverse ecosystem, and risk to infrastructure from future flooding. The four alternatives developed to address each of the aforementioned issues are Floodplain Connectivity, Channel Complexity, Revegetation and Infrastructure Protection, respectively. Each alternative addressed one specific issue facing the corridor.

Floodplain connectivity involves activating the floodplain at frequent intervals to enable critical floodplain functions, including:

- Sediment storage
- Reduction of erosive forces in main channel
- Nutrient transfer
- Healthy riparian/wetland ecosystem

Strategies used to illustrate floodplain connectivity in the alternative include:

- Activating overflow channels
- Incorporating channel/floodplain benching (sediment removal)

Channel complexity refers to channel features that contribute to geomorphically effective bedforms, as well as habitat quality and diversity. These features include:

- Low flow channel
- Pools, riffles, steps
- Bars (point, lateral, mid-channel)
- Large woody material (bank protection/habitat enhancement)
- Roughened channels/boulder clusters

Revegetation provides the framework for increased ecosystem diversity, function and aesthetic appeal along the corridor. Revegetation strategies include:

- Protecting and preserving existing stands of vegetation.
- Incorporating bioengineering measures to increase habitat maturation and resiliency.
- Planting a diverse palette of native plant species.

Infrastructure protection includes the protection of key infrastructure elements and other onsite “assets” to the corridor. Infrastructure elements include:

- Roads
- Bridges
- Houses
- Ditches

Infrastructure protection features include:

- Bank stabilization
- Bioengineering
- Buried rootwads
- Offset buried natural/structural aspects (i.e. Rockeries, soil nail walls, etc.)

- Buried riprap revetment
- Buried boulders
- Structural walls
- Channel alignment (in-depth analysis required)
- Slope, sinuosity, wavelength, belt width
- Detention

These four alternatives were presented at the public meeting on June 30, 2016 with a PowerPoint presentation to explain the location and benefit of each alternative. Aerial roll maps that showed the location of each alternative were available for the public to view. Meeting participants had an opportunity to ask questions and comment on each alternative and improvement locations. These comments were compiled into Appendix I - Public Comments. Recommendations were incorporated into the preferred alternative.

Following the public meeting a robust alternative analysis process evaluated both qualitative input from the public and quantitative technical data to prioritize aspects of each alternative. The Decision Making Process Diagram and Decision Matrix illustrate the alternative analysis process and prioritization methods used. With the Diagram and Matrix, the Design Team was able to emphasize the aspects of each alternative that most closely represented the desires of the public and stakeholders to produce an optimum preferred alternative.

Further explanation of the Alternative Analysis was submitted to the Saint Vrain Creek Coalition on July 8, 2016 and can be found in Appendix J - South St. Vrain Creek Restoration at Hall Ranch – Alternative Analyses and Preferred Alternative.

c. Alternative Analysis

i. Decision Making Process

Public comments were distilled into critical issues that represent the key concerns and desires the public and stakeholders have for this project. Based on the critical issues developed, seventeen questions formed the basis of the prioritization criteria.

The prioritization criteria were incorporated into a Decision Matrix that allowed the Design Team to determine how each alternative addresses the concerns of the public and stakeholders.

Utilizing, the project goals statement, core values, critical issues, the prioritization criteria, and technically sound and implementable design, the Design Team developed the preferred alternative.

For additional information please see Appendix H - Decision Making Process Diagram and Decision Matrix

ii. Decision Matrix

The decision matrix used the prioritization criteria to rank each of the alternatives on a scale of “best, better and fair”. Technical and empirical notes define reasoning for ranking each criteria. Ranking was conducted by the Design Team with input from Boulder County. The alternative with the most “best” ranks represented the alterative used as a basis for the preferred alternative.

For this project, floodplain connectivity ranked the “best”. As such, that the majority of the design emphasis and funding allocation was placed on strategies that reconnect the floodplain. However, aspects of channel complexity, revegetation and infrastructure protection were also included in the preferred alternative, to a lesser extent, as important contributors to restoration and resiliency.

d. Preferred Alternative

Based on the alternative analysis presented in the previous section, an emphasis for the preferred alternative was placed primarily on floodplain connectivity, secondarily on revegetation, thirdly on channel complexity, and infrastructure protection was incorporated in select areas. The main channel alignment will remain in its existing flow path for the majority of the project reach, with the exception of three locations (vicinity of the quarry, vicinity of Hall property, upstream portion of EWP #1 reach, and downstream of the Longmont Diversion). Given the dynamic nature of the project reach, as discussed in Section 8 Geomorphology, in most locations there is not necessarily a preferred alignment from a geomorphic standpoint, the channel will move laterally across the valley as it adjusts to the incoming discharge and sediment load. In the locations where infrastructure is at risk, the channel alignment can be located to minimize that risk, but with the inherent understanding that in larger flows the channel will adjust. Additionally, design calculations suggested that it is possible to achieve equilibrium channel dimensions with the current alignment. Therefore, considerable construction budget can be re-purposed for other aspects of the restoration. Reach map is provided as Figure 24.

The biggest component of the proposed design to increase floodplain connectivity is the incorporation of overflow channels and benches. These channels and benches are activated at frequent flows (1.5-yr recurrence interval flows) and moderate flows (approximately 5-yr recurrence interval flows), for multiple purposes including reducing erosive forces within the main channel, activating the adjacent floodplain, and functioning as depositional areas for the sediment loads coming from upstream. Establishing connections to existing overflow channel paths that are disconnected at frequent recurrence intervals will restore the sediment storage function of the alluvial valley considering the mainstem alignment is disconnected from the floodplain in many locations in the project area. The proposed overflow channel alignments were selected almost exclusively based on existing flow paths, which will limit the amount of grading and vegetation disturbance and conserve construction funds. As the overflows become activated, the channels may fill and erode again, or fill completely and become level with the adjacent floodplain. They may also capture the main channel, altering its alignment. This behavior is fundamental to how rivers evolve through alluvial valleys and is a key component of the design as it promotes the storage of sediments, alleviating the deposition on downstream areas. The proposed design restores this essential floodplain function, meeting the objective of the preferred alternative, floodplain connectivity. The overflow channels will not require maintenance (unless an altered main channel alignment becomes undesirable). As the watershed moves further in time from the disturbance, the availability of readily transported sediments will decrease, requiring less storage in the floodplain. Obviously, subsequent floods have the potential to start the cycle over again.

Revegetation will occur in all areas disturbed during the construction process and in areas currently void of vegetation. Specific methods of revegetation are based on access to the water table and elevation of plantings above the base flow water surface elevation. The preferred alternative provides a variety of floodplain benches with heights varying from approximately 12” to 42” above the base flow water surface elevation. These benches, in conjunction with the overflow channels, provide increased floodplain connectivity and greater opportunities for plant biodiversity and the expansion of wetland, riparian and upland habitat.

Channel complexity will be enhanced through installation of large wood structures in the stream banks, hardened riffles (i.e., bedforms), a low flow channel, and boulder clusters.

A summary of key features of the preferred alternative for the entire project reach is presented below (broken out by sub reach) starting with upstream and moving downstream.

i. Canyon to the Quarry (geomorphic reach R8)

- Minor regrading of right floodplain at inside of bend, and revegetation
- Addition of wood structures to aid in bank stability and initiation of pool formation
- Keep pre-flood alignment as overflow channel (minimal grading necessary, considering channel is already at a low elevation)

ii. Quarry (geomorphic reaches R7 and R6)

- Main channel will be realigned to mimic historical alignment pre-mining (upstream portion) and pre-flood alignment (downstream portion)
    - Existing flow paths through floodplain will be utilized to minimize grading
    - Other existing flow paths will be utilized as overflow channels (activated at approximately 1.5- and 5-yr flows), including existing channel (some fill will be necessary, and potential for grade control to initiate natural sediment deposition)
    - To minimize the risk of avulsions, rock sills will be installed to provide grade control in the proposed overflow channels that follow the existing main channel alignment.
- Addition of wood structures to aid in bank stability and to initiate pool formation
- Extensive floodplain grading – especially in the upstream portion of the reach. Excess fill may be place in the current channel alignment and perhaps utilized in the mine reclamation effort.
- Extensive revegetation
- Potential offset buried riprap for the private parcel (depending on buy-out situation)
- Potential reestablishment of Otto diversion at base of vertical andesite walls

iii. Quarry to EWP #1 (geomorphic reaches R5 through R3)

- Vicinity of Bedrock Bend (R5):
    - Addition of wood structures to aid in bank stability, and initiate pool formation
    - Grade right and left banks to create floodplain benches to reduce hydraulic forces near the proposed road alignment at higher flows.
- Vicinity of Hall Property (R4)
    - Reactivate pre-flood channel as main channel and keep existing alignment as overflow channel (activated at approximately 5-yr flows)
        - The pre-flood channel, at the upstream end, has already started recovering with a young riparian corridor – would need to widen existing channel, but will minimize amount of disturbance to existing vegetation
        - Enhance pool-riffle morphology in pre-flood channel
        - To minimize the risk of avulsion, rock sills will be installed to provide grade control in the proposed overflow channels on the floodplain
    - Grade the vertical left bank upstream of structures and revegetate
    - Utilize the existing riprap on the left bank as offset protection – bury and revegetate
    - Overflow channel (activated at approximately 5-yr flows) in the left floodplain requires some grading at the upstream end to activate the existing flow path at the downstream end
    - Grading and removal of floodplain deposits to create benching
    - Extensive revegetation

- Addition of wood structures in specific locations to aid in initiation of pool formation

- Vicinity of Proposed Bridge (upstream R3)
    - Upstream of proposed bridge, an existing group of downed trees has created a functioning pool (with a riffle up and downstream of the pool), enhancement and stabilization of the existing wood structure is proposed, as well as an additional large wood structure further upstream on outside of channel bend
    - Grading/removal of excess flood deposits to create lower elevation floodplain benching (mostly on right floodplain)
    - In the existing eroded bank/scar area downstream of the proposed bridge, coarse fill (larger boulder material) should be pushed up against the toe of the existing bank and grading/revegetating of the area
    - Addition of wood structures in specific locations to aid in bank stability and initiation of pool formation
    - Grading of both right and left floodplain areas to remove excess sediment and create floodplain benching

iv. EWP #1 [geomorphic reaches R2 and R3 (downstream)]

- Reactivate the pre-flood channel and keep the existing alignment as an overflow channel (activate at approximately 1.5-yr flows); grade/enhance pool-riffle morphology in the re-activated channel. It should be noted that the work limits of the EWP project may require that the main channel remain in place.
    - To minimize the risk of avulsion, a rock sill will be installed to provide grade control in the proposed overflow channel that follows the existing main channel alignment
- Activate an overflow channel through the right floodplain (activated at approximately 5-yr flows)
- Across from Hall Ranch trailhead – grade right bank to alleviate confinement in this portion of the reach (repurpose existing andesite boulders)
- Addition of wood structures is proposed at specific locations to aid in bank stability and initiate pool formation
- Overflow channel on the left floodplain, upstream of the private parcels, using an existing overflow path that will be activated at the approximate 5-yr flow. Additional analysis will be performed during the next design phase to determine if the existing berm on the left bank should be modified or removed to achieve project goals. A memorandum was developed to discuss the hydraulics influenced by this berm and to understand under what hydrologic regimes this berm effects water surface elevations. The overall consensus is that the berm can actually provide more harm than good under greater storm events. Please see the memorandum in Appendix
- Overflow channels in the right floodplain were selected based on existing flow paths, therefore grading will be minimal, although some grade control will be necessary to stabilize knickpoints.
    - The southernmost overflow channel initiates in the upstream portion of the reach and will activate a previous flow path before the wetland area at approximately a 1.5-yr event. The channel will be routed into the wetland area, but no earthwork will take place within the wetland boundary. Flow will exit wetland area into several existing flow paths which tie into the existing ditch/flow path adjacent to Old St. Vrain Road. The ditch adjacent to the road

has some existing bedforms/grade control created as part of the South Ledge/Meadows ditch project (to hold grade where the pipe crosses under the channel), but additional controls should be added in the upstream portions of the alignment.
    - The middle overflow path skirts around the wetland area and would be activated at approximately the 1.5-yr flow event.
    - The northernmost (downstream) overflow channel (close to the main channel alignment) follows an existing flow path and would be activated at approximately the 1.5-yr flow event
    - To reduce the risk of avulsion, three rock sills will be installed across the right bank floodplain to provide grade control in the proposed overflow channel at the upstream connection point
- Minor riffle enhancement is necessary mid-reach, but otherwise riffles already exist within most of this reach and will be supplemented by the addition of wood structures in specific locations to initiate pool formation. (Stability of riffles will be further enhanced with larger rock to provide bed grade control, if necessary).
- Existing main channel split flow alignment will remain
    - Bank protection measures required along outer bend
- Just downstream of South Ledge/Meadows diversion, an additional wood structure is recommended for bank stabilization

v. EWP #1 to Longmont Diversion [geomorphic reach R2 (downstream) and R1 (upstream)]

- Upstream of diversion, the main channel will remain in existing alignment and abandoned main channel will become an overflow channel (activated at approximately 5-yr flow). Minimal grading will be needed for the majority of the overflow channel with the exception of the upstream approximate 8-foot tall sediment plug (which will need to be removed and regraded/revegetated)
    - Bank protection will be necessary at outside bend of overflow channel (adjacent to Highway 7), currently the bank consists of unstable riprap. Recommend benching and revegetating.
- Right bank upstream of diversion (adjacent to Old St. Vrain Rd) consists of riprap (and some other debris still buried), vegetation has started to establish, but could be supplemented with additional willow staking.
- Left bank upstream of diversion is mostly bedrock, but upstream of the bedrock the bank is currently unstable and will require bank stabilization

vi. Longmont Diversion to EWP #2 (geomorphic reach R1)

- Existing channel downstream of diversion will become an overflow channel activated at 1-5-yr flow. The adjacent flow path on the right floodplain will become the main, low-flow channel.
- Overflow channel and floodplain benching on the outside of the bend (activated at approximately 1.5-yr flow) will only need minor grading (flow path already exists throughout most of this alignment).
    - Existing underground pipe on the downstream end of the overflow channel will need to be located to ensure protection

        - To reduce the risk of avulsion, two rock sills will be installed across the floodplain to provide grade control
    - Grading of the remaining floodplain to allow for lower elevation benching and revegetation.
    - Buried offset protection is recommended for the existing ditch infrastructure just downstream of diversion (box and ditch).
    - A berm exists on the outside of the bend, therefore no additional offset protection is necessary on the outside of the bend, with the exception of some additional revegetation along portions of the berm.
    - Wood structures are proposed in specific locations to aid in bank stability, but also to initiate pool formation

vii. EWP #2 [geomorphic reach R1 (downstream)]

- Regrade the bar upstream of the bridge on left bank (remove sediment and create benches) and revegetate as necessary
    - Activate existing flow path as an overflow channel during 1.5-yr flow events
- Riprap embankment on right bank is pushed out into the flow causing even more of a constriction, it is recommended to pull back the riprap and a portion of the upstream fill to increase conveyance through the bridge
- Potential overflow channel on downstream side of Old St. Vrain Rd that could return to the creek downstream, if capacity exists (construction of overflow channel not covered under EWP funding and would need coordination with the EWP project downstream).

e. Prioritization of Projects/Alternatives

While a portion of the proposed plan will be implemented under the EWP program funding, prioritization of other potential projects along the reach have been conducted to allow for a plan to move forward once the EWP construction is complete. Evaluations at this level are very qualitative.

One of the first recommended projects would be from the Longmont Diversion to EWP #2. The diversion structure located at this location is potentially a fish passage barrier and an alternative diversion design could help promote connectivity between upstream and downstream locations. This would allow for the development a new main channel alignment, two overflow channels and a connected floodplain. A new main channel alignment will be constructed through an existing split flow reach that would become one of the overflow channels. This would also allow for the development of designs to remove the cross channel stream diversion. The diversion could either be located upstream at grade or a sloping structure could be constructed from the existing diversion location.

The next recommended project would be in the vicinity of the Quarry. This area has great potential as a storage reach for sediment and a wide floodplain for riparian and wetland vegetation. There are no properties in the vicinity of this reach which would allow for freedom in design. Multiple overflow channels and connected floodplain could be established. Coordination with mining reclamation plans should take place as this project comes to fruition.

The next recommended project would be stretch from the Quarry to the EWP# 1 boundary. This project would allow two concurrent projects to be connected with a stream restoration design to reduce the potential for future failures at these locations. Development of designs through this area could also reduce the risk to the private residence along this reach.

The section from the EWP #1 project limits to the Longmont Diversion could also be completed next. While this area requires minimal main channel work, the pre-flood channel could be activated as an overflow channel, increasing floodplain connectivity and thus achieving many of the goals of this project.

Additional projects could evaluate the existing infrastructure concerns throughout the Project Area. This would consist in rectifying the sedimentation issues at the Meadows and South Ledge diversion with construction of a sediment sluice, or re-design of the eastern Old St. Vrain Road Bridge to allow for great conveyance capacity and improved alignment with the creek and Highway 7.

The reach from the canyon to the Quarry is of least concern through this reach. The overflow channel in this area is well defined and would require little grading to activate it at the correct elevation. Revegetation of the corridor through the canyon is recommended to both provide ecologic benefit and reduce potential erosion issues.

11. Meeting Notes

The Design Team engaged in two public meetings at Rogers Hall in Lyons. The overall purpose of these meetings was to receive input from the public and stakeholders about key project elements at different phases of the design.

More specifically, the purpose of the first public meeting (May 24, 2016) was to inform the community about the project team and project process. The following topics were addressed:

1. Introduce the Design Team personnel and roles
2. Explain the project funding
3. Explain the project goals and objectives
4. Collect important input from the public

At the meeting, a list of critical issues and concerns were voiced by the public and stakeholders. These critical issues were documented and grouped into the following categories:

1. Community
2. Resiliency
3. Safety
4. Environment
5. Project Implementation

Following the public meeting, additional comments were submitted to Ernst Strenge by email or via the project website. A sign in sheet was provided and a total of sixteen people signed in. For more information on the first public meeting, including detailed meeting minutes and public comments, please see Appendix A - Public Meeting Minutes.

The purpose of the second public meeting on June 30, 2016 was to present the public with four design alternatives and explain the project prioritization process. This involved explaining how aspects of each alternative will be prioritized to develop the preferred alternative. The Design Team gave a presentation of the work that had been done to date and explained each alternative that had been developed.

A series of maps were displayed at the meeting showing each of the alternatives. A representative of each discipline was stationed at these maps to further explain the alternatives and answer any questions from the attendees. All questions and comments received at this meeting were recorded for further consideration and evaluation during development of the preferred alternative.

A sign in sheet was provide and a total of twelve people signed in, although many more were present. For more information on the second public meeting, including detailed meeting minutes and public comments, please see Appendix A - Public Meeting Minutes.

12. 30% Design Plan Set

A set of plans evaluating the entire 3.2 mile reach of South St. Vrain Creek has been developed to the 30% design level as part of this Project. Design guidelines from DOLA, BCPOS, SVCC, and NRCS were followed as the basis for these designs. Preliminary review of these plans was completed by BCPOS, DOLA, SVCC, and the EWP at a 15% level to get approval on the major design elements prior to progressing the design to the 30% level. Draft 30% plans were also submitted to DOLA, EWP, SVCC, and BCPOS for acceptance prior to final design.

These plans include existing conditions as surveyed in the field along with information acquired from BCPOS and other sources. Existing conditions plans accounted for existing projects along this reach along with proposed design elements through other projects that will be constructed in the near future. Existing topography was developed from LiDAR and ground survey from multiple sources, including a longitudinal survey of the existing channel thalweg.

Based on the existing conditions plans and project goals, various stream enhancement elements were designed and are shown in the proposed conditions plans. These proposed elements include floodplain connectivity improvements, channel complexity enhancements, bioengineered bank treatments, grade control measures and buried revetments. The design plans also include revegetation aspects in the form of a planting plan. Proposed grading was developed based upon multiple new channel alignments and profiles along with various cross sections that were modeled with the use of 3D computer aided drafting techniques. The entire 3.2 mile extents of the project are shown in plan and profile views at a 1”=50’ scale.

a. Main Channel Planform

As described in Section 8 Geomorphology, the majority of South St. Vrain Creek through the project reach can currently be characterized as a single-thread channel with a meandering planform. A few short segments have split flow paths and minor braiding. The 2013 flood event resulted in significant modifications to the planform throughout the project area, but previous emergency stream improvements have already returned many areas of the creek to its pre-flood position.

The proposed planform is very similar to the existing condition through most sub-reaches. In some areas, the main channel has been realigned to increase channel sinuosity and connect to historical flow paths. The most notable channel realignment is in the vicinity of the Andesite Quarry where the proposed channel position mimics the 1944 alignment. The existing channel will also be shifted to the pre-flood channel alignments to protect infrastructure at the Hall Property and along Highway 7 downstream of the Andesite Quarry Bridge.

Multiple overbank flow paths have also been proposed to significantly improve floodplain connectivity during higher flow events, as described in the Overflow Channel Design section below. These alterations are expected to decrease the risk to critical infrastructure by reducing the shear stresses on the channel bed and banks. The channel realignment also helps to shape channel structure, which will improve habitat and increase sediment storage in the stream corridor.

b. Main Channel Profile

The South St. Vrain Creek project reaches have average existing bed gradients ranging between 1.0% and 2.0%. An equilibrium bed slope analysis was performed to assess the stability of the existing channel and determine if longitudinal profile adjustments were needed. The required median grain size, D50, to achieve equilibrium at the 1.5-year peak discharge was predicted for each design reach using Shields method for incipient motion. The equilibrium bed slopes were estimated by applying the Manning and Shields equation. The methodology for these calculations is detailed in Technical Supplement 14B of the National Engineering Handbook part 654 from the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS, 2007).

Based on this analysis, the existing median grain sizes in Reaches 2 and 8 are expected to be mobilized during a 1.5-year recurrence flow given the existing channel geometry. Furthermore, the bed slopes are predicted to downcut in most design reaches at the 1.5-year recurrence flow based on the existing channel geometry and bed substrate. The construction of additional grade control measures, such as riffles, coupled with planform adjustments and floodplain connectivity improvements would reduce this risk. It should be noted that the equilibrium bed slope analysis is based on a long-term (i.e., multiple decades) prediction of bed adjustment, and the short-term (i.e., next few years) response in the South St. Vrain system may be very different because of the elevated sediment supply following the 2013 flood event. For this reason, the results of the equilibrium bed slope analysis were coupled with the predicted channel trajectories from the sediment transport analysis in Section 8 Geomorphology to inform the profile design for the proposed alignment. The design calculations for these analyses can be found in Appendix L - Channel Geometry and Rock Structure Design Calculations.

c. Channel and Floodplain Dimensions

The proposed cross-section geometry will be modified in select locations to improve river function, flood conveyance, aquatic habitat, and facilitate fish passage. A multi-stage channel cross section was designed for a large portion of the project area to restore river processes (i.e., increase flood frequency in the overbank and bench areas, and deposit sediment along the margins of the channel) and accommodate flows from low flow to moderate flood events. With an interest of limiting channel impacts, instream grading is generally only proposed for realigned segments of channels and in the vicinity of proposed riffle-pool structures.

To the extent possible, the channel geometry was designed so the 1.5-year discharge could be conveyed by the bankfull channel. Hydraulic geometry equations for streams in Colorado (Andrews, 1984) and elsewhere (Hey and Thorne, 1986) were compared and used for estimating bankfull geometry—width and mean depth. The formula for bankfull width is a power equation in the form $w=aQ^b$. The variable "a" depends on factors such bank vegetation, bank cohesion, and sediment load. Given the characteristics of the project site, the bankfull geometry was calculated with the assumption of relatively thin bank vegetation. The variable "b" is a fixed value with a narrow range between 0.48 and 0.50.

A range of bankfull widths and depths were calculated for straight segments of channels, meanders, and transition reaches, using both sets of equations. A summary of the proposed bankfull channel geometry is shown in Table 13. The equations, calculations, and results for these analyses can be found in Appendix J.

Table 12. Proposed Bankfull Channel Geometry

Description	Top Width (ft)	Bed Width (ft)	Max. Depth (ft)	Bank Slopes
Straight Reach	40 - 55	31 - 44	2.1 - 2.5	3:1 - 5:1
Transition Reach	40 - 55	N/A	2.5 – 3.6	3:1 - 5:1
Meander Reach	40 - 55	N/A	3.6 – 4.4	2.5:1 - 5:1

The bankfull channel was designed to include a "low flow" channel that concentrates stream flow to improve habitat quality and facilitate fish passage during periods with lower discharge. The low flow channel was sized to convey the baseflow (~25 cfs), and the geometry is summarized in Table 14.

Table 13. Proposed Low Flow Channel Geometry

Description	Top Width (ft)	Typ. Depth in Straight Reach (ft)	Typ. Depth in Meander Reach (ft)
Low Flow Channel	26 - 32	0.76	2.5

Proposed design elements also include floodplain benches along one or both banks to maximize flow conveyance. These benches will typically be activated at the 1.5-Year design flow. The floodplain benches were proposed to be graded at a 50:1 H:V slope and the bench widths will vary depending on the space available. The upper slopes would have a typical grade of 4:1 H:V slope to tie into the existing ground.

d. Bed Morphology/Riffle Structure Design

As described in Section 8 Geomorphology, the bed morphology in the existing project reach was dominated by extended riffles followed by shallow pools. The stream design aimed to improve hydraulic complexity with the creation of pool-riffle morphology in specific locations with more pronounced riffles and deeper pools. This type of morphology is commonly found in natural coarse-bed systems with similar bed gradients. The riffle and pool sequences are expected to improve aquatic habitat, stabilize the longitudinal bed slope, and dissipate instream energy, which ultimately reduces erosive forces on the banks.

Riffles consist of channel-wide accumulations of larger cobbles and boulders, and they typically transition into either a lower gradient run or directly into a pool. Water depth is relatively shallow over the riffle, and the slope is steeper than the average channel slope. At low flow, water accelerates over the riffle, mobilizing finer sediments, keeping interstitial spaces in the channel substrate clean, and oxygenating the water. Energy is dissipated through tumbling flow and grain roughness.

Riffles are generally spaced at 5-7 bankfull channel widths apart in natural channels (NRCS, 2007). Given the average design width of 48 ft for the bankfull channel, riffle spacing was calculated to be between 240 and 336 ft for this reach of South St. Vrain Creek, with an average spacing of 288 ft. When feasible, existing riffles will be enhanced to minimize earthwork and to position the structures in areas they would be more likely to naturally persist.

The design of each riffle structure includes three distinct sections: a ramp, a boulder crest, and the riffle face. Short ramps are constructed on the upstream end of the riffle to transition the bed grade between the existing channel elevation and the proposed riffle crest elevation. The structure accommodates ramp slope adjustment over time as additional substrate is trapped immediately upstream of the constructed riffle. The crest of the riffle consists of a collection of larger boulders that serve as grade control and help shape the flow path through the riffle. The crest has a “V-shape” that points slightly upstream and slopes towards a low flow path in the center of the channel. This geometry directs flow away from the bank and helps maintain the shape of the riffle. The crest rock is keyed into the bed, floodplain benches, and upper banks to reduce the risk of the stream avulsing to a new flow path and/or flanking the structure. The riffle face was designed to be approximately 75 ft long, and the riffles for this project were designed to a have a bed gradient ranging from 3 to 4%, defaulting to shorter, steeper riffle faces that would scour deeper pool habitat at the base of the riffle face.

Pool excavations are proposed downstream of the riffles in areas where pools are expected to form naturally. These pools are designed to have deeper water depth than the average channel and have a water surface with very little slope at low flow. The pools will likely shift position slightly in the future as the pool geometry will continuously be shaped by bed scour during high flows. At low flow, the pools will act as a depositional feature, temporarily storing fines, sediments, and organic matter. Depth and slope increase over the pools during larger flow events, increasing shear stress, initiating scour that mobilizes fine materials.

Each riffle crest will be designed to remain stable during a 100-year design flow. The limited supply of boulders from the upper watershed may not be able to replenish the necessary size rock to fill in voids in the riffle crest if these larger rocks are mobilized. To reduce future maintenance requirements, and increase the probability of long-term stability in the riffle structures, the minimum rock size in each riffle crest was designed to remain stable using Shield's method of incipient motion (NRCS, 2007) with a factor of safety of 1.5. The hydraulic design parameters at each riffle will be based on the SRH-2D model of the proposed conditions. The proposed riffle crest boulders for the riffles will have a minimum diameter of 18 inches, and a maximum diameter of 36 to 48 inches.

The ramp and riffle face were designed to remain stable during a 1.5-year design flow, and be partially mobilized during larger flood events to work with natural fluvial processes. The D84 is commonly used as a threshold grain size for riffle design since bed stability is often reliant on the largest particle sizes. If the largest particles remain stable in the riffle, the remainder of the bed material will be less likely to mobilize. Shield's method of incipient motion (NRCS, 2007) was used to calculate the necessary D84 equivalent rock diameter to achieve stability at the design flow. Based on the existing substrate gradation analysis, it is expected that the coarse substrate needed to construct the riffles can be salvaged from instream grading activities. Furthermore, the upstream supply of cobbles and gravels will provide an adequate source of bed substrate to replenish rock that is mobilized and transported from the ramp and riffle face. These sections are proposed to be constructed with salvaged coarse native alluvium ranging in grain size from sand to small boulders, with a D50 of approximately 3 inches and a D84 of 8 inches.

A summary of the design parameters and median grain sizes for each section of the riffle are shown in Table 14.

Table 14. Proposed Riffle Design Parameters

Section	Length (ft)	Longitudinal Bed Slope	Width	Rock Depth (ft)	Required Grain Size (ft)
Ramp	5 - 10	10 - 20% up	Bankfull Channel	2	D84 = 0.67
Crest	3 - 4	0%	Extend across floodplain	3 - 4	Dmin = 1.5
Riffle Face	70 - 80	3 - 4% down	Bankfull Channel	2	D84 = 0.67

Larger habitat boulders are proposed to be placed in the riffles and pools to increase channel roughness and provide alternate migration paths and resting areas for a variety of fish species and sizes. It is expected that the habitat boulders will shift slightly but not move any appreciable distance during a flood event with a recurrence interval of 100 years. The required size of the boulders was determined using Shield's method of incipient motion (NRCS, 2007) with a factor of safety of 1.5. The proposed habitat boulders ranged in size from 2.5 to 5 ft in diameter. A minimum of one-third of each boulder will be embedded in the channel bed to increase sliding resistance. In several areas, clusters of boulders may be appropriate to encourage stream flow to either diverge or converge, depending on the water depth, to increase the presence of micro habitat.

The remaining segments of the channel that are adjacent to the riffles and pools will function as runs. In general, minimal in-channel earthwork is proposed in these sections other than the construction of a low flow channel. The runs will have a longitudinal bed slope close to the equilibrium bed slope so they are expected to remain stable. The available sediment supply is expected to replenish the substrates that will be periodically transported out of the runs. Fine sediments will either deposit along the channel margins or will be able to pass through the stream as wash load.

Detailed riffle design formulas and calculations are included in Appendix L - Channel Geometry and Rock Structure Design Calculations, and additional details are shown on the design plan set. The methods for rock sizing are further described in the National Engineering Handbook part 654, Technical Supplement 14C, from the Natural Resources Conservation Service (NRCS 2007).

e. Overflow Channel Design

Overflow channels were designed to re-establish the overbank area as functioning floodplain and better protect assets in the vicinity. Planform alignment and channel dimensions were chosen as a function of available space and where flow paths currently exist. Through geomorphic and hydraulic analyses, it was determined that the floodplain would ideally be activated at roughly the 1.5-year recurrence interval, but this was not considered to be feasible in a few areas since it would require massive overbank excavations. The 5-year flow was selected as a minimum design target in the areas with higher floodplain elevations, although the design aimed to maximize connectivity to the extent possible. As a result, many of the 5-year flow overflow channels designated on the plans will be activated at more frequent flow intervals.

The overflow channels will have a minimum width of 20 feet. Typical overflow channel bed gradients are similar to the existing floodplain gradient along the chosen path, although adjustments were made to further improve floodplain connectivity where possible. Bank heights were minimized to provide flood flow relief into the floodplain.

f. Sill Design

Sills will be constructed to provide grade control in floodplain areas that have a high degree of susceptibility to erosion and may result in an unacceptable risk to adjacent infrastructure, private property, or wetlands. The sills will consist of coarse rock embedded in the floodplain such that the top of the rock is flush with the final grade. These features will act as a flow spreader to disperse flow over wider sections of the floodplain and limit erosion potential, and they will provide launchable rock which can help minimize the risk of avulsion through knickpoint propagation. Existing knickpoints located downstream of the wetland in EWP #1 will be stabilized using a similar technique to reduce the risk of habitat degradation. In some cases, such as upstream of the wetland in EWP #1, the sills may be placed at an angle (pointed upstream) to keep the channel from migrating towards the outer valley walls. The use of sills will be limited to only a few key locations within the project area since the project does not intend to limit channel migration through most of its length. The minimum rock sizing in the sills will match the rock gradation selected for the riffle crest design since these sills could conceivably face similar hydrodynamic forces if the channel begins to avulse.

As described in the Preferred Alternatives in Section 10d, some realigned segments of the main channel will be converted into overflow channels. In this case, grade controls at set intervals may be constructed in lieu of filling the entire existing channel. This approach will provide additional sediment storage capacity in the project area.

g. Large Wood Structure Design

A total of seventy-seven (77) large wood structures are proposed in the project reach to provide a variety of physical and ecological functions. Sixty-four (64) instream large wood structures are proposed to enhance aquatic habitat and deflect flows away from actively eroding banks. An additional thirteen (13) large wood structures are proposed on the floodplain to increase overbank roughness and improve riparian habitat.

Three types of log configurations, referred to as Type A, B, and C structures, are being proposed in locations suitable for large wood accumulations. The Type A and B structures are designed with the purpose of increasing hydraulic diversity, scouring pool habitat, and stabilizing banks by deflecting flows. These structures are proposed in areas where pools are expected to form naturally, and these structures are expected to encourage bed scour to increase pool depth and provide cover habitat. The Type C structures are proposed in relatively wide floodplain areas that have minimal existing vegetation to increase floodplain roughness and improve terrestrial habitat.

The Type A structure is designed with nine logs stacked in two levels, and a footer log placed at the toe of the bank to reduce the risk of the structure being undermined by scour. The logs have rootwads that are exposed to flow with stems embedded in the bank. The rootwads will be set flush with the streambank to reduce the hazard to boaters.

Type B structures consist of eight logs stacked in three levels. The rootwads of all eight logs project into the flow to maximize the area of the bank that will be protected. Type B structures could be placed next to each other in order to deflect flows away from the outside bank of a meander bend. This type of structure is designed to allow some flexibility when selecting individual log sizes in the field.

Type C structures consist of a 6 or more logs placed on the floodplain to increase roughness to reduce the chance of channel migration. Many of the logs will be partially buried and boulders will be placed on top to improve stability. Wood piles (i.e., vertical posts) can also be used to further stabilize the structure. This type of structure can be designed to allow significant flexibility when selecting individual log sizes and configurations in the field.

Despite the restricted access for recreational users in the reach, safety concerns for river users will be considered during the design of all large wood structures. Most logs will be positioned close to the bank so there is a low probability that the structures will recruit other mobile logs in the future which could create potential trapping hazards (e.g., “strainer logs”).

The source of logs has not yet been identified for this project. It should be noted that much of the available wood in the area appears to be cottonwood, which is considered to have a short engineering design life, particularly when the wood goes through a repetitive wetting and drying cycle. Although it is unknown exactly when the logs will likely decay, they are expected to function long enough for mature woody vegetation to establish.

Each type of log structures will be designed to remain stable during a storm event with a 50-year recurrence interval. In order to resist hydrodynamic forces, the logs will be primarily stabilized using soil ballast through partial burial. Where necessary, boulders can be added as a secondary measure to provide additional resistance to buoyancy. Each structure type will be designed to have a minimum factor of safety of 1.5 for vertical, horizontal, and moment forces. The stability evaluation calculations will follow the methodology described in USFS Technical Note 103.1 (Rafferty, 2016). Additional details are shown on the design plan sets, and detailed structure stability evaluations will be completed during the next phase of design since they are dependent on having advanced grading plans and identifying the likely source of large wood material (i.e., species, size).

Rock toe protection is proposed in the vicinity of the instream large wood structures to provide additional long-term scour protection. The rock sizing is based on USACE riprap sizing standards (USACE, 1994). The angular riprap will have a median grain size of 18 inches, and a minimum thickness of 3 feet. Detailed riffle design formulas and calculations are included in Appendix L - Channel Geometry and Rock Structure Design Calculations, and additional details are shown on the design plan set.

h. Revegetation Recommendations

Revegetation methods will preserve the existing stands of healthy vegetation on site, re-establish denuded areas and mitigate for future flood events through grading measures, diverse revegetation of disturbed areas and bioengineering solutions.

Existing healthy stands of mature vegetation will be preserved by minimizing grading in their immediate proximity. This will not be possible in all cases, but a site specific approach will be taken to preserve areas that survived the floods and continue to hold ecologic value.

The plant communities that survived the 2013 floods were segmented by flood flows. Revegetation will recreate existing and proposed plant communities. Revegetation efforts will focus on growing these areas to increase the productive ecosystem into denuded or disturbed areas, as well as increase continuous habitat corridors.

Revegetation efforts will be primarily determined by the plantings proximity to the water table. The Design Team will grade a series of floodplain benches in-between the overflow channels. These benches average between 12” and 42” above the base flow water surface elevation and will be planted with a variety of riparian and upland species based on the required proximity to the water table. Existing wetlands will be planted with appropriate species to repair flood damage.

Wetland plants will be located closer to the limits of the bankfull height between 0”-24” above the base flow water surface elevation. Riparian plants will be planted at elevation between 18”-42” above the base flow water surface elevation. Upland plants will be planted at elevations greater than 42” above the base flow water surface elevation.

For more information on planting locations and heights, please see Figure 43. Typical Creek Ecosystem Section.

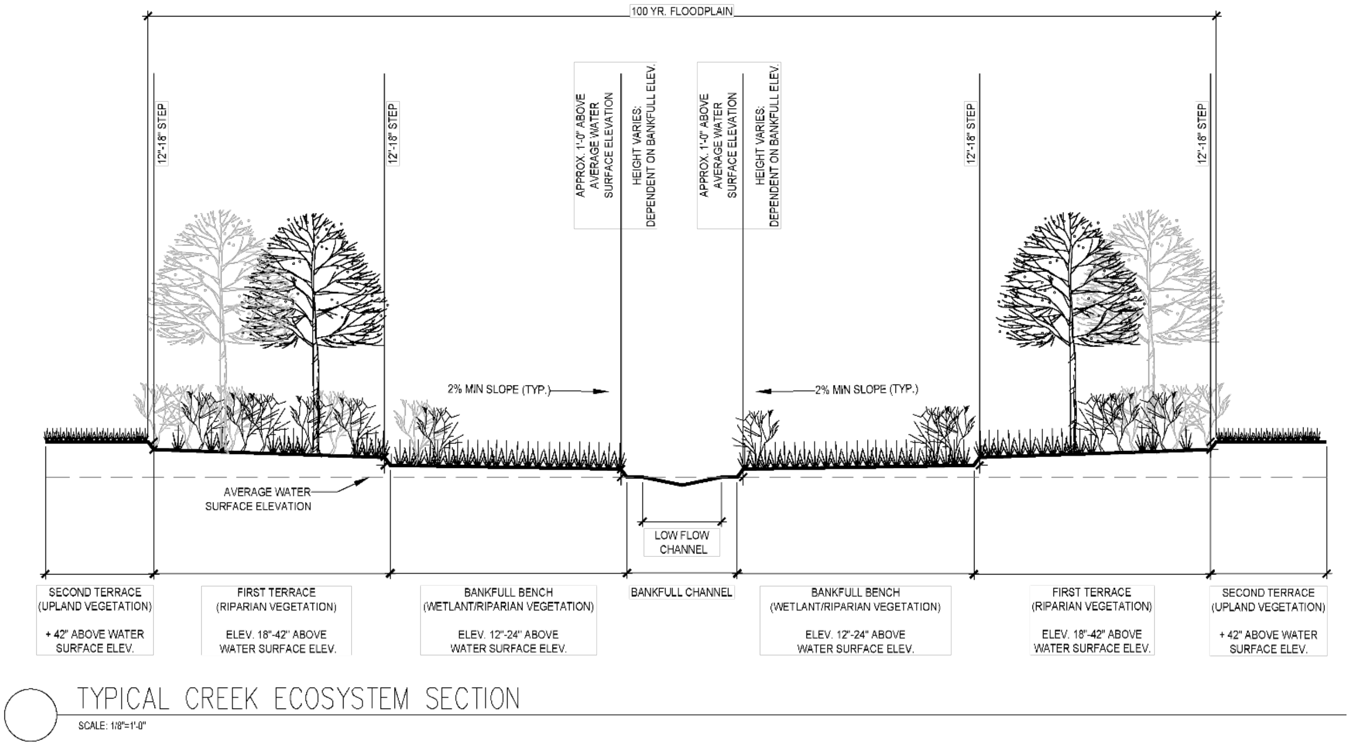


Figure 43. Typical Creek Ecosystem Section

Specific locations for plant material were selected based on the elevation above the base flow water surface elevation as well as the velocity of flows. Perennial tubelings will be planted in protected flow areas. These areas include point bars of the main channel and the ends of the overflow channels where velocities will be lower. Similarly, wetland and riparian sod will be installed in select locations at the mouths and ends of the overflow channels where water will inundate more regularly, but high velocities will be rare. Willow stakes will be installed on the outside bends of the main channel and overflow channels, at the confluence of the main and overflow channels and in areas where the grades steeply rise from the main channel.

All the plant species for this project were selected from Boulder County's Flood Recovery Plant Materials List that was included in the recently released Plant Material RFP. The selected plant material is shown in Table 15. Boulder County's Flood Recovery Plant Materials List.

A combination of upland seeding, riparian seeding, willow stakes, cottonwood poles, tree and shrub plantings, perennial tubelings and wetland and riparian sod will be used on this project to create a biodiverse and vibrant naturalized ecosystem.

Upland Seeding: The Design Team worked with a Boulder County Parks and Open Space Restoration Ecologist, to determine the herbaceous upland plants that exist on the site and the seeding measures that have been successful in the past. The BCPOS Restoration Ecologist informed members of the Design Team that reseeding over areas with high concentrations of cobble have been unsuccessful in the past, but seeding certain varieties in sandy and alluvial areas had yielded positive results. Many varieties of upland species that have been successfully reseeded are incorporated in the South St. Vrain Bridge Seed Mix and were provided to the Design Team by BCPOS. Boulder County gave the Design Team additional recommendations for this seed mix and those recommendations have been incorporated into the 30% design plans.

The upland seeding will only be applied to areas that are twenty-four inches or more above the water table.

Riparian Seeding: The Design Team also worked with the BCPOS Restoration Ecologist to identify onsite riparian and wetland plants that were currently thriving. Based on these observations and extensive experience in the area, the BCPOS Restoration Ecologist recommended a revised mesic/wetland mix for the project that has been incorporated into the 30% design plans.

The riparian seeding will be applied at elevations up to twenty-four inches above the bankfull water surface elevation. Riparian seeding will also be applied in conjunction with other riparian revegetation measures such as willow plantings and perennial tubelings.

Riparian and Upland Seeding: Due to sediment transport/deposition issues, and hydraulic and geomorphic conditions, the average floodplain bench is located 2.25' above the base flow water surface elevation. Both riparian and upland species can exist at this elevation, however, upland species are more common. The Design Team worked with the BCPOS Restoration Ecologist to establish a seeding treatment of 70% upland seed and 30% riparian seed for these areas. By seeding with both upland and riparian seed in areas that are greater than 24" above the base flow water surface elevation, the Design Team can ensure successful revegetation of either or both upland and/or riparian species.

Willow Stakes: Willow stakes will be harvested onsite and will be predominantly Coyote Willows and installed in areas between 12"-42" above the base flow water surface elevation. The stakes can be installed in a variety of locations including cobble areas and sandy alluvial soils. They can also be inserted into existing and proposed bank stabilization structures to create a living grid of organic matter that will enhance stabilization measures.

Willow stakes can either be installed by hand or machinery depending on their application. All willow stakes will be inserted to contact the water table.

Cottonwood Poles: Cottonwood poles will be a key revegetation element for this project. Poles can be used in place of 40 CI container plantings where access to the water table is difficult to reach. Poles can be harvested onsite from the sapling cottonwoods that have begun to colonize since the floods. These saplings are congregated in dense clusters primarily around historic wetland areas. By transplanting saplings or using them as poles, the Design Team will disperse these native eco-types in the productive areas of the site, reducing the competition and congestion in the areas of secondary succession, while revegetating damaged areas.

Cottonwood poles are also an affordable revegetation option. By harvesting the poles onsite, the only cost will include labor for their harvesting and installation. The installation method is similar to the willow stakes in that the most important factor for survival is access to the water table.

Tree and Shrub plantings: Tree and shrub plantings will be abundant on this project and will be located in areas that receive riparian and upland seeding. Large trees and shrubs will be placed in locations identified on the plans. Small shrubs will be placed in naturalized stands of 3, 5, 7 and 9 with direction from the Landscape Designer and Boulder County Representative. Small shrubs will cover approximately 32% of riparian and upland areas creating rich biodiversity and habitat throughout the Project site.

All trees and shrubs will either be 40 CI or 14 Inches, as described on Table 15. Boulder County's Flood Recovery Plant Materials List

Perennial Tubelings: Due to cobbly soils and high creek banks, perennial tubelings will be used sparingly within this project site. Perennial tubelings will only make up 1.24 acres and be planted at 3' on center in locations that are below 12" from the water table. They will be placed in groupings located in low velocity areas and at the mouths of specific over flow channels, where inundation will more gradually occur.

All perennial tubelings will be 10 CI and will be of varieties as described in Table 15. Boulder County's Flood Recovery Plant Materials List.

Scientific Name	Common Name	Size / Form
RIPARIAN SHRUBS AND TREES		
Acer glabrum	mountain maple	40 CI
Alnus incana ssp. tenuifolia	thinleaf alder	40 CI
Amelanchier alnifolia	serviceberry	40 CI
Amorpha fruiticosa	leadplant	40 CI
Betula occidentalis	water birch	40 CI
Chrysothamnus nauseosus	rubber rabbitbrush	40 CI
Cornus sericea ssp. sericea	red-osier dogwood	40 CI
Humulus lupulus var. neomexicanus	hops	40 CI
Pinus ponderosa	Ponderosa pine	40 CI
Populus angustifolia	narrowleaf cottonwood	40 CI
Populus angustifolia	narrowleaf cottonwood	14 inch
Populus deltoides var. monilifera	plains cottonwood	14 inch
Prunus americana	american plum	40 CI
Prunus virginiana var. melanocarpa	chokecherry	40 CI
Ribes aureum	golden currant	40 CI
Ribes cereum	wax currant	40 CI
Ribes inerme	white-stem gooseberry	40 CI
Rosa woodsii	Wood's rose	40 CI
Salix amygdaloides	peachleaf willow	40 CI
Salix amygdaloides	peachleaf willow	14 inch
Salix exigua	coyote willow	40 CI
Salix irrorata	bluestem willow	40 CI
Symphoricarpos albus	common snowberry	40 CI
Symphoricarpos occidentalis	western snowberry	40 CI
WETLAND		
Asclepias incarnata	marsh milkweed	10 CI
Asclepias speciosa	showy milkweed	10 CI
Calamagrostis canadensis	bluejoint reedgrass	10 CI
Carex emoryii	Emory's Sedge	10 CI
Carex nebrascensis	Nebraska sedge	10 CI
Carex pellita	woolly sedge	10 CI
Carex praegracilis	clustered field sedge	10 CI
Eleocharis palustris	creeping spikerush	10 CI
Glyceria grandis	American mannagrass	10 CI
Helianthus nuttalii	Nuttall's sunflower	10 CI
Juncus balticus	Baltic rush	10 CI
Juncus torreyi	Torrey's rush	10 CI
Panicum virgatum	switchgrass	10 CI
Scirpus microcarpus	small fruited bulrush	10 CI
Spartina pectinata	prairie cordgrass	10 CI
Verbena hastata	blue vervain	10 CI

Table 15. Boulder County's Flood Recovery Plant Materials List

Wetland Sod and Riparian Sod: The Design Team will use wetland sod and riparian sod as part of this project. Wetland and riparian sods are made from native plant material grown from local seed in coconut fiber blankets and installed along the creek channel for immediate revegetation. Seed will be harvested from within the project site and grown specifically for this project by a reputable supplier. That will provide an eco-type planting that will have immediate growth and be naturally adapted to this area.

Wetland and riparian sod is costlier than traditional revegetation materials and their application on this project has been discussed with BCPOS Restoration Ecologist. The Design Team recommends installing wetland and riparian sod in protected areas of high visibility. This will immediately improve the aesthetics of the surrounding area, and increase bank stability directly after construction.

Figure 44. Wetland/Riparian Sod during installation: May 2016

Figure 45. Wetland/Riparian Sod: July 2016

Bioengineering and Bank Stabilization Measures: Bioengineering is a method of engineering utilizing natural materials and living systems to stabilize streambanks in a manner that is conducive with natural stream processes.

This project aims to provide dynamic stability, which infers that the channel boundaries will be allowed to shift over time at a natural rate. However, the current South St. Vrain Creek system has a severely degraded riparian zone, so the bank soils lack root binding which leaves the channel susceptible to frequent avulsions. The Design Team found it paramount to stabilize vulnerable banks through a variety of bioengineering methods that incorporate living plant material into the streambanks for increased erosion protection and bank stability.

Boundary Category	Boundary Type	Permissible Shear Stress (lb/ft^2)	Permissible Velocity (ft/sec)	Citation(s) (see below)
Soils	Fine Colloidal sand	0.02 – 0.03	1.5	A
	Sandy loam (noncolloidal)	0.03 – 0.04	1.75	A
	Alluvial silt (noncolloidal)	0.045 – 0.05	2	A
	Silty loam (noncolloidal)	0.045 – 0.05	1.75 – 2.25	A
	Firm loam	0.075	2.5	A
	Fine gravels	0.075	2.5	A
	Stiff clay	0.26	3 – 4.5	A, F
	Alluvial silt (colloidal)	0.26	3.75	A
	Graded loam to cobbles	0.38	3.75	A
	Graded silts to cobbles	0.43	4	A
	Shales and hardpan	0.67	6	A
Gravel / Cobble	1-in.	0.33	2.5 – 5	A
	2-in.	0.67	3 – 6	A
	6-in.	2.0	4 – 7.5	A
	12-in.	4.0	5.5 – 12	A
Vegetation	Class A turf	3.7	6 – 8	E, N
	Class B turf	2.1	4 – 7	E, N
	Class C turf	1.0	3.5	E, N
	Long native grasses	1.2 – 1.7	4 – 6	G, H, L, N
	Short native and bunch grass	0.7 – 0.95	3 – 4	G, H, L, N
	Reed plantings	0.1 – 0.6	N/A	E, N
	Hardwood tree plantings	0.41 – 2.5	N/A	E, N
Temporary Degradable Rolled Erosion Control Products (RECPs)	Jute net	0.45	1 – 2.5	E, H, N
	Straw with net	1.5 – 1.65	1 – 3	E, H, N
	Coconut fiber with net	2.25	3 – 4	E, M
	Fiberglass roving	2.0	2.5 – 7	E, H M
Non-Degradable RECPs	Unvegetated	3.0	5 – 7	E, G, M
	Partially established	4.0 – 6.0	7.5 – 15	E, G, M
	Fully vegetated	8.0	8 – 21	E, G, M
Riprap	6-in. D_{50}	2.5	5 – 10	F, L ,M
	9-in. D_{50}	3.8	7 – 11	H
	12-in. D_{50}	5.1	10 – 13	H
	18-in. D_{50}	7.6	12 – 16	H
	24-in. D_{50}	10.1	14 – 18	E

Figure 46. Permissible Shear and Velocity for Selected Lining Materials (Giordanengo, 2016)

Bioengineering treatments are a natural approach to achieving long-term dynamic stability and ecological function, but they carry more short-term risk than hardened approaches (e.g., riprap) since they require mature bank vegetation to maximize the erosion resistance. Published design standards, such as *Living Streambanks*, provide guidance for the “initial” and “ultimate” flow resistance (allowable shear and velocity) for various treatment types. According to *Living Streambanks*, “The period following construction is a critical time of risk because the root systems of plants have yet to become fully established” (Giordanengo, 2016). That is why the implementation of bioengineering initiatives requires a balance between addressing short-term risks with the tolerance for natural adjustments. The majority of the South St. Vrain Creek project site poses relatively minimal risk to infrastructure, so a moderate tolerance for natural adjustments during unanticipated high flow events immediately following construction was deemed appropriate in areas with minimal risk to infrastructure. However, in areas where the protection of infrastructure is essential, more robust bioengineering and bank stabilization methods are proposed.

Two methods of bioengineering were used to address areas that pose a relatively minimal risk to infrastructure and areas where it was important to have infrastructure protection. Plant-based bioengineering treatments, such as willow staking and live willow fascines, were used in areas where the risk to infrastructure was low. Structural-based bioengineering treatments, such as rootwads and boulder toes, were used in areas where the risk to infrastructure was greatest (Giordanengo, 2016). Treatments near infrastructure have a low tolerance for failure, so hardened approaches were considered where necessary to provide immediate protection against the ultimate design discharge (i.e., 100-year).

The integration of plant-based and structural-based bioengineering methods will be the predominant method of stabilization and incorporates traditional hardened approaches, such as vegetated riprap with softer stabilization strategies such willow staking. The structural-based treatments will resist higher velocities in the short term directly after construction allowing the plant’s root network to expand and further stabilize the creek banks.

The Design Team referenced the Permissible Shear and Velocity for Selected Lining Materials (Figure 46) and the Permissible Shear Stress and Velocity Levels for Streambank Bioengineering Treatments found in *Living Streambanks: A Manual of Bioengineering Treatments for Colorado Streams* to develop the bioengineering treatments used for this project. (Giordanengo, 2016).

Bioengineering Treatment	Permissible shear stress (lb./ft2)	Permissible velocity (ft./s)
Live poles (Dependent on length of poles & nature of the soil)	Initial: 0.5 to 2 Established: 2 to 5+	Initial: 1 to 2.5 Established: 3 to 10
Live poles in woven coir TRM (Dependent on installation & anchoring of coir)	Initial: 2 to 2.5 Established: 3 to 5+	Initial: 3 to 5 Established: 3 to 10
Live poles in riprap (joint planting) (Dependent on riprap stability)	Initial: 3+ Established: 6 to 8+	Initial: 5 to 10+ Established: 12+
Live brush sills with rock (Dependent on riprap stability)	Initial: 3+ Established: 6+	Initial: 5 to 10+ Established: 12+
Brush mattress (Dependent on soil conditions & anchoring)	Initial: 0.4 to 4.2 Established: 2.8 to 8+	Initial: 3 to 4 Established: 10+
Live fascine (Very dependent on anchoring)	Initial: 1.2 to 3.1 Established: 1.4 to 3+	Initial: 5 to 8 Established: 8 to 10+
Brush layer / branch packing (Dependent on soil conditions)	Initial: 0.2 to 1 Established: 2.9 to 6+	Initial: 2 to 4 Established: 10+
Live crib wall [Dependent on nature of the fill (rock or earth), compaction & anchoring]	Initial: 2 to 4+ Established: 5 to 6+	Initial: 3 to 6 Established: 10 to 12
Vegetated reinforced soil slopes (VRSS) (Dependent on soil conditions & anchoring)	Initial: 3 to 5 Established: 7+	Initial: 4 to 9 Established: 10+
Grass turf - Bermuda grass, excellent stand (Dependent on vegetation type & condition)	Established: 3.2	Established: 3 to 8
Live brush wattle fence (Dependent on soil conditions & depth of stakes)	Initial: 0.2 to 2 Established: 1.0 to 5+	Initial: 1 to 2.5 Established: 3 to 10
Vertical bundles (Dependent on bank conditions, anchoring, & vegetation)	Initial: 1.2 to 3 Established: 1.4 to 3+	Initial: 5 to 8 Established: 6 to 10+

Figure 47. Permissible Shear Stress and Velocity Levels for Streambank Bioengineering Treatments (Giordanengo, 2016)

For this project, the following design criteria were applied to bioengineering treatments:

- In the short term, the modeled shear stresses and velocities for the 5-year peak discharge were used for allowable "initial" velocities for bioengineering treatments. The velocities during the 5-year peak discharge were modeled and evaluated and bioengineering treatments were developed to withstand the "initial" permissible velocities of the 5-year peak discharge. See Table 17. Bank Stabilization: Bioengineering Treatments.
- In areas especially susceptible to widespread erosion and/or avulsion (i.e., outer meanders, undesirable flow paths established during 2013 flood), toe protection measures such as coarse substrate or large wood will be used as a structural-based bioengineering technique to help mitigate short-term risks. This is especially effective given the fact that the upper bank is less susceptible to erosion since shear stress decreases with depth. Therefore, a bank segment with toe protection would immediately be able to withstand a discharge much larger than the 5-year event.
- As vegetation establishes, the bank will become progressively more resistant to hydrodynamic forces. Within approximately four years, the bioengineered treatment is often able to withstand a flow event that approaches the ultimate design flow (i.e. 50-year flow).
- The following is an example of how risk of bioengineering failure may decrease over time (this example does NOT include toe protection measures):
    - A 5-year flow has a 20% probability of occurring in the first year following construction. Assuming the vegetation is partially established by Year 2, the channel will be able to resist a flow event larger than the 5-year flow. However, it is important to note that there is limited information in the literature about the transitional period between installation and full establishment of vegetation. For the sake of demonstration, if the treatment is able to withstand a 5-year flow in Year 1, a 10-year flow by Year 2, a 25-year flow by Year 3, and a 50-year flow by Year 4, the risk of "failure" is dramatically decreased. See Table 16. Bioengineering Treatment Assessment:

Year (N)	Allowable Recurrence Interval	Probability of Flow Exceeding Allowable Recurrence Interval in the "Nth" Year
1	5 Year	20%
2	10 Year (assumed)	10%
3	25 Year (assumed)	4%
4+	50 Year (assumed)	2%

Table 16. Bioengineering Treatment Assessment

The Design Team used these design criteria to evaluate the permissible velocities of bioengineering treatments and created a map showing the velocities of the proposed condition during a 5-year peak discharge. This map was then analyzed and used to apply bioengineering treatments in locations that would withstand the "initial" velocities during the 5-year event. See Figure 48 5-year Peak Discharge Velocities.

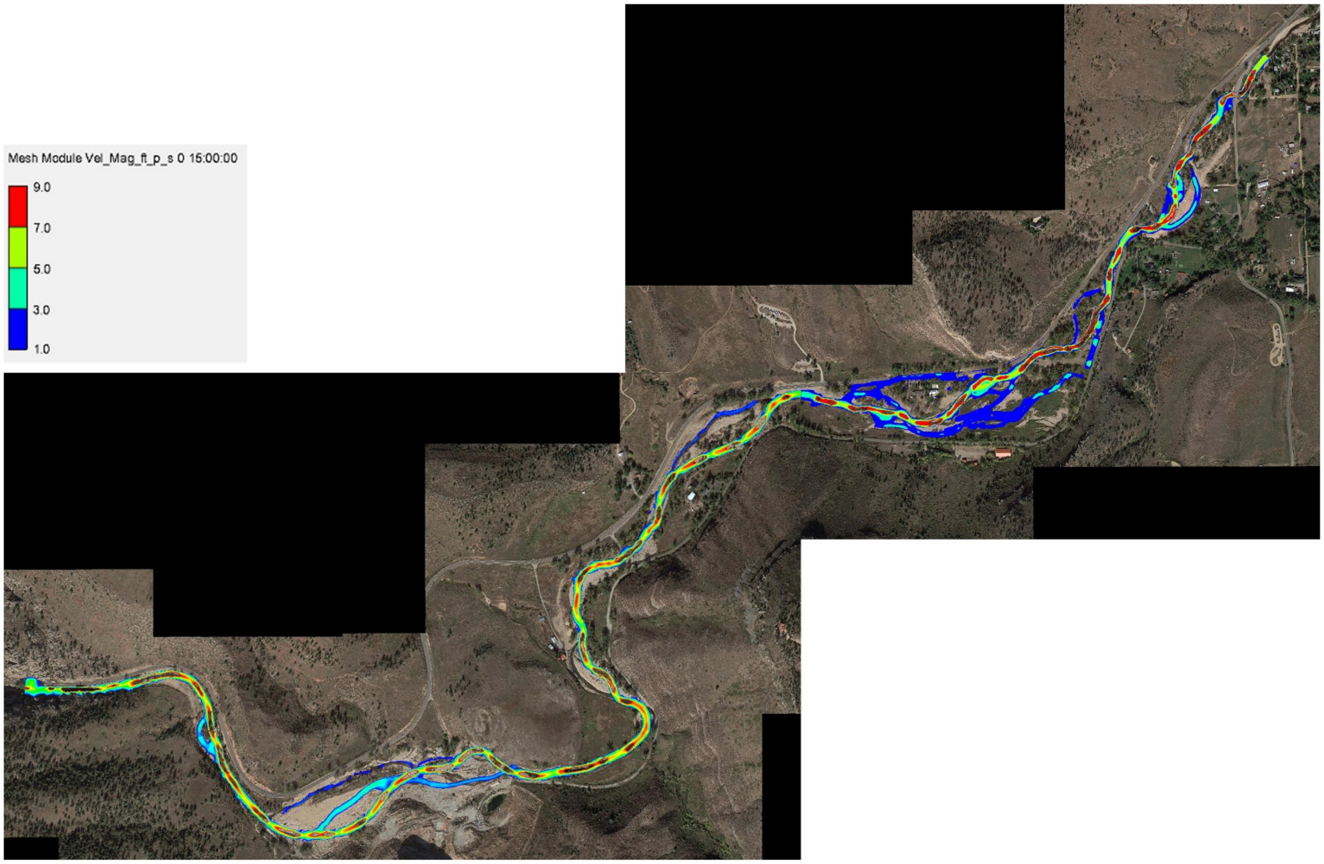


Figure 48. 5-year Peak Discharge Velocities

The velocity map shows creek flows between 1-9+ feet per second (ft/s) at the 5-year peak discharge. Specific locations where velocities were higher and/or infrastructure needed to be protected were selected to receive bioengineering treatments that would resist initial velocities greater than or equal to the 5-year peak discharge ensuring increased protection of vital assets. The bioengineering treatments used are identified per area in Table 17. Bank Stabilization: Bioengineering Treatments.

Bank Stabilization: Bioengineering Treatments

September 14, 2016

	Bioengineering Treatment	Channel	STA Start	STA End	Total Length (lf.)	Initial Premissible Velocity (ft./s)	Established Premissible Velocity (ft./s)
1	Willow Stakes in Riprap	Main	168+96	176+79	839	5 to 10	12+
2	Willow Stakes in Cobble Toe	Main	148+55	158+43	1028	5 to 10	10+
3	Willow Stakes in Riprap	Overflow 2 (5 year)	5+67	12+39	657	5 to 10	12+
4	Willow Stakes in Riprap	Overflow 3 (1.5 year)	2+53	4+40	254	5 to 10	12+
5	Willow Stakes in Cobble Toe	Main	131+47	134+46	308	5 to 10	10+
6	Willow Stakes in Riprap	Main	119+73	126+72	765	5 to 10	12+
7	Willow Stakes in Cobble Toe	Main	116+47	119+73	308	14 to 18	18+
8	Willow Stakes in Riprap	Overflow 5 (5 year)	8+21	12+71	500	5 to 10	12+
9	Live Willow Fascine	Main	111+68	114+85	355	5 to 8	8 to 10+
10	Live Willow Fascine	Main	110+30	111+97	182	5 to 8	8 to 10+
11	Willow Stakes in Cobble Toe	Main	108+45	110+50	225	5 to 10	10+
12	Boulder Toe	Main	101+67	106+43	474	14 to 18	18+
13	Boulder Toe	Main	100+70	104+22	370	14 to 18	18+
14	Willow Stakes in Riprap	Main	98+47	102+14	450	5 to 10	12+
15	Willow Stakes in Cobble Toe	Main	97+13	100+13	316	5 to 10	10+
16.1	Willow Stakes in Riprap	Main	95+31	96+53	119	5 to 10	12+
16.2	Willow Stakes in Riprap	Overflow 6 (1.5 year)	10+54	13+59	298	5 to 10	12+
17	Willow Stakes in Cobble Toe	Main	89+91	95+55	556	5 to 10	10+
18	Willow Stakes in Cobble Toe	Main	85+28	89+08	399	5 to 10	10+
19	Willow Stakes in Riprap	Main	77+89	83+02	522	5 to 10	12+
20	Willow Stakes Cobble Toe	Main	76+39	77+33	95	5 to 10	10+
21	Live Willow Fascine	Main	72+86	77+50	469	5 to 8	8 to 10+
23	Live Willow Fascine	Overflow 10 (1.5 year)	0+78	2+07	126	5 to 8	8 to 10+
24	Boulder Toe	Main	68+63	71+86	352	14 to 18	18+
25	Boulder Toe	Main	65+75	68+13	248	14 to 18	18+
26	Live Willow Fascine	Main	65+00	67+05	206	5 to 8	8 to 10+
27.1	Willow Stakes in Cobble Toe	Overflow 9 (1.5 year)	0+00	1+01	160	5 to 10	10+
27.2	Willow Stakes in Cobble Toe	Overflow 11 (1.5 year)	1+10	1+64	55	5 to 10	10+
28	Live Willow Fascine	Main	51+48	56+84	583	5 to 8	8 to 10+
29	Boulder Toe	Main	44+75	49+88	503	14 to 18	18+
30	Live Willow Fascine	Main	45+88	47+39	154	5 to 8	8 to 10+
31	Vegetated Reinforced Soil Slopes	Main	42+83	45+09	356	4 to 9	10+
32	Willow Stakes in Cobble Toe	Overflow 13 (5 year)	33+29	8+77	829	5 to 10	10+
33	Willow Stakes in Riprap	Overflow 13 (5 year)	0+28	8+11	823	5 to 10	12+
34	Willow Stakes in Cobble Toe	Main	31+06	36+00	514	5 to 10	10+

Total Willow Stakes in Riprap	5227
Total Willow Stakes in Cobble Toe	4793
Total Boulder Toe	1947
Total Live Willow Fascine	2075
Total Vegetated Reinforced Soil Slopes	356

Notes:

1. All bioengineering treatments and assicated permissable vocities were sourced from references in the Manual of Bioengineering Treatments for Colorado Streams.
2. Permissable velocity for Willow Stakes in Cobble Toe was approximated by using the information from Table 4 - Permissible Shear and Velocity for Slected Lining Materials (Fischenich, 2001) and Table 5 - Permissible Shear Stress and Velocity Levels for Streambank Bioengineering Treatments found in the Living Streambanks: A Manual of Bioengineering Treatments for Colorado Streams (Living Streambanks, 2016)

Table 17. Bank Stabilization: Bioengineering Treatments

13. Additional Design Elements

There are a few design elements that have been developed based upon comments received from stakeholders. A majority of these items are outside the scope of this Project, and furthermore are not eligible for funding under the current EWP projects. Nonetheless, the Design Team evaluated these areas and have provided design recommendations that can be evaluated further under different planning and design projects.

a. Large Woody Material

There have been discussions with the Project team and BCPOS staff along with the Boulder Office of Emergency Management to ensure the designs as part of this Project address woody vegetation management as much as possible under this contract. Site evaluations throughout the entire 3.2 mile reach evaluated potential woody vegetation that might meet requirements. It is noted that further investigations by the Boulder Office of Emergency Management (OEM) are required to ensure a safe riverine corridor and that County guidelines are followed.

Woody vegetation management along the corridor has already taken place prior to the Project. Emergency debris removal, which was funded by FEMA, removed debris within the post-flood channel below the 5-year flow event. This occurred primarily near the Andesite Bridge, the Old St. Vrain Bridge, and along the southern high flow channel where it was constrained within existing vegetation. The OEM also conducted site visits with coalition members and homeowners to evaluate woody vegetation along the South St. Vrain Creek.

Following the guidelines below, the Design Team evaluated the 3.2 mile stretch of South St. Vrain Creek for potential locations of woody vegetation management. Included on the plans are locations where woody vegetation might need to be evaluated by OEM for potential removal. Below are discussions about large woody material, including the natural benefits in the corridor along with management guidance from Boulder County and EWP.

i. Benefits

Woody vegetation in a creek corridor is a natural process and evident along most creeks. Woody vegetation accumulates in rivers through biological and physical processes. Accumulation of vegetation generally occurs at specific sites along the corridor. Woody material can play in important role in the ecological processes of a stream by providing habitat structure and food sources for a variety of organisms, aquatic and terrestrial. Woody vegetation can also provide ecological benefits at an ecosystem level outside of the creek environment. The amount of nutrient cycling and energy transfer in a stream ecosystem is often related to the amount of wood present in the stream (Wallace et al., 1993). By retaining the debris, macroinvertebrates are able to process it into a form, through shredding and filtering, that can be used as a food resource and incorporated into the food web. If retention of this woody vegetation did not occur, the nutrients and energy in the organic debris would be transported downstream.

Large woody vegetation can also influence the geomorphology of a stream through alteration of sediment transport and storage, channel dynamics and processes. At the channel unit scale, wood affects bed and bank erosion and influences the size and type of individual pools, bars, and steps. Large woody vegetation diversifies the velocity of water within a stream channel (Rutherford et al., 2002). Localized increases and decreases in velocity near LWD cause scour and deposition, respectively. Directly downstream from a channel spanning log, water velocity increases due to the flow being constricted. Upstream of a channel spanning log, velocity can decrease, creating sediment bars. Typically, erosion will occur directly downstream of LWD due to increased water velocity and scour, whereas deposition is more likely on the upstream end of LWD due to the decreased water velocity (JF New, 2007).

ii. Boulder Office of Emergency Management Guidance

Homeowners and stakeholders have expressed concerns with some of the woody vegetation along the South St. Vrain Creek corridor. While woody vegetation can be a benefit to the ecology and biology of a riverine corridor woody, vegetation under certain situations can increase flood risks. Understanding this risk, Boulder County led a significant effort to identify high hazard locations along all creeks and rivers in Boulder County. Boulder Office of Emergency Management released a report titled, "Threat Hazard Identification and Risk Assessment" (THIRA). This report provides guidance to the county, coalitions and other officials about the steps that need to take place to manage wood vegetation in river corridors.

This report outlined that FEMA supplied funding that reimbursed vegetation clearing activities prior to the 2014 spring runoff. Currently issues related to woody vegetation are addressed in the long term recovery projects of the watershed coalitions and the County's *Emergency High Hazard River and Creek Program*. The Emergency High Hazard Program is designed to act once a report is made into the Boulder Sheriff's Communications Center by a resident or business owner. Deputies and road crews are dispatched to evaluate the problem and if required act to stabilize the incident.

The aforementioned THIRA report documents criteria to evaluate the potential negative impacts of large woody material in a riverine corridor is summarized below:

Tree Criteria

- The fallen tree is in an identified hazard polygon.
- The tree is ¾ or completely spanning the river channel.
- The fall attitude is orthogonal within 70-110 degrees of creek or river flow.

Multiple Tree Removal Criteria

- The fallen tree is in an identified hazard polygon.
- The trees are 1/2 or completely spanning the river channel.
- The fall attitude is orthogonal within 70-110 degrees of creek or river flow.
- There are multiple trees (2 or more additional trees) within the visual observation area of the tree site upstream or downstream.
- There are signs of vegetation collection within the river or creek at the review site location.

Debris Dam Removal Criteria

- The debris dam is spanning ½ to 100% of the river or creek channel width.
- The debris dam is already or going to cause a change in flow around the dam causing erosion or cause water to back up.
- Further collection of woody vegetation is going to create a complete dam.
- Is this a potential flash flood CFS release situation?

The recommended solution advised by the Boulder Office of Emergency Management is a multi-year mitigation program that complements the watershed coalition activities moving forward. The program should be funded based on yearly assessments of hazard mitigation sites. This program, if implemented, addresses the gap that is not included in the longer term watershed coalition projects and emergency programs. In the meantime, citizens are recommended to call Boulder OEM offices when they see vegetation that might be of concern. The OEM office will then send out a representative to document the site conditions using a new program called Crisis Track that can document these site conditions on a smart phone with pictures and text.

A site visit by the Director of the Boulder OEM was completed with the Design Team members. This site visit evaluated the 3.2 mile reach of the South St. Vrain to note areas that meet the OEM guidelines for removal or warrants continued observations.

iii. EWP Program Woody Vegetation Guidance

EWP has potential funding for two reaches along the 3.2 mile corridor, which requires evaluation of EWP's guidance on large woody material. The EWP Program *Project Engineering Guidance* outlines the various removal aspects of woody vegetation in an EWP eligible Project. NRCS EWP funds may be used to remove all flood deposited anthropogenic vegetation (structural material, vehicles, appliances, etc.) and sediment (sand, gravel, cobble, boulders, etc.) where necessary to reduce threats to life or property by restoring the pre-flood hydraulic capacity of channels and floodplains (EWP, 2016).

NRCS recognizes the value of natural woody material in the riparian corridor where it supports ecological functions retains sediment and contributes to channel stability. Therefore, NRCS will not use funds from the EWP program to remove large woody material (4 or more inches in diameter) from impaired channels and floodplains, except where it is necessary to:

- Reduce threats to life or property by restoring the pre-flood hydraulic capacity of channels and floodplains.
- Reduce potential for large wood to accumulate at bridges, culverts, and other in-channel infrastructure in quantities that could cause damage or impair functions of those structures; or
- Facilitate construction of other in-channel recovery measures.

Clearing and snagging should only remove as much large wood as needed to reestablish the pre-flood capacity of the channel and floodplain. Large wood in the riparian zone should be left in place where it does not create a risk to life or property. Where possible, logs should be used to construct channel and bank stabilization measures. The following are some additional guidelines regarding large woody vegetation:

- To the extent possible, leave logs with a diameter greater than 1/3 the flow depth that are aligned or can be realigned at an angle less than 30 degrees with the direction of flow.
- Large wood with a diameter of less than 1/3 the flow depth left in the floodplain should be anchored.
- During mobilization to the construction site, minimize disturbance to the primary stream channel, side channels, and streambanks.

b. Longmont Diversion Structure

The Longmont diversion structure located near the downstream extents of the Project has been an area of concern for homeowners and stakeholders throughout the South St. Vrain Creek. The diversion structure is under the jurisdiction of the City of Longmont and the property is owned by the City of Longmont. The existing diversion structure underwent repairs as discussed earlier and had intended to have a sloping grouted drop structure at the downstream side of the diversion. Since the sloping structure was removed from the Project due to permitting issues, stakeholders requested further design elements be evaluated as part of this Project. The premise for the 30% construction designs as part of this Project were to evaluate stream restoration techniques assuming existing infrastructure, such as the diversion, would remain in place.

A few members of the public have suggested the relocation of the Longmont Diversion, which is owned and managed by the City of Longmont, to situate it in a location that may work better with the existing floodplain and stream flows. The idea has been called out in the preferred alternative and will continue to be included in the plan. It has been referred to as “master plan” level recommendations. This is due to the complexities associated with potential changes to this structures, the vetting of which is well beyond the scope of the current grant funding and contract. These issues include but are not limited to the need for high level engineering for design, legal ramifications with regard to water and property rights, permitting constraints, and the need to find the necessary funds for engineering and implementation of such projects. In addition, it is not appropriate to allocate additional time and resources to this level of analysis without the acceptance of the controlling agencies. Therefore, they will remain as potential future projects in the current plan, but the Project team will also continue to work within the existing conditions.

The Design Team evaluated potential alternatives that could be constructed in this location under future projects. One of the major concerns from stakeholders is that the 3-foot drop after the cross channel diversion has safety concerns along with potential influences on fish passage. Low head dams are known to cause safety risks due to the turbulent eddies that can form on the downstream side of these drops which can trap people underwater. While this area is closed to public recreational uses, this is an area known to be used by kayakers and fisherman, therefore design aspects are presented below to address both of these issues. The Team’s fishery biologist noted that only smaller and/or native species of fish are unable to pass this drop structure.

Another concern of the diversion structure is the possibility of the channel diverting around the structure to the south. In this location during the flood, the water scoured the inside of the bank where the concrete dam interfaced with the creek banks. The existing vegetation upstream of the diversion helped to stabilize the banks and floodplains so that the flood did not scour the bank further upstream, which could have caused more damage. Design elements will be evaluated to help preclude the banks from eroding in this location and activate the floodplain bench at the appropriate level.

i. Sloping Drop Structure or Stepped Drops

The Design Team considered reinstalling the sloping drop structure that was previously planned for this area. Design plans currently exist that could be implemented with minor modifications based upon this stream restoration project. A sloping drop would facilitate improved safety for recreational uses through this area. A sloping drop will also allow for a greater range of fish passage. It should be noted though that by increasing the elevation of the channel bed, there might be floodplain implications that need to be evaluated to ensure there is not a rise in the base flood elevations through this reach.

A series of stepped drop structures could also be designed to reach the same goals. By stepping the larger 4' impoundment down to a series of multiple smaller drops, the drop height at each structure could be reduced. This would improve fish passage for native and/or smaller species while also removing the low head dam.

ii. Fish Passage Channel or Sediment Sluice

Stakeholders have noted that sediment accumulates on the upstream side of this diversion and needs to be removed periodically. A sediment bypass channel or sediment sluice might alleviate the buildup of this sediment. This would constitute designing a small channel that could convey flow around the diversion structure itself to remove the buildup of sediment. The secondary feature of this channel is that it could also be used by fish to move upstream past the diversion. This channel would require some grading and potential vegetation removal to allow a stable slope that could match existing grades, upstream beyond the diversion.

iii. Relocation of Diversion Structure

Another possibility would be to install a new diversion structure further upstream than its current location. This diversion structure could be moved upstream at a location where a cross channel impoundment would not be required, but could still deliver water to its intended use. This is known as chasing grade upstream. The relocation of the diversion structure would allow recreationalists to safely pass this area while also improving fish passage. The location of the proposed division structure could be on the straight segment of the creek about 300 feet upstream along the right bank of the river.

c. South Ledge / Meadows Ditch Diversion Structure

As discussed previously, it has been noted that there is sediment building up in the newly combined diversion of the South Ledge and Meadows Ditch. Based upon field visits to the site, it can be seen that sediment is building within the diversion structure itself beyond where the sediment sluice can clear the sediment. During one of the site visits there was 1 to 3 feet of sediment in the diversion. The sediment sluice is located at the front of the structure so sediment cannot be removed from the back of the diversion itself except by physically shoveling sediment out of the structure.

There are a couple ways to address this issues. The first would be to either relocate the sediment sluice further within the diversion itself, or allow for a secondary sediment sluice that could be activated to allow sediment to wash out of the diversion back to the creek. Also, an in channel drop structure could be used to help promote clear water to enter the diversion by allowing the sediment to deposit on the upstream side of the drop structure.

d. Mathews / Holcomb Diversion Structure

One of the proposed projects that currently has founding from FEMA is the relocation and combining of the Mathews and Holcomb diversion structures. Both of these diversion structures provide water to ditches that irrigate fields along the South St. Vrain, however, both were washed away or damaged in the flood. The assumption is that the diversions will be combined and located in the vicinity of the Hall Ranch 2 Road Repair and Hazard Mitigation Project.

This location for the combined diversion is a good location due to its position on the outside of a river bend that will preclude sediment from entering the diversion, while there are also bedrock outcrops that can be used to anchor this diversion in place. A combined diversion was evaluated as part of this project. Ensuring that the creek is in a location where water can be diverted both horizontally and vertically is paramount to coordinate future designs. The 30% design plans call out the approximate horizontal and vertical location of the proposed features that would improve delivery of water the ditch.

Under the Old St. Vrain Road Bridge Project there currently are plans to install a 24” reinforced concrete pipe in the abutment so that the future alignment of the proposed ditch can convey water through the bridge safely. The vertical location of the diversion was evaluated based upon the invert of this 24” pipe, 5466.03’, at a minimum slope of 0.5% to the newly proposed location of the combined diversion, which constitutes a minimum elevation of the diversion at 5472.5’. The proposed invert of the channel at the combined diversion location is 5483. Therefore, a stabilized rundown at the diversion or increased slope of the ditch is necessary at this new location. Bank stabilization aspects along with buried riprap revetment are included with this design to protect the ditch infrastructure in critical locations.

e. Otto Diversion

The Otto Diversion was another vested water right diversion that was impacted by the 2013 flood. The diversion for the Otto Ditch was damaged during the flood and remnants of it are assumed to have been washed downstream. The pre-flood location of this diversion is along an andesite rock outcrop on the outside of a river bend near the Andesite Quarry. An evaluation of the pre-flood grade in the vicinity of the diversion compared to a post flood evaluation show that the area has actually degraded since the flood. Degradation could be the result of increased velocities around this bend due to the bedrock outcrop and scoured bed material.

The proposed design for the stream restoration in this area is to align the creek back to its pre-flood location so that a new diversion structure can be built in the future. The diversion might need to be relocated upstream further in order to catch grade with the diversion, which is allowed by Colorado Water Law within 500 feet without action through Water Court. The actual ditch alignment itself also needs to be monitored due to its proximity of a sloughing bank near the downstream Hall property where exigent NRCS work was completed.

f. Old St. Vrain Road Bridge

A few members of the public have suggested the replacement of the Old South St. Vrain Road Bridge, which is under the jurisdiction of Boulder County Transportation, to increase its hydraulic capacity. The idea has been called out in the preferred alternative and will continue to be included in the plan. It has been referred to as "master plan" level recommendations. This is due to the complexities associated with potential changes to this structures, the vetting of which is beyond the scope of the current grant funding and contract. These issues include, but are not limited to, the need for high level engineering for design, legal ramifications with regard to property rights, permitting constraints, and the need to find the necessary funds for engineering and implementation of such projects. Therefore, they will remain as potential future projects in the current plan, but the Project team will also continue to work within the existing conditions.

The existing hydraulic capacity of the bridge near the downstream extents of the Project on Old St. Vrain Road cannot convey a 100-year flood. The HEC RAS model of this bridge verifies that it cannot pass any storm greater than the 25-year event, 3,168 cfs. The current capacity of the bridge is about 4,200 cfs, which is about 3,000 cfs less than the revised 100-year hydrology of 7,234 cfs. Furthermore, the bridge was not designed to pass the pre-flood hydrology 100-year event.

The bridge will have approximately 1 foot of overtopping during the 50-year event and about 1.5 feet of overtopping during the 100-year event. It also should be noted that the majority of the overtopping in the HEC-RAS model occurs at the low point in the road, south of the bridge crossing. The existing opening for the bridge is about 403 square feet. In order to convey the entire 100-year storm through the bridge, the opening would need to be approximately 700 square feet, therefore increasing the size by about 75%.

The increase in needed area for conveyance could be completed by either increasing the vertical profile of the bridge and/or increasing the span of the bridge. Increasing the vertical profile of the bridge would require considerable grading to the south to raise the low point. Consequently, increasing the span of the bridge could lead to issues in the downstream channel where the existing bridge span does mimic the downstream channel width. Furthermore, reevaluation of the horizontal alignment of the bridge where the Old St. Vrain Road ties into Highway 7 could be engineered to allow for a more perpendicular crossing of South St. Vrain Creek and a safer intersection junction.

Consequently, in this scenario the bridge is not the limiting factor when evaluating floodplain aspects. Even if the capacity of the bridge is increased, the downstream capacity of the channel is still less than adequate to convey the entire 100-year storm. The channel downstream of the bridge cannot convey the 25-year storm adequately in the some of the downstream reaches. Therefore, during a 50-year storm and greater (in some places at a 25-year event) the creek spills out of its banks, inundating properties along the corridor. Backwater could potentially affect the conveyance capacity of the bridge. Increasing the size of the bridge to convey to 100-year event may still result in overtopping due to backwater and conveyance limitations of the downstream channel.

i. Connection of Overflow over Old St. Vrain Road towards Bohn Park

Due to the lack of conveyance capacity of the Old St. Vrain Road bridge at the downstream extents of the project and the channel downstream of that bridge, floodwaters overtop Old St. Vrain Road south of the bridge. This split flow that occurred in the 2013 flood will likely reoccur in this same path again in future floods of this magnitude regardless of the size of the bridge. This flow path was evident during the 2013 flood and was validated by the hydraulic modeling. While the project scope is limited to upstream of Old St. Vrain Road at this location, the Design Team evaluated potential channel aspects to convey the flow that overtops at this location back to the creek.

The project team developed an alternative to manage this split flow, which was an overflow channel that would direct the flow in a safe and resilient manner into Lyons. However, this alternative was adamantly opposed by members of the public even though the flood wave will travel in that direction under existing conditions. Therefore, this alternative, which occurs outside the planning area for the current study, was removed from further consideration, and the Project team continues to examine a modified alternative, which is an overflow channel that parallels the east side of Old South St. Vrain Road. This overflow channel would return this flow back to South St. Vrain Creek on the downstream side of the bridge. Ultimately, projects downstream of Old South St. Vrain Road will need to be coordinated with Lyons and the EWP #3 Project teams. This project provided necessary information to these other teams to determine if a viable and publically acceptable alternative exists.

g. Detention Along the Corridor

The public has requested examination of potential detention options available throughout the corridor. Upstream detention in the vicinity of the Andesite Quarry was vetted and evaluated in the St. Vrain Creek Master Plan (Baker, 2014). It was determined that there is a lack of significant reduction in downstream flood risk with the design of a detention facility in this area. There are also safety concerns with a dam of this height and scale at this location. Furthermore, it determined that such a facility would not be cost effective as a result of the large cost of designing, building, maintaining, and operating such a facility with limited public benefit.

The St. Vrain Creek Master Plan evaluated two different dam locations in vicinity of the Andesite Quarry to provide flood storage and peak flow attenuation. For the purposes of their evaluation, the maximum dam height was set to an elevation such that Highway 7 would not be inundated during maximum storage conditions. Highway 7 is a major highway that must remain operable for emergency service vehicles. There is a potential future evaluation that could examine the realignment of Highway 7 so that is located at a higher elevation to provide more storage, but is beyond the scope of this project. The Master Plan (Baker, 2014) evaluated the benefit for flood attenuation by comparing the maximum storage capacity of each dam alternative with the volume of the inflow hydrograph.

It was determined that neither detention alternative would be feasible to implement. Placing a dam at either location would inundate infrastructure upstream and would likely not provide enough peak flow attenuation to alleviate flooding downstream. For each alternative is was determined that only 7% and 18% of the 100-year peak flow would be attenuated at Sites 1 and 2, respectively. The dam at Site 1 would be 320 feet wide and 38 feet tall, while the dam at Site 2 would be 680 feet wide and 56 feet tall.

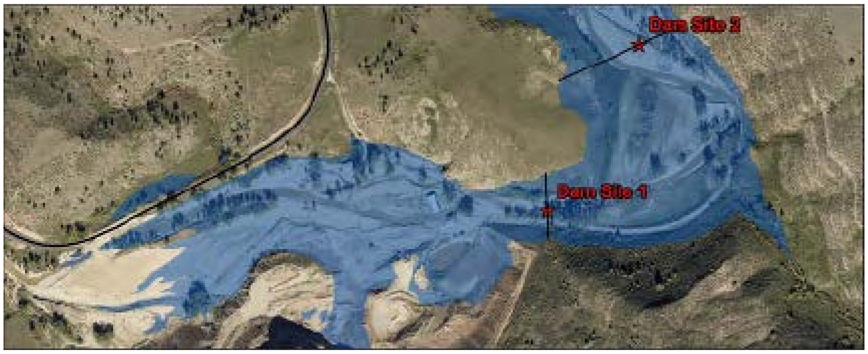


Figure 49. Alternative Dam Locations

A dam structure of this magnitude would cost a considerable amount of money in design, construction and maintenance, but not provide a significant amount of relief during a peak flood. Also the impoundment would cause significant loss of ecological and biological benefits throughout the corridor. Furthermore, the idea of a detention in this area does not fit with the purpose or vision of county open space. For these reasons, detention is considered unfeasible.

h. Andesite Quarry

Currently the Andesite Quarry, managed by Aggregate Industries, is in the process of submitting revised mine reclamation plans to the State after a 5-year cessation since mining. The Design Team met with stakeholders regarding the plans for the mine to coordinate design aspects. The Design Team was able to provide comments and inform Aggregate Industries of plans for this area while also learning their plans for the mine site.

In evaluation of the mine reclamation plans, the existing toe of slope along the quarry wall will remain in its current location and fill will be used to balance the slope to the top of the quarry. This will allow proposed stream restoration to be implemented in the future. The ultimate final plan for the mine reclamation has not been approved and is currently being reviewed by the State. The final mine reclamation plan should be evaluated once complete to ensure this project will not be affected.

The Design Team explored the use of excess fill material at the Andesite Quarry either from the EWP projects or other projects in the County that could benefit both parties. Furthermore, there were discussions of revegetating the corridor and implementing potential designs from this plan as part of their project for future funding applications. Incorporating elements from the stream restoration plan might allow Aggregate Industries to apply for various grants to help fund the Project.

14. Benefits of the Project

The resiliency objectives of the Project are to restore the stream channel in a way that both protects and increases the ability of critical infrastructure and environmental and cultural resources to withstand a future disaster, while reducing future recovery time by mitigating risks and assisting in local community disaster preparedness. Sustainability objectives have focused on reconstructing the channel in a way that protects the existing homes and built environment, while also improving the local economic, social and natural environments.

Resilience metrics for critical infrastructure included:

- Mitigation of flood erosion hazard upon roads and bridges through bank revetments and bioengineering.
- Increased sediment transport ability at ditch diversions and headgates which increases structural stability and function during flood.
- Re-direction of creek flows away from existing homes and roads using a geomorphic approach.
- Reduction of maximum stream flow velocity and erosion potential through increased floodplain connectivity and designed natural channel sinuosity.

Resilience metrics for environmental and cultural resources included:

- Using a natural channel design to increase bank and channel stability and to reduce restoration and regeneration time following future flooding.
- Providing in-stream habitat including riffles, pools, large wood, and point bars to restore and enhance the biological productivity of the creek.
- Reducing or eliminating hard engineering in the creek corridor where possible that will reduce stream velocity and increase long-term bank stability and ecological health.
- Promoting floodplain connectivity which alleviates erosion, speeds ecological regeneration and reduces impact on cultural resources within the floodplain by reducing flood velocities and avulsion hazards (such as at historic agricultural homes).

Sustainability metrics considered future home and business reconstruction, as well as economic, social and environmental revitalization, and must not compromise the needs of future generations. These include:

- Restoration of riparian and in-stream habitats.
- Construction of a native fish passageway for two ditch diversions which will significantly improve long-term stream habitat health.
- Planning the natural channel design of the stream to sustain long-term ecological health and reduce “hard” engineering features (i.e. using existing tree shade, increasing sinuosity, improving water quality, and large wood placement).
- Providing economic and social value to the surrounding community (i.e. enhanced trout fishery, Open Space aesthetics, and property values).
- Protecting homes and infrastructure in a way that considers the future (i.e. distanced channel alignments, reduced flow velocity, and sediment transportation).

The overall economic health of the corridor will also benefit from this Project. The design and eventual restoration and recovery of the St. Vrain Creek Watershed will foster the resilience and resurgence of the local economy surrounding St. Vrain Creek. The flood event caused millions of dollars in damages to area homes, businesses, and infrastructure. Damage to area roads and bridges led to a stoppage or reduction in business traffic and operations. The design plans contribute to improving the resiliency of the public roads and corresponding infrastructure that the community relies on for economic and personal welfare activities, as well as for emergency response vehicles. Restoring roads, bridges, creeks, parks and trails quickly and in a manner that mitigates against future hazards will help regenerate economic activity in the area.

15. Map and Acres of Areas Requiring Revegetation

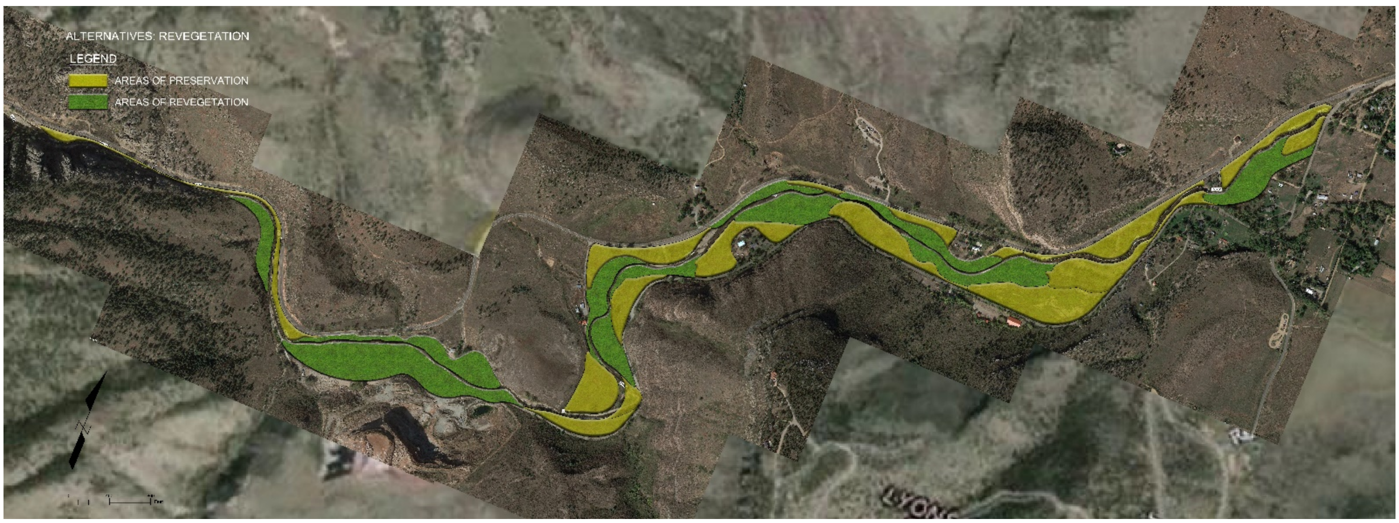


Figure 50. Areas Requiring Revegetation

The revegetation effort for this project will focus on preserving existing stands of mature and healthy vegetation and reconnecting the wetland, riparian and upland ecosystems through additional revegetation for the entire 3.2 miles.

The Design Team began by evaluating the most current aerial information to determine areas that survived the 2013 flood and where mature, healthy, native vegetation is thriving. Following the evaluation of the aerial imagery, the Design Team conducted field observations in which the initial “Areas of Preservation” were broken down in more detail and areas where healthy secondary succession is occurring were identified. Sensitive areas, such as the wetland in the EWP 1 reach, were also delineated by ERO, as part of this phase. All areas where mature, healthy, native vegetation exists, or where secondary succession is occurring and sensitive habitats are present were included in the “Areas of Preservation” and used as a guide for the limits of disturbance for this Project.

The same method was used to determine the “Areas of Revegetation”. These areas had been stripped of their vegetation during the 2013 flood and secondary succession has been slow to occur. “Areas of Revegetation” are characterized by a lack of healthy mature vegetation, lack of biodiversity, predominantly sandy soils and little to no floodplain connection. These areas will be identified where grading efforts will take place in order to increase the floodplain connectivity, re-established native revegetation and ultimately restore ecosystem function.

The "Areas of Revegetation" have been broken down into specific methods of revegetation based on the hydrology, soil condition, proximity to the water table, surrounding plant material as listed in Section 12.g – Revegetation Recommendations.

All methods of revegetation are shown in the 30% design plans and total areas of the each method are shown in Figure 51. Revegetation Area Totals.

Revegetation Total		
Revegetation Method	**Square Feet (SF)**	**Acres (AC)**
Willow Stakes	212025	4.87
Upland Seed	880431	20.21
Riparian Seed	294750	6.77
Perennial Tubelings	54115	1.24
Riparian / Upland Seed	615450	14.13
Wetland Sod	11375	0.26
Total Area	**2068146**	**47.48**

Figure 51. Revegetation Area Totals

16. Cut/Fill Estimates

Cut and fill estimates were developed for the entire 3.2 mile study area and then also subdivided into physical areas applicable to the cost estimates, see attached map in the Section 19. The cut and fill estimates are approximate at this level of design. Additional in depth survey will refine the existing grade to allow for a better comparison to proposed design grades. Also as designs are refined, boulder ribs along the main channel and sills in the overflow channel may allow areas to fill naturally rather than being filled during construction, which will reduce some of the large fill numbers described below. The overall goal of this project is to connect the floodplain, therefore a majority of the earthwork will be the removal of deposited sediment in order to allow the floodplain to be accessed. Below is table outlining the preliminary cut and fill volumes for these areas showing a net export of 79,147 cubic yards of material.

Table 18. Cut Fill Estimates

Location	Cut [cy]	Fill [cy]	Gross [cy]	Net [cy]	
Canyon to the Quarry	1,482	377	1,859	1,105	Cut
At Quarry	36,854	4,147	41,001	32,707	Cut
Quarry to EWP #1	5,172	2,274	7,446	2,898	Cut
EWP #1	21,871	2,407	24,278	19,464	Cut
EWP #1 to Longmont Diversion	3,610	352	3,962	3,258	Cut
Longmont Diversion to EWP #2	1,614	2,236	3,850	-622	Fill
EWP #2	668	283	951	385	Cut
OFC #1	1,282	13	1,295	1,269	Cut
OFC #2	961	8,026	8,987	-7,065	Fill
OFC #3	14,935	926	15,861	14,009	Cut
OFC #4	7,862	2,221	10,083	5,641	Cut
OFC #5	3,111	3,602	6,713	-491	Fill
OFC #6 & #7	5,047	1,710	6,757	3,337	Cut
OFC #8	6,489	1,170	7,659	5,319	Cut
OFC #9 & #11	1,239	763	2,002	476	Cut
OFC #10	65	996	1,061	-931	Fill
OFC #12	1,283	254	1,537	1,029	Cut
OFC #13	442	2,879	3,321	-2,437	Fill
OFC #14	65	996	1,061	-931	Cut
Total	**114,052**	**35,632**	**149,684**	**78,420**	Cut

BCPOS is tracking projects in need of fill or removal of excess material. As designs progress for the EWP areas, these other projects will be evaluated to determine appropriate locations where material can be disposed. The Andesite Quarry discussed the potential use of the project's excess material at the quarry for their reclamation plans.

The cut-fill balance for EWP #1 is almost four times greater than what was developed in the initial EWP scope of work. This is due to realignment of the creek to its pre-flood location, which has aggraded with sediment from the flood. Realignment is necessary because it will allow for a more resilient stream system with increased sinuosity and length along with protecting infrastructure. Reduction in the amount of cut required will be evaluated as designs progress to 80%.

Excess fill from the Longmont Diversion is available for the EWP #2 area due to filling in the existing channel and the large overflow channel to the south. The proposed design could be modified to allow for greater overflow channel widths along while allowing the areas to fill naturally.

17. Permit Plan

a. Summary of Permits

i. Clean Water Act (CWA)

All projects that could result in the discharge of dredged or fill material into a waters of the U.S. will require a Section 404 permit from the USACE required through the CWA. South St. Vrain Creek is considered a jurisdictional water of the U.S. The Project would likely affect wetlands associated with South St. Vrain Creek. Two levels of Section 404 permitting are possible:

- Authorization under a Nationwide Permit (NWP) – based on specific activities and have threshold limits, which generally allow up to ½ acre of impacts on waters of the U.S. including wetlands.
- Authorization under an Individual Permit (IP) – based on larger projects and generally do not have impact thresholds. IPs can take at least a year to authorize and require public comment.

Proposed work within identified EWP project areas will likely be permitted under NWP 37 for Emergency Watershed Protection and Rehabilitation. The description and limits for NWP 37 are listed below (taken from the Corps Omaha District website).

"*NWP authorized work funded by:*

- *The Natural Resources Conservation Service for a situation requiring immediate action under its emergency Watershed Protection Program (7 CFR part 624);*
- *The U.S. Forest Service under its Burned-Area Emergency Rehabilitation Handbook (FSH 2509.13);*
- *The Department of the Interior for wildland fire management burned area emergency stabilization and rehabilitation (DOI Manual part 620, Ch. 3);*
- *The Office of Surface Mining, or states with approved programs, for abandoned mine land reclamation activities under Title IV of the Surface Mining Control and Reclamation Act (30 CFR Subchapter R), where the activity does not involve coal extraction; or 21*
- *The Farm Service Agency under its Emergency Conservation Program (7 CFR part 701).*
- *In general, the prospective permittee should wait until the district engineer issues an NWP verification or 45 calendar days have passed before proceeding with the watershed protection and rehabilitation activity. However, in cases where there is an unacceptable hazard to life or a significant loss of property or economic hardship will occur, the emergency watershed protection and rehabilitation activity may proceed immediately and the district engineer will consider the information in the pre-construction notification and any comments received as a result of agency coordination to decide whether the NWP 37 authorization should be modified, suspended, or revoked in accordance with the procedures at 33 CFR 330.5.*

Notification: Except in cases where there is an unacceptable hazard to life or a significant loss of property or economic hardship will occur, the permittee must submit a pre-construction notification to the district engineer prior to commencing the activity." USACE requires submittal of a Preconstruction Notification (PCN), which includes a wetland delineation and determinations, as well as potential mitigation measures, to be covered under NWP 37.

Impacts on South St. Vrain Creek outside of the EWP areas would likely require authorization under a separate Section 404 permit. Depending on the nature and scale of future activities, authorization under one or more Nationwide or Individual Permits will likely be required.

ii. Endangered Species Act (ESA)

Section 10 of the Endangered Species Act (ESA) is designed to regulate a wide range of activities that affect endangered and threatened plants and animals and the habitats upon which they depend. Unless specifically allowed by permit, the ESA prohibits activities that affect listed species and their habitats. The U.S. Fish and Wildlife Service (FWS) may issue permits for purposes consistent with the conservation of the species. The ESA allows three different kinds of permits: incidental takes, enhancement of survival, and recovery and interstate commerce permits.

The project area is located in the overall range for federally listed threatened or endangered species that potentially occur in Boulder County – particularly ULTO, CBP, and Preble's. Trapping surveys for Preble's conducted in 1997 and 2015 yielded no captures; however, a capture in 2005 at Hall Meadows did yield a capture (Meaney, 2005). It is possible the Service would consider portions of the project area as "occupied" habitat for Preble's and request formal consultation under Section 7 of the ESA. According to conversations with Boulder County Open Space staff, ULTO surveys have been conducted. No ULTOs have been found, and there are no known seed sources along South St. Vrain Creek (Hirt 2016). Additionally, no known seed sources for the CBP exists in the project area and no known populations exist near the project area. The majority of the vegetation in wetland and riparian areas is possibly too dense to allow establishment of these species. Nonetheless, ERO recommends that Boulder County Open Space coordinate with the Service prior to construction.

iii. National Historic Preservation Act (NHPA)

As part of the federal process (i.e., Section 404 permitting), Section 106 (which requires an assessment of cultural or historic resources in the project area) of the NHPA must be addressed. It is possible that cultural resources or historic properties eligible for listing on the National Register of Historic Places occur in the project area. In addition to prehistoric artifacts, structures (e.g., railroads and bridges), irrigation ditches, and historic districts more than 50 years old are potentially eligible for listing. A cultural resource file search and Class III pedestrian survey would likely be necessary for the project area if a Section 404 permit were required.

The Project team recommends coordination with the permitting agencies during the conceptual Project development phase. Early coordination with the agencies typically allows for more of a streamlined permitting process. Contracting a permitting specialist is recommended to help facilitate the environmental permitting process. The current Project team is capable of supporting these needs.

iv. National Environmental Policy Act

The National Environmental Policy Act (NEPA) of 1969 was created to ensure federal agencies consider the environmental impacts of their actions and decisions. Federal agencies are required to systematically assess the environmental impacts of their proposed actions and consider alternative ways of accomplishing their missions, which are less damaging to and protective of the environment. NEPA Section 101(b) states "it is the continuing responsibility of the federal government to use all practicable means, consistent with other essential considerations of national policy" to avoid environmental degradation, preserve historic, cultural, and natural resources, and "promote the widest range of beneficial uses of the environment without undesirable and unintentional consequences". Each agency designates a "responsible official" who must ensure NEPA issues are addressed as part of the agency's actions. All agencies must use a systematic interdisciplinary approach to environmental planning and evaluation of projects which may have an effect on the environment.

The primary goals of NEPA (as per the BLM NEPA handbook) include:

- Requiring every Federal agency prepare a detailed document of the effects of “major Federal actions significantly affecting the quality of the human environment.”
- An alternatives analysis of those actions conducted by the agencies.
- Use of an interdisciplinary approach in developing alternatives and analyzing environmental effects.
- Requiring that each agency consult with and obtain comments or permits of any Federal agency which has jurisdiction by law or special expertise with respect to potential environmental impacts.
- Requiring that any federal, local tribal or municipal permits, statements, or comments be made available to the public.

Environmental analysis documents, which must be made available to the public, include environmental impact statements (EIS) and environmental assessments (EA) (40 CFR 1506.6(b)). Projects that are likely to include serious environmental effects require preparation of an EIS. If the environmental effects are unclear, then an EA is prepared.

v. Land Use Permit

A land use permit will also need to be acquired from Boulder County for construction implementation of this project. Acquiring a land use permit can be a timely endeavor. Working with project sponsors and BCPOS, the Design Team will help apply for the Land Use Permit for the EWP eligible project areas. BCPOS has initiated pre-application conversations with the Land Use Department for project aspects. It is recommended that a meeting be schedule at the onset of further design with the Boulder County Land Use Department to further this process.

The Boulder County Land Use department has developed a Limited Impact Special Use Review application for stream restoration projects. The application requires general information about the project with regard to flood damage, proposed action, volume of earthwork, linear feet of stream work, affected parcels, construction traffic access points, erosion control measures and landscaping details. The Land Use department has attempted to streamline the process to meet tight outside deadlines. The department has waived the fees for internal submittals.

More information can be found at:
http://www.bouldercounty.org/property/build/pages/buildingpermitreqs.aspx
http://www.bouldercounty.org/property/build/pages/lu.aspx

vi. Floodplain Development Permit

Any stream alteration activity must be evaluated for its impact on the regulatory floodplain and be in compliance with all applicable federal, state, and local floodplain regulations. If a stream has an identified Special Flood Hazard Area (SFHA) on an effective FEMA Flood Insurance Rate Map (FIRM) and the community participates in the National Flood Insurance Program (NFIP), then a floodplain development permit must be obtained for any proposed manmade activity in the SFHA before work begins. Since the flood, recommendations and guidelines for developing floodplain permits have changed requiring coordination with permitting agencies to determine permitting requirements and baseline information.

Evaluations for the floodplain development permit will compare existing conditions (post-flood) with post-flood hydrology developed through CDOT. A meeting with BCPOS floodplain department was conducted to verify hydrologic and hydraulic model inputs. The existing and proposed conditions 1D HEC-RAS model can be used to develop this permit to compare existing conditions base flood elevation to proposed conditions base flood elevations. In order to acquire a floodplain permit either a no-rise certification must be met or development of a CLOMR followed by a LOMR once construction is complete. The FEMA application fee to review CLOMR and LOMR applications is approximately $8,000.

Due to the tight deadline based upon funding it is imperative that the EWP eligible project areas show no-rise in the base flood elevations from the proposed work. The CLOMR process can require additional time for development and review which would impact the construction schedule and potentially limit funding. It will be the goal of this Design Team, as designs are refined, to show no rise in the base flood elevations through the EWP project areas. The Design Team will support BCPOS in applying for a floodplain development permit.

More information can be found at: http://www.bouldercounty.org/roads/permits/pages/floodcontrol.aspx

vii. Roadway Permits

Any work that might impact the roadways will require a permit from the appropriate agencies. This could either be CDOT for Highway 7 or Boulder County for Old St. Vrain Road. No proposed elements at this time impact the roadway. Recommendations are made with regard to the design of the eastern Old St. Vrain Road that could be visited with Boulder County Transportation.

viii. County Grading Permit

A county grading permit will be required for grading, excavation or placement of fill in excess of 50 cubic yards. It is recommended that a pre-application conference with a Land Use Department staff occur prior to the permit application being submitted. Required with the submittal is a grading plan with existing and proposed contours and calculations of grading, excavation or placement of fill to be move. Grading plans for a Limited Impact Special Use Review must be sealed by a qualified Colorado-licensed engineer. There is a fee associated with County Grading Permit, but might be waived in this case where Boulder County Parks and Open Space is the applicant.

ix. CDPHE Stormwater Discharge General Permit

A stormwater permit will be necessary for disturbance activities in excess of 1 acre. In order to apply for a stormwater permit a stormwater management plan must be developed that outlines best management practices to be used to limit the erosion and control sediment. The stormwater permit must be applied to both Boulder County and the Colorado Department of Public Health (CDPHE). CDPHE will issue a Water Quality Construction permit once approved.

CDPHE requires a permit for stormwater discharges associated with construction activities. A permit is required for projects involving one or more acres of land disturbance for construction activities including, but not limited to, clearing, grading, excavation, demolition, installation of new or improved haul and access roads, staging areas, stockpiling of fill materials, and borrow areas.

- A Stormwater Management Plan (SWMP) must be prepared that includes potential sources of pollution and descriptions of the Best Management Practices (BMPs) that will be implemented and maintained to adequately minimize pollutants in the stormwater discharge to assure compliance with the terms and conditions of the permit.
- At least 10 days prior to commencement of construction activities, the owner/operator of the construction site must submit an original completed Notice of Intent (NOI), which includes signed certification that the SWMP is complete.
- Once coverage under the General Permit is issued, the owner/operator must follow the conditions for coverage.
- Once all activities and discharges at the construction site have ceased and final stabilization has been achieved, the owner/operator must submit a Notice of Termination to CDPHE.

More information can be found at: http://www.bouldercounty.org/env/water/pages/stormwater.aspx
More information can be found at: https://www.colorado.gov/pacific/cdphe/wq-construction-general-permits

x. CDPHE Construction Dewatering Permit

CDPHE administers construction dewatering permits for construction activities. This general permit is to authorize discharges of construction dewatering source water associated with construction activities to waters of the State in Colorado. Construction dewatering source water can be groundwater, surface water, or stormwater that has commingled with the groundwater and/ or surface water. The permit only authorizes the discharge from the source water from the specific area(s) that has been identified in the permittee's application, or in subsequent notifications to the Division.

For construction dewatering permits, evaluations of potential contamination sources within proximity to the proposed construction site must be performed. If potential contamination sources are found in database searches, then no sampling of construction dewatering activities is required. If it is determined that a potential contamination sources is nearby, CDPHE can require sampling of discharged water and potentially reclamation of the contaminated water prior to discharge back into the stream course. In order to acquire the permit a description of the proposed work, investigation of potential contamination sources along with location of dewatering activities and proposed pumping rates must be provided. If no contamination is expected and a CDPHE Stormwater Permit is also applied for then a general Construction Dewatering Permit can be issued.

xi. Additional Permit Support Being Provided by EWP

Each EWP project must have an environmental review to comply with Federal Acts. This is being managed separately from permitting as part of the EWP Program. The Federal Acts that are being supported directly by the EWP Program are National Environmental Policy Act (NEPA), Endangered Species Act (ESA) and National Historic Preservation Act (NHPA).

b. Contacts

U.S. Army Corps of Engineers:
Kiel Downing – Regulatory Chief
Denver Regulatory Office
9307 South Wadsworth Boulevard
Littleton, Colorado 80128
303-979-4120
Kiel.g.downing@usace.army.mil

U.S. Fish and Wildlife Service:
Drue DeBerry – Colorado Field Supervisor
Colorado Ecological Services Field Office
134 Union Boulevard, Suite 670
Lakewood, Colorado 80228
303-236-4774
drue_deberry@fws.gov

Colorado Office of Archaeology & Historic Preservation:
Holly Norton – Director and State Archeologist
1200 Broadway, Suite 400
Denver, Colorado 80203
303-866-2736
holly.norton@state.co.us

Boulder County Land Use:
Dale Case
Courthouse Annex Building
2045 13th Street
Boulder CO, 80302
303-441-3930

Boulder County Floodplain Development Permit:
Varda Bloom
2525 13th Street, Suite 203
Boulder, CO 80304
303-441-3900
floodplainadmin@bouldercounty.org

County Stormwater Quality:
Boulder County Stormwater Management
3450 Broadway
Boulder, CO 80302
303-441-3926

State Stormwater Quality
CDPHE, Water Quality Control Commission
Margo Griffin
303-692-3607

c. Timelines

Understanding the time requirement of a permitting process is critical to completing a project on schedule. Depending on workloads and complexities of projects and funding sponsors the timeframe to complete permitting projects can vary greatly. It is recommended that individual meetings be set up with administrating agencies to ensure permit requirements are met and documented. Additional request for information can add delays to acquiring permits for the project. The Design Team will support BCPOS as they move the EWP project designs into construction in applying for necessary permits.

Floodplain permits requiring a CLOMR can required up to 6 to 9 months. If a no rise certification can be achieved, then a CLOMR may not be required which would save considerable time. County Land Use Permits can require additional time to acquire. Further discussions are necessary to determine the time frame for the Land Use Permit reviews. A Section 404 Permit application can require between 1 and 3 months to prepare depending on complexity of the projects. Early evaluations of potential project impacts can allow for a more efficient process. ESA Permits, which might not be required for this area, can also take 1 to 3 months. Endangered species can cause delays in construction though due to work restrictions during certain times of the year. Acquiring a Section 106 Permit can be very timely. Additional evaluation of the project area will need to be determined if a permit for NHPA would be required. Some permits may be applied for before the design is complete.

18. Implementation Plan and Timeline

The implementation plan and timeline of all proposed restoration activities along the South St. Vrain Creek is currently unknown. Additional funding needs to be secured to restore extents outside the EWP-eligible reaches. Priority projects outlined above could be constructed with other grants or funding sponsors to ensure a holistic design throughout the corridor. As discussed, two areas along the South St. Vrain Creek are currently eligible for construction funding through the EWP program.

The EWP project areas have the ability to be built this spring, therefore a plan needs to be developed to reach that goal. BCPOS is currently in the process of acquiring additional funding to allow the Design Team to advance the 30% designs for the EWP areas to 80% designs. This will allow for a more refined design and development of project specifications. Once these area designs are refined the design plans will be submitted to the EWP team in December 2016 for consideration for construction.

While the designs are being refined additional evaluations will take place to ensure permitting requirements are met. The timeline allows for approximately 3 months to finalize and acquire all the necessary permits. The Design Team will support BCPOS in applying for the various permits and ensure proper documentation takes place. The designs for the 80% aspects will be developed until final submittal to the EWP team at the end of January.

If BCPOS is awarded the funding for construction they will release a Request for Proposals to construct the two EWP-eligible reaches. The contractor selection and bidding process will be supported by the Design Team as necessary. Once a qualified contractor is selected and the appropriate permits acquired, construction will start. Construction is scheduled to start in the late winter before spring runoff. At this time, the EWP constructing funding must be complete before the end of 2017. The estimated total duration for construction is between 3 and 6 months. This mainly depends on the amount of snowpack and the duration of spring runoff. It could be recommended to not revegetate all construction areas until spring runoff has decreased to increase the chance of vegetation establishment.

Ongoing construction support will be provided by the Design Team to ensure the design is built per plan and will address any changes in the field. Once construction is complete the Design Team will support closeout procedures necessary including as-built verifications and post-construction monitoring.

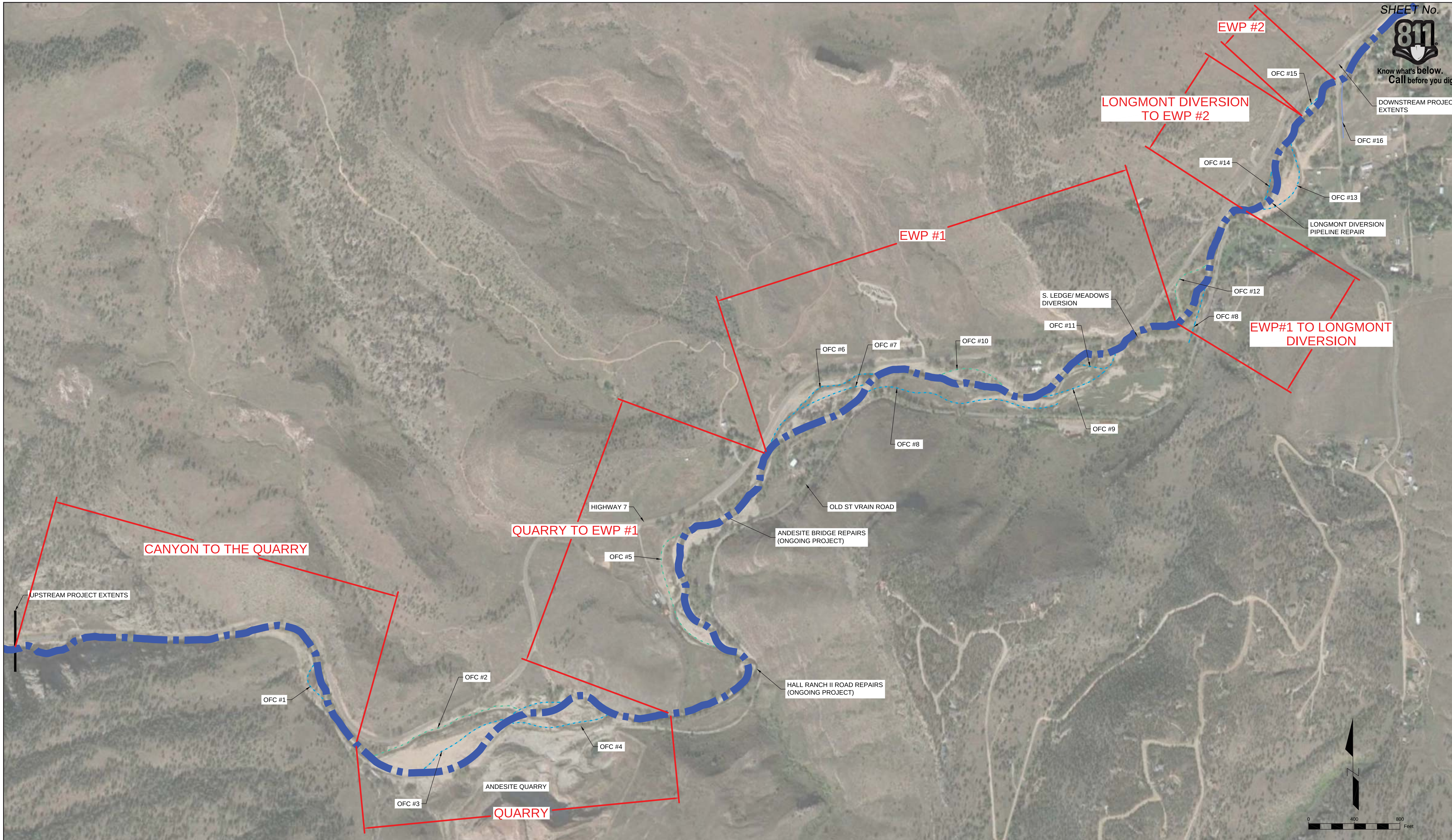
19. Opinion Probable Construction Costs

Anticipated construction costs have been developed as part of this 30% design. The cost presented below are approximated based upon 30% designs. Additional refinement of the costs shall be completed as designs move forward. Soft costs such as mobilization, surveying, water control, erosion control and engineering can vary greatly depending on the complexities of the project. Estimated percentages of the hard costs were used to develop cost estimates for these items. A contingency of 20% was also added to the costs.

For the purposes of estimating project costs, the 3.2 mile project area was broken out into distinct areas based upon physical constraints and geographical location (not necessarily following the geomorphic reach breaks). The areas were chosen to identify potential projects that could be (or should be) implemented together. This allows for a better understanding of approximate costs for potential projects and identification of the cost of a particular feature. See the map on the following page for cost estimate area extents.

The cost estimate for EWP #1 is greater than the developed budget by the EWP team. Design modifications will take place to ensure a restoration and design techniques developed can fit within the allocated construction budget. Additional funding could also be acquired to support construction.

A breakout of the costs per area and total is shown on the following pages.



REFERENCE DRAWINGS

812-TITLEBLOCK-22x34
AERIALS
Proposed Linework

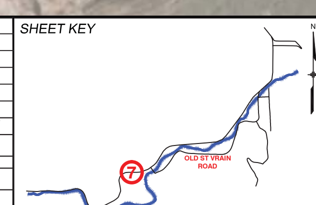
No.	DATE	DESCRIPTION	BY

REVISIONS

COMPUTER FILE MANAGEMENT

FILE NAME: R:\16.812.003 (South St Vrain Stream Restoration)\Dwg\Construction Plans\QUANTITY BREAKOUTS.dwg
CTB FILE: ----
PLOT DATE: 9/18/2016 4:10 PM
THIS DRAWING IS CURRENT AS OF PLOT DATE AND MAY BE SUBJECT TO CHANGE.

SHEET KEY



PREPARED FOR:

Boulder County Parks & Open Space

PREPARED BY:

Matrix DESIGN GROUP
AN EMPLOYEE-OWNED COMPANY

SEAL

PRELIMINARY
THIS DRAWING HAS NOT BEEN APPROVED BY GOVERNING AGENCIES AND IS SUBJECT TO CHANGE

FOR AND ON BEHALF OF MATRIX DESIGN GROUP, INC.
PROJECT No. 16.812.003

SOUTH ST. VRAIN CREEK RESTORATION

BOULDER COUNTY PARKS AND OPEN SPACE
30% DESIGNS

QUANTITY BREAKOUTS

DESIGNED BY: SDS	SCALE (22" X 34")	DATE ISSUED: 09/19/16	DRAWING No.
DRAWN BY: SDS	HORIZ. 1" = 400'		QUAN
CHECKED BY: RDK	VERT. N/A	SHEET 1 OF 1	

Table 19. Cost Estimate 1

South St Vrain Creek 30% Cost Estimate

Material	Unit Price	Pay Unit	Canyon to the Quarry Main Channel Sta 198+00 to Sta 160+79				Quarry Main Channel Sta 160+79 to Sta 129+68							
			Main Channel (Length ≈ 3,721 ft)		Overflow Channel #1 (Length ≈ 360 ft)		Main Channel (Length ≈ 3,111 ft)		Overflow Channel #2 (Length ≈ 1,358 ft)		Overflow Channel #3 (Length ≈ 1,255 ft)		Overflow Channel #4 (Length ≈ 846 ft)	
			Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
General Construction														
Mobilization	10%	LS	1	$6,880	1	$3,799	1	$96,781	1	$15,836	1	$33,320	1	$18,638
Water Control	10%	LS	1	$6,880	1	$3,799	1	$96,781	1	$15,836	1	$33,320	1	$18,638
Erosion Control	5%	LS	1	$3,440	1	$1,900	1	$48,391	1	$7,918	1	$16,660	1	$9,319
30% to 80% Engineering	10%	LS	1	$6,880	1	$3,799	1	$96,781	1	$15,836	1	$33,320	1	$18,638
Earthwork														
Earthwork, Excavation and Fill On-Site	$8	CY	377	$3,016	13	$104	4,147	$33,176	8,026	$64,208	926	$7,408	2,221	$17,768
Earthwork, Excavation and Haul Off-Site	$17	CY	1,105	$18,785	1,269	$21,573	32,707	$556,019	0	$0	14,009	$238,153	5,641	$95,897
Stream Restoration														
Buried Riprap Revetments	$90	CY		$0		$0		$0		$0		$0		$0
Instream Large Wood Structures	$5,500	EA	3	$16,500	0	$0	16	$88,000	0	$0	0	$0	0	$0
Floodplain Large Wood Structures	$5,000	EA	0	$0	0	$0	0	$0	1	$5,000	1	$5,000	2	$10,000
Habitat Boulders	$125	EA	0	$0	0	$0	300	$37,500	0	$0	0	$0	0	$0
Riffle-Pool Structures	$15,000	EA	0	$0	0	$0	9	$135,000	0	$0	0	$0	0	$0
Boulder Sills	$60	LF	0	$0	0	$0	0	$0	210	$12,600	0	$0	200	$12,000
Landscape														
Erosion Control Blanket	$4	SY	0	$0	1,173	$4,692	1,384	$5,536	0	$0	4,143	$16,572	2,290	$9,160
Seeding (Native)	$750	AC	0.60	$450	0.00	$0	4.63	$3,473	1.85	$1,388	2.43	$1,823	2.49	$1,868
Seeding (Riparian)	$3,000	AC	1.10	$3,300	0.70	$2,100	1.61	$4,830	0.22	$654	0.82	$2,460	0.79	$2,370
Soil Amendment	$1,600	AC	1.71	$2,736	0.73	$1,168	6.51	$10,416	2.07	$3,312	3.74	$5,984	3.33	$5,328
Hydro Mulch	$2,000	AC	0.60	$1,200	0.22	$440	5.36	$10,720	2.07	$4,140	3.25	$6,500	3.15	$6,300
Willow Stakes	$4	EA	5,295	$18,533	1,764	$6,174	3,197	$11,190	0	$0	1,072	$3,752	452	$1,582
40 CI Planting/14 inch Planting/Cuttings	$20	EA	214	$4,280	68	$1,360	2,069	$41,380	725	$14,500	1,126	$22,520	1,166	$23,320
10 CI Perennial Tubeling	$3	EA	0	$0	127	$382	1,284	$3,852	0	$0	931	$2,793	263	$789
Wetland Sod	$7	SF	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Willow Stakes in Riprap	$80	LF	0	$0	0	$0	0	$0	657	$52,560	253	$20,240	0	$0
Boulder Toe	$250	LF	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Willow Stakes in Cobble	$20	LF	0	$0	0	$0	1,336	$26,720	0	$0	0	$0	0	$0
Live Willow Fascine	$35	LF	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Vegetated Reinforced Soil Slopes	$300	LF	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Subtotal														
Subtotal without General Construction Aspects				$68,800		$37,993		$967,811		$158,361		$333,205		$186,382
Subtotal				$92,879		$51,290		$1,306,545		$213,788		$449,826		$251,615
Contingency			20%	$18,576	20%	$10,258	20%	$261,309	20%	$42,758	20%	$89,965	20%	$50,323
Subtotal				**$111,455**		**$61,548**		**$1,567,854**		**$256,545**		**$539,791**		**$301,938**
Subtotal Cost for Each Area			**$173,003**				**$2,666,129**							

*30% to 80% Engineering and Support includes normal levels of permit and construction support. *Bank stabilization measures include cost of willow stakes

Table 20. Cost Estimate 2

South St Vrain Creek 30% Cost Estimate

Material	Unit Price	Pay Unit	Quarry to EWP #1 Main Channel Sta 129+68 to Sta 95+46				EWP #1 Main Channel Sta 95+46 to Sta 54+14							
			Main Channel (Length ≈ 3,422 ft)		Overflow Channel #5 (Length ≈ 1,263 ft)		Main Channel (Length ≈ 4,132 ft)		Overflow Channel #6 & #7 (Length ≈ 1,719 ft)		Overflow Channel #8 (Length ≈ 1,706 ft)		Overflow Channel #9 & #11 (Length ≈ 991 ft)	
			Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
General Construction														
Mobilization	10%	LS	1	$74,105		$11,043	1	$110,068	1	$14,460	1	$21,375	1	$9,971
Water Control	10%	LS	1	$74,105		$11,043	1	$110,068	1	$14,460	1	$21,375	1	$9,971
Erosion Control	5%	LS	1	$37,053		$5,521	1	$55,034	1	$7,230	1	$10,687	1	$4,986
30% to 80% Engineering	10%	LS	1	$74,105		$11,043	1	$110,068	1	$14,460	1	$21,375	1	$9,971
Earthwork														
Earthwork, Excavation and Fill On-Site	$8	CY	2,407	$19,256	3,602	$28,816	2,407	$19,256	1,710	$13,680	1,170	$9,360	763	$6,104
Earthwork, Excavation and Haul Off-Site	$17	CY	2,898	$49,266	0	$0	19,464	$330,888	3,337	$56,729	5,319	$90,423	476	$8,092
Stream Restoration														
Buried Riprap Revetments	$90	CY	575	$51,750		$0	1724	$155,160		$0		$0		$0
Instream Large Wood Structures	$5,500	EA	15	$82,500	0	$0	23	$126,500	0	$0	0	$0	0	$0
Floodplain Large Wood Structures	$5,000	EA	0	$0	3	$15,000	0	$0	0	$0	3	$15,000	1	$5,000
Habitat Boulders	$125	EA	120	$15,000	0	$0	200	$25,000	0	$0	0	$0	0	$0
Riffle-Pool Structures	$15,000	EA	4	$60,000	0	$0	6	$90,000	0	$0	0	$0	0	$0
Boulder Sills	$60	LF	0	$0	100	$6,000	0	$0	150	$9,000	550	$33,000	0	$0
Landscape														
Erosion Control Blanket	$4	SY	1,950	$7,800	0	$0	5,269	$21,076	4,841	$19,365	4,778	$19,112	4,191	$16,764
Seeding (Native)	$750	AC	3.87	$2,903	1.46	$1,095	5.80	$4,350	1.87	$1,403	1.44	$1,080	0.63	$473
Seeding (Riparian)	$3,000	AC	0.94	$2,820	0.33	$995	2.39	$7,170	1.75	$5,250	1.30	$3,900	1.14	$3,420
Soil Amendment	$1,600	AC	5.33	$8,528	1.80	$2,880	8.27	$13,232	3.62	$5,792	2.75	$4,400	1.99	$3,184
Hydro Mulch	$2,000	AC	4.66	$9,320	1.80	$3,600	8.00	$16,000	3.26	$6,520	2.43	$4,860	1.61	$3,220
Willow Stakes	$4	EA	547	$1,915	0	$0	1,495	$5,233	1,281	$4,484	1,149	$4,022	596	$2,086
40 CI Planting/14 inch Planting/Cuttings	$20	EA	1,759	$35,180	602	$12,040	2,871	$57,420	1,119	$22,380	792	$15,840	542	$10,840
10 CI Perennial Tubeling	$3	EA	1,950	$5,850	0	$0	363	$1,089	0	$0	0	$0	517	$1,551
Wetland Sod	$7	SF	5,240	$36,680	0	$0	0	$0	0	$0	0	$0	4,680	$32,760
Willow Stakes in Riprap	$80	LF	1,319	$105,520	500	$40,000	315	$25,200	0	$0	0	$0	0	$0
Boulder Toe	$250	LF	843	$210,750	0	$0	587	$146,750	0	$0	51	$12,750	12	$3,000
Willow Stakes in Cobble	$20	LF	861	$17,220	0	$0	1,038	$20,760	0	$0	0	$0	161	$3,220
Live Willow Fascine	$35	LF	537	$18,795	0	$0	1,017	$35,595	0	$0	0	$0	0	$0
Vegetated Reinforced Soil Slopes	$300	LF	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Subtotal														
Subtotal without General Construction Aspects				$741,052		$110,426		$1,100,679		$144,602		$213,747		$99,714
Subtotal				$1,000,420		$149,075		$1,485,916		$195,213		$288,558		$134,613
Contingency			20%	$200,084	20%	$29,815	20%	$297,183	20%	$39,043	20%	$57,712	20%	$26,923
Subtotal				**$1,200,504**		**$178,890**		**$1,783,099**		**$234,256**		**$346,269**		**$161,536**
Subtotal Cost for Each Area			**$1,379,394**				**$2,560,061**							

Table 21. Cost Estimate 3

South St Vrain Creek 30% Cost Estimate

Material	Unit Price	Pay Unit	EWP #1 Main Channel Sta 95+46 to Sta 54+14		EWP #1 to Longmont Diversion Main Channel Sta 54+14 to Sta 41+63				Longmont Diversion to EWP #2 Main Channel Sta 41+63 to Sta 30+82					
			Overflow Channel #10 (Length ≈ 575 ft)		Main Channel (Length ≈ 1,251 ft)		Overflow Channel #12 (Length ≈ 642 ft)		Main Channel (Length ≈ 1,081 ft)		Overflow Channel #13 (Length ≈ 760 ft)		Overflow Channel #14 (Length ≈ 249 ft)	
			Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
General Construction														
Mobilization	10%	LS	1	$2,154	1	$38,432	1	$2,844	1	$14,411	1	$13,366	1	$1,446
Water Control	10%	LS	1	$2,154	1	$38,432	1	$2,844	1	$14,411	1	$13,366	1	$1,446
Erosion Control	5%	LS	1	$1,077	1	$19,216	1	$1,422	1	$7,206	1	$6,683	1	$723
30% to 80% Engineering	10%	LS	1	$2,154	1	$38,432	1	$2,844	1	$14,411	1	$13,366	1	$1,446
Earthwork														
Earthwork, Excavation and Fill On-Site	$8	CY	996	$7,968	352	$2,816	254	$2,032	2,236	$17,888	2,879	$23,032	996	$7,968
Earthwork, Excavation and Haul Off-Site	$17	CY	0	$0	3,258	$55,386	1,029	$17,493	0	$0	0	$0	0	$0
Stream Restoration														
Buried Riprap Revetments	$90	CY		$0	576	$51,840		$0	233	$20,970		$0		$0
Instream Large Wood Structures	$5,500	EA	0	$0	2	$11,000	0	$0	5	$27,500	0	$0	0	$0
Floodplain Large Wood Structures	$5,000	EA	0	$0	0	$0	0	$0	0	$0	2	$10,000	0	$0
Habitat Boulders	$125	EA	0	$0	30	$3,750	0	$0	20	$2,500	0	$0	0	$0
Riffle-Pool Structures	$15,000	EA	0	$0	1	$15,000	0	$0	0	$0	0	$0	0	$0
Boulder Sills	$60	LF	90	$5,400	0	$0	0	$0	0	$0	0	$0	0	$0
Landscape														
Erosion Control Blanket	$4	SY	0	$0	0	$0	0	$0	6,178	$24,712	228	$913	783	$3,132
Seeding (Native)	$750	AC	0.36	$270	0.58	$435	0.63	$473	1.79	$1,343	1.08	$810	0.12	$90
Seeding (Riparian)	$3,000	AC	0.07	$210	0.18	$540	0.14	$420	1.23	$3,690	0.49	$1,470	0.16	$480
Soil Amendment	$1,600	AC	0.42	$672	0.76	$1,216	0.80	$1,280	3.15	$5,040	1.56	$2,496	0.28	$448
Hydro Mulch	$2,000	AC	0.37	$740	0.61	$1,220	0.73	$1,460	2.95	$5,900	1.26	$2,520	0.28	$560
Willow Stakes	$4	EA	204	$714	529	$1,852	154	$539	277	$970	1,113	$3,896	0	$0
40 CI Planting/14 inch Planting/Cuttings	$20	EA	121	$2,420	196	$3,920	237	$4,740	1,079	$21,580	413	$8,260	89	$1,780
10 CI Perennial Tubeling	$3	EA	0	$0	0	$0	0	$0	573	$1,719	0	$0	0	$0
Wetland Sod	$7	SF	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Willow Stakes in Riprap	$80	LF	0	$0	0	$0	0	$0	0	$0	796	$63,680	0	$0
Boulder Toe	$250	LF	0	$0	454	$113,500	0	$0	0	$0	0	$0	0	$0
Willow Stakes in Cobble	$20	LF	0	$0	0	$0	0	$0	515	$10,300	829	$16,580	0	$0
Live Willow Fascine	$35	LF	90	$3,150	430	$15,050	0	$0	0	$0	0	$0	0	$0
Vegetated Reinforced Soil Slopes	$300	LF	0	$0	356	$106,800	0	$0	0	$0	0	$0	0	$0
Subtotal														
Subtotal without General Construction Aspects				$21,544		$384,325		$28,437		$144,111		$133,656		$14,458
Subtotal				$29,084		$518,838		$38,389		$194,550		$180,436		$19,518
Contingency			20%	$5,817	20%	$103,768	20%	$7,678	20%	$38,910	20%	$36,087	20%	$3,904
Subtotal				**$34,901**		**$622,606**		**$46,067**		**$233,460**		**$216,523**		**$23,422**
Subtotal Cost for Each Area			**$2,560,061**		**$668,673**				**$473,405**					

Table 22. Cost Estimate 4

South St Vrain Creek 30% Cost Estimate										
Material	Unit Price	Pay Unit	EWP #2 Main Channel Sta 30+82 to Sta 26+22 / Main & Overflow Channel #15 (Length ≈ 601 ft)		Main Channel Total		Overflow Channel Total		Total	
			Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
General Construction										
Mobilization	10%	LS	1	$1,942	1	$342,619	1	$148,252	1	$490,872
Water Control	10%	LS	1	$1,942	1	$342,619	1	$148,252	1	$490,872
Erosion Control	5%	LS	1	$971	1	$171,310	1	$74,126	1	$245,436
30% to 80% Engineering	10%	LS	1	$1,942	1	$342,619	1	$148,252	1	$490,872
Earthwork										
Earthwork, Excavation and Fill On-Site	$8	CY	283	$2,264	12,209	$97,672	23,556	$188,448	35,765	$286,120
Earthwork, Excavation and Haul Off-Site	$17	CY	385	$6,545	59,817	$1,016,889	65,452	$528,360	125,269	$1,545,249
Stream Restoration										
Buried Riprap Revetments	$90	CY		$0	3,108	$279,720	0	$0	3,108	$279,720
Instream Large Wood Structures	$5,500	EA	0	$0	64	$352,000	0	$0	64	$352,000
Floodplain Large Wood Structures	$5,000	EA	0	$0	0	$0	13	$65,000	13	$65,000
Habitat Boulders	$125	EA	30	$3,750	700	$87,500	0	$0	700	$87,500
Riffle-Pool Structures	$15,000	EA	0	$0	20	$300,000	0	$0	20	$300,000
Boulder Sills	$60	LF	0	$0	0	$0	1,300	$78,000	1,300	$78,000
Landscape										
Erosion Control Blanket	$4	SY	524	$2,095	15,305	$61,219	22,428	$89,710	37,732	$150,929
Seeding (Native)	$750	AC	0.12	$90	17	$13,043	14	$10,770	32	$23,813
Seeding (Riparian)	$3,000	AC	0.23	$690	8	$23,040	8	$23,729	16	$46,769
Soil Amendment	$1,600	AC	0.35	$560	26	$41,728	23	$36,944	49	$78,672
Hydro Mulch	$2,000	AC	0.24	$480	22	$44,840	20	$40,860	43	$85,700
Willow Stakes	$4	EA	418	$1,463	11,758	$41,153	7,785	$27,248	19,543	$68,401
40 CI Planting/14 inch Planting/Cuttings	$20	EA	74	$1,480	8,262	$165,240	7,000	$140,000	15,262	$305,240
10 CI Perennial Tubeling	$3	EA	0	$0	4,170	$12,510	1,838	$5,515	6,008	$18,025
Wetland Sod	$7	SF	0	$0	5,240	$36,680	4,680	$32,760	9,920	$69,440
Willow Stakes in Riprap	$80	LF	0	$0	1,634	$130,720	2,206	$176,480	3,840	$307,200
Boulder Toe	$250	LF	0	$0	1,884	$471,000	63	$15,750	1,947	$486,750
Willow Stakes in Cobble	$20	LF	0	$0	3,750	$75,000	990	$19,800	4,740	$94,800
Live Willow Fascine	$35	LF	0	$0	1,984	$69,440	90	$3,150	2,074	$72,590
Vegetated Reinforced Soil Slopes	$300	LF	0	$0	356	$106,800	0	$0	356	$106,800
Subtotal										
Subtotal without General Construction Aspects				$19,417		$3,426,193		$1,482,523		$4,908,716
Subtotal				$26,213		$4,625,361		$2,001,406		$6,626,767
Contingency			20%	$5,243	20%	$925,072	20%	$400,281	20%	$1,325,353
Subtotal				**$31,455**		**$5,550,433**		**$2,401,688**		**$7,952,121**
Subtotal Cost for Each Area			**$31,455**							

20. Next Steps

The next step in this process is to refine designs. This report and the plans only constitute 30% designs and should be developed further. It is recommended that additional survey be acquired for the project area to refine designs and evaluate changing topography. Further refinement of the hydraulic models could allow for greater accuracies in channel designs. Overtime as the channel evolves additional evaluations of the project site should take place.

As discussed, some of the areas are eligible for further funding. Currently the Design Team is in the process of supporting BCPOS in acquiring additional funding for refinement of designs. The Design Team will move directly into 80% designs for the EWP areas once those funds are secured. Additional survey and updated hydraulic models will be developed to refine designs along with updated site assessments. The Design Team will also support BCPOS with permitting the EWP eligible projects.

Once designs have been complete and permits have been acquired, BCPOS will obtain a contractor and construction will commence. Once the EWP project areas have been constructed it is recommended to monitor the restoration techniques. It is imperative to learn how the measures perform to re-evaluate further designs. Monitoring of the vegetation growth is also necessary and a temporary irrigation system might be required to ensure growth. EWP eligible projects require post-construction monitoring. BCPOS will be required to provide funding for monitoring.

Areas outside of the EWP projects should be evaluated for their implementation potential based upon the priorities previously outlined. Securing additional designs and funding for these areas could allow for a holistically restored creek. Also learning from previous designs along the corridor and adjusting as necessary is part of the process.

Some design elements in the plans and report require additional investigation beyond the scope of this Project. These designs could be implemented with further refinements and additional funding. Continued coordination with the stakeholders and project partners is recommended when these designs are evaluated more in depth.

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22. Appendices

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