30% DESIGN REPORT

# St. Vrain Creek Restoration
# Highway 36 to Crane Hollow Road
# Boulder County, Colorado

Prepared by:

Engineering Analytics, Inc.

ecos ecosystem services LLC

Lidstone and Associates - A Wenck Company

ERC

Denver, CO ■ Fort Collins, CO ■ Raton, NM ■ Lewisville, TX

# 30% Design Report
# St. Vrain Creek Restoration
# Highway 36 to Crane Hollow Road
# Boulder County, Colorado

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## TABLE OF CONTENTS

## TABLES

## FIGURES

## APPENDICES

# 1.0 INTRODUCTION

## 1.1 General

Significant flooding and damage occurred along the St. Vrain Creek during the September 2013 flooding in Boulder County, Colorado. The Engineering Analytics (EA) Team consisting of Engineering Analytics, Inc., Ecosystem Services, LLC (Ecos), Lidstone and Associates, Inc./Wenck Associates (Lidstone), and Ecological Resources Consultants, Inc. (ERC), was retained by Boulder County Parks and Open Space (BCPOS) to provide a 30% design for the St. Vrain Restoration Project for restoration of the St. Vrain Creek and the adjacent riparian corridor for the area known as "Reach 3" between US Highway 36 and Crane Hollow Road.

The Colorado Emergency Watershed Protection (EWP) program[1] and the federal Community Development Block Grant – Disaster Recovery (CDBG-DR) program[2] provide guidance and funding for flood restoration projects. The CDBG-DR program requires a 30% design which is intended to provide clear direction for detailed project engineering and specifications to be completed in the future (EWP 2016). The Technical Assistance Team of the Department of Local Affairs/Colorado Water Conservation Board (DOLA/CWCB) further defines 30% design as the "development of a plan set to a level of sufficient detail to evaluate major design features prior to advancing to the design/build phase or construction drawings" (EWP 2016). This report presents a summary of the initial site assessment, the basis of design for the project, an alternatives analysis, and a 30% design.

## 1.2 Site Location

The project site is located along the St. Vrain Creek, approximately one-quarter mile east of the intersection of US Highway 36 East/N Foothills Highway and State Highway 66/Ute Highway, downstream to Crane Hollow Road in Boulder County, Colorado. The project area is within what is known as Reach 3 of the St. Vrain Creek, as defined in the St. Vrain Creek Coalition (SVCC) St. Vrain Creek Watershed Master Plan (Baker Team 2014). As indicated in the SVCC Master Plan, Reach 3 includes the length of the creek extending from US Highway 36 to Airport Road. An overview of the site location is depicted on Figure 1-1.

## 1.3 Project Background

The St. Vrain Creek flows to the east from the town of Lyons to its confluence with Boulder Creek where the St. Vrain River is formed. The section of the St. Vrain Creek between Lyons and Longmont has been altered and reshaped by human activity over time, including residential and commercial development, irrigation structures, sand and gravel mining operations, and reservoirs (Baker Team 2014). Reach 3 of the creek crosses between BCPOS, City of Longmont, and private properties, and is generally rural and agricultural with some existing sand and gravel mining sites. The mining and agricultural operations in Reach 3 have been prominent and have encroached upon the channel over time resulting in various degrees of channel realignment that

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[1] The EWP Program is sponsored by the Colorado Water Conservation Board (CWCB) and administered by the Natural Resources Conservation Service.

[2] The CDBG-DR program is administered by the U.S. Department of Housing and Urban Development (HUD)

are not well documented. According to a review of historical aerial photography by Baker Team (2014), the riparian corridor ranged from 200 to more than 500 feet wide and was densely vegetated with a combination of native and non-native species. The creek channel is moderately sinuous and appeared to be generally stable over the past 60 years; however, some natural lateral migration occurred across the floodplain during this time period, and though the adjacent floodplain was historically connected to the channel, mining, and agricultural operations have altered the natural floodplain connection through the reach (Baker Team 2014). In addition to mining operations through the reach and adjacent to the channel, the reach has been impacted by man-made processes including concrete stream channel diversions, bridges and bridge abutments, and adjacent agricultural and residential land uses, which have altered the natural channel development.

Significant damages occurred across the floodplain and within the stream channel along the St. Vrain Creek during the September 2013 flooding, which resulted in disturbance to approximately 136 acres of the project site. The flooding in 2013 impacted areas that were previously considered outside of the mapped 500-year floodplain. A significant portion of the riparian habitat was disturbed through sediment deposition, erosion, avulsion, and channel incision. Floodplain habitat connectivity was severed in locations along the reach due to flood-related habitat disturbance. Erosion occurred in the gravel mining sites and the eroded material was deposited in other gravel mining sites or in the channel downstream of the reach. Additionally, multiple breaches of the river bank occurred through the project area. Emergency temporary repairs including debris removal along the reach and temporary breach repairs were made during the winter of 2013/2014 to restore critical facilities and help mitigate further flood damages. Details of the breaches and the temporary repairs are provided in Section 2.2 of this report. The site overview, Figure 1-1, highlights the breach locations along the reach. Additional breaches occurred within and between several reservoirs through the reach.

Since the completion of temporary repairs, the stream, streambanks, and floodplain have continued to naturally recover from the impacts of the 2013 flood. Native and non-native vegetation has re-established in areas along the riparian corridor and within the floodplain. The stream has continued to meander and create a new natural centerline, particularly in areas of the creek where excess unconsolidated sediment was deposited during the 2013 flood. Bank erosion has accelerated in some areas, while point bars have developed in new areas as a result of the excess sediment in the reach. Wildlife has started to become re-established, with the exception of riparian cut-offs resulting from 2013 flood damages. Additionally, flood repair work has been ongoing for other smaller projects throughout the reach since the flood event: reconstruction of diversion structures, design and construction of reservoir repairs, road and culvert repairs and reconstruction, etc. A comprehensive restoration for the entire reach is necessary, incorporating the individual restoration efforts of individual projects through the reach, to provide a single holistic restoration approach for the entire reach.

## 1.4 Project Goals and Objectives

In accordance with the BCPOS Request for Proposal (RFP #6413-16), we understand that the overall project goal is to provide a 30% design level evaluation to mitigate the impacts of the 2013 flooding and to reduce the impact of future flooding on life and property, while restoring the riparian and wildlife habitat throughout the reach. In accordance with the Colorado EWP Program Vision, recovery projects should 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. To meet this vision, our specific project goals and objectives include:

- Reduce risk to life and property
    - Prioritize protection of private property, public infrastructure, and critical facilities
    - Enhance stream stability
    - Establish measures to reduce impact of future flooding
- Restore, enhance, and promote wildlife and aquatic habitat
    - Maintain connectivity along linear corridors of riparian habitat
    - Consider habitat requirements of sensitive species including native fishes and Preble's meadow jumping mouse
    - Prepare planting plans for designated restoration areas (portions of the site where trees, shrubs, and grasses are absent) and enhancement areas (portions of the site where trees are present, but generally lack shrubs and grasses and will benefit from adding younger trees for age diversity)
- Develop restoration alternatives to enhance the health and resilience of the stream corridor
    - Improve geomorphic and ecological structure and function according to the Stream Function Pyramid (Harman et al. 2012) framework
    - Catalyze natural stream recovery and stabilization processes to minimize need for operations and maintenance
    - Evaluate temporary breach repairs
    - Design potential permanent breach repairs considering impact both upstream and downstream
    - Restore the hydraulic capacity to the maximum extent practical based on pre-flood conditions
- Encourage stakeholder involvement
    - Consider impacts of restoration on separate projects within the reach or incorporate and implement smaller projects into the restoration approach
    - Coordinate review of design with watershed leaders (e.g., SVCC, St. Vrain Water Commissioner, St. Vrain and Left Hand Water Conservancy District)
    - Collect feedback on proposed restoration throughout the design process
    - Work directly with property owners and neighboring community members to receive input on desired outcomes of project

The overarching goal for the project is to create a design that reduces threat to life and property and resiliently restores the creek channel, adjacent riparian areas, and the breached locations.

## 1.5 Scope of Work

In accordance with our proposal dated February 29, 2016, the scope of work within this report includes a site assessment (including hydraulic analyses, geomorphology, sediment transport analyses, and initial characterization of aquatic and terrestrial species of the reach), an alternatives definition and analysis for restoration of the creek, and a 30% design. Hydraulic analyses and design were performed by EA, geomorphology and sediment transport analyses were performed by Lidstone, stream restoration design was performed by ERC, and ecological assessment and restoration design was performed by Ecos. This report compiles the results of the initial site assessment, establishes our basis of design for the project, discusses the alternatives for site restoration, presents an analysis of the restoration alternatives selecting a preferred alternative for design, and provides the preliminary 30% level design for the project.

# 2.0 WATERSHED SITE ASSESSMENT

## 2.1 General

The watershed site assessment included site visits, photo documentation, and a desktop review of available information regarding the impact of the 2013 flooding, topography data, aerial imagery (historical and current), local property lines, and significant features across the site. EA performed an initial site visit for the project kickoff on April 27, 2016. BCPOS personnel guided a tour of the breach locations for the project team on May 9, 2016. Details regarding the breach locations and temporary repairs are described in Section 2.2 below, and depicted on Figures 2-1A through 2-1D.

Lidstone performed field sediment sampling for the geomorphology and sediment transport analyses on May 9 and May 10, 2016, as discussed further in Section 2.6 of this report. Ecos performed an ecological site assessment on May 9, 2016, and a wetland delineation of the site between October 25 and November 11, 2016, as presented in Section 2.7. EA performed a geotechnical exploration at the site on June 8 and 9, 2016, as discussed in Section 2.4, below. EA performed an additional site visit on June 7, 2016 to further inspect some of the breaches and diversion structures. ERC performed a preliminary restoration site assessment on November 16, 2016.

Topographic surveys of specific areas of the site were performed by King Surveyors. The survey data was combined with the existing topographic information from the available digital terrain data. Further details about specific site features including the subsurface conditions determined in the geotechnical exploration, geomorphology and sediment transport analyses for the reach established in the geomorphic assessment, and ecological characteristics recorded in the ecological site assessment, are included in separate reports provided in Appendices A, B, and C, respectively.

Several significant property features throughout the site were identified during the site visits and desktop review. These property features include the breaches that occurred during the 2013 flooding and the temporary flood repairs, private property, existing bridges and roads, and several diversion structures and diversion ditches. Details of the site features are discussed in Section 2.2 below.

## 2.2 Site Features

### 2.2.1 Breaches and Temporary Repairs

**Breach 1**, shown on Figure 2-1A, occurred along the south streambank over a length of approximately 1,200 feet, leading to spatially varied sheetflow for approximately 1 mile along the historic floodplain.

A temporary breach repair berm was installed in the area of Breach 1. According to the FEMA project worksheet (FEMA 2013) provided by Boulder County, we understand this berm was designed to consist of fill material derived from native on-site flood-deposited sand and cobbles capped with 12 inches of imported clay. The clay cap as designed covered the top and front slope of the berm and extended 20 feet toward the stream channel from the toe of the slope. Type M and H sandstone riprap was designed to cover the clay cap along the front slope of the berm. The elevation of the temporary breach repair ranges from approximately Elevation (El.) 5257 to 5251 feet along the length of the berm. With the temporary berm in place, the creek currently flows through the pre-flood channel in the area of Breach 1.

**Breach 2**, shown on Figure 2-1B, may have occurred as a result of a channel plug in the main creek channel in combination with a breach of the south streambank over a length of approximately 100 feet. Material from the breach and bed load being carried by the floodwater washed into Lake 2, and the floodwater continued both as overland flow out of Lake 2 eastward back to the creek and southeastward to join the floodplain flow occurring from Breach 1.

A temporary breach repair berm was installed in the area of Breach 2. The temporary breach repair berm at Breach 2 was designed to consist of a mix of about 60% fill material derived from native on-site sand and cobble materials with about 40% clay/loam materials (FEMA 2013). The berm materials were mixed and compacted in lifts, and the slope face dressed with sandstone riprap (FEMA 2013). Based on information provided in the RFP, we understand an additional 2 to 3 feet of on-site material was added to the height of the breach repair and imported granite riprap and a spillway were added in 2014. The elevation of the temporary breach repair berm at Breach 2 ranges from approximately El. 5203 to 5202 feet along the length of the berm. Immediately after the flood, prior to the emergency repairs, the creek flowed through the breach and through Lake 2. With the temporary debris removal and breach repair, the creek flow was returned to the pre-flood channel in the area of Breach 2. Downstream of Breach 2, primary creek flows are currently bypassing the pre-flood main channel and passing through what was considered an overflow section of the pre-flood channel (leading to the Longmont Supply Diversion Structure).

Though termed a "breach," **Breach 3** is more accurately defined as the area where overland flow of water from Breach 2 returned to the creek channel. This area is noted on Figure 2-1B. Restoration of Breach 3 is intended to be addressed through ongoing restoration planning with the surrounding property's mineral-rights owner.

The combined southeastward flow of water from Breaches 1 and 2 destroyed the berms separating Lake 3 and Lake 4, Lake 4 and West Lake, and West Lake and A-Frame Lake, among other infrastructure. These floodwaters returned to the creek immediately downstream of the 63rd Street bridge at **Breach 4**, shown on Figure 2-1C. Breach 4 resulted in the destruction of 61st Street. Restoration of this breach area is being addressed through separate projects for Lake 4 and 61st Street.

Further downstream, flooding impacted the area between Breaches 5 and 9, including several water-filled gravel pits. These areas are shown on Figure 2-1D. This area is privately owned by James Hepp, and is also referred to as the Hepp property and the Hepp reservoirs. A small amount of floodplain flow originating from Breaches 1 and 2 continued overland south of the pre-flood creek channel, returning to the creek at **Breach 5** through Sadar Pond.

**Breach 6** occurred along the south streambank into Hepp #1 Reservoir. Return flow of the floodwater from Breach 6 to the pre-flood creek channel occurred through **Breach 8** on the east side of Hepp #1 Reservoir. Additionally, a man-made cut was excavated adjacent to Breach 8 to enable water to return more directly from the Hepp #1 Reservoir to St. Vrain Creek, which is now known as **Breach 9**. The current post-flood creek channel passes through Breach 6 and Hepp #1 Reservoir, and returns to the pre-flood channel via Breaches 8 and 9.

**Breach 7a** occurred along the north streambank into Hepp #2 Reservoir, where the floodwaters continued through **Breach 7b** to Hepp #3 Reservoir, and overland floodplain flow occurred eastward toward the City of Longmont. A man-made cut was made through Hygiene Road on the southern edge of Hepp #3 for water to flow more directly from Breaches 7a and 7b back to the creek. This Hygiene Road cut was closed and the road repaired during the emergency repairs. A temporary breach repair berm was installed in the area of Breach 7a by FEMA. We understand this berm was designed to consist of fill material derived from native on-site flood-deposited sand and cobbles capped with 12 inches of imported clay. The clay cap as designed covered the top and front slope of the berm and extended 20 feet toward the stream channel from the toe of the slope. Type M and H sandstone riprap was designed to cover the clay cap along the front slope of the berm (FEMA 2013). The elevation of the temporary repair berm ranges from approximately El. 5128 to 5125 feet along the length of the berm. Creek flows currently bypass the pre-flood channel through Hepp #1 Reservoir as described above, and since its construction, no flow has been documented to pass the repaired Breach 7a.

### 2.2.2 Private Property

A large portion of the property in the reach adjacent to the St. Vrain Creek is owned by Boulder County, while the remainder of the reach is privately owned. Commercial gravel mining properties, owned by CEMEX and Martin Marietta, encompass large parcels surrounding the St. Vrain Creek, particularly in the area between Breach 1 and Breach 2. Additional private residences and agricultural land is located through the reach, interspersed between the commercial properties and the Boulder County land. Property lines and property ownership information are depicted on the 30% design plans.

During the 2013 flooding, the CEMEX property, including offices and mining operations structures, flooded as a result of Breach 1, and the business was impacted by closures until floodwaters receded. As noted in the discussion of the breaches above, Mr. James Hepp owns a large parcel of land on the south end of the reach that was severely impacted by the 2013 flood event. Property losses are a concern for future flooding events, particularly in looking at alternatives for the area surrounding Breach 1 and Breaches 5 through 9. Protection of private property must be considered in the restoration design.

### 2.2.3 Bridges and Roads

Access to the CEMEX property and Boulder County property is currently limited to access via the North 51st Street Bridge over the St. Vrain Creek. The North 51st Street Bridge is privately owned by the CEMEX property. Protection and maintenance of this bridge must be considered in the restoration design for the site.

Riprap around the North 63rd Street Bridge was damaged during the 2013 flooding and is being enhanced in a separate project. The North 63rd Street Bridge is owned by Boulder County, and was designed to convey 5,000 cfs. North 61st Street, also owned by Boulder County, was damaged as a result of Breach 4 during the 2013 flooding. Reconstruction and restoration of North 61st Street and Breach 4 is part of an ongoing project restoring Lake 4, and is not included within the scope of this report. Protection of the roads and bridges against future flooding should be considered in the design for this project.

The Hygiene Road Bridge crosses over the St. Vrain Creek in the southeastern portion of the site and was designed to convey 5,200 cfs with 18 inches of freeboard. During the 2013 flooding, flows may have been impeded in this area from a combination of sediment and debris buildup near the bridge. Additionally, the channel in the area of the Hygiene Road Bridge was altered significantly from the pre-flood channel to the post-flood channel through Hepp #1 Reservoir returning to the creek just north of the bridge at an approximately 90° angle. In developing restoration design for the project, impact to the bridge and protection of the bridge must be considered. Additional flow capacity, erosion control, and other measures may be required to limit future damages in this area.

The Crane Hollow Road Bridge crosses over the St. Vrain Creek on the southeastern boundary of the project area. While the actual design for the bridge was not available, Boulder County Transportation Department estimates that the bridge was designed to convey approximately 6,500 cfs. No significant impacts from flooding were recorded for this bridge. Protection and maintenance of this bridge must be considered in the restoration design for the site.

A “Low Flow Crossing” also crosses over the St. Vrain Creek, downstream of Breach 2. Continual maintenance of this crossing is ongoing to remove debris, particularly during high flows. While not a major property concern for future flooding, general recommendations for the Low Flow Crossing should be considered in developing the proposed alternatives for the site.

Recommendations for bridge improvements or modifications to improve the overall stream function are discussed as part of the 30% design (Section 5.0 of this report).

### 2.2.4 Diversion Structures and Diversion Ditches

Downstream of Breach 1, adjacent to the CEMEX property, the Foothills Reservoir Inlet Canal carries water from the St. Vrain Creek to the Foothills Reservoir. The diversion structure is located on the right bank of the creek immediately downstream of the 51st Street Bridge. The ditch runs approximately north-south across the site, and was impacted by the southeastward flows resulting from Breach 1 during the 2013 flood. Protection of this ditch from frequent overtopping and sediment deposition should be considered during the design for restoration in the area of Breach 1.

The South Branch Diversion Ditch is located just upstream of Breach 2, diverting water from the St. Vrain Creek to communities south and east. The diversion structure is located across the creek, diverting water from the right bank of the creek. The ditch runs approximately north-south to the west of Lake 2 and Lake 3, and was impacted by the southeastward flows resulting from Breach 1 during the 2013 flood. Protection of this ditch from frequent overtopping and sediment deposition should be considered during the design for restoration in the area of Breach 1.

The Longmont Supply Diversion Ditch is located downstream of Breach 2, providing water from the St. Vrain Creek to the City of Longmont. The diversion structure is located on the left bank of the overflow channel downstream of Breach 2. This ditch was cut off during the 2013 flood event by debris plugging immediately downstream of Breach 2 and primary flows passing through Lake 2. Since the flooding, the temporary breach repair restored flow to the pre-flood channel, and debris removal downstream of Breach 2 has restored flows to the Longmont Supply Ditch. In considering alternative solutions for the area surrounding Breach 2, a major consideration is the Longmont Supply Ditch and maintaining pre-flood flow conditions to the ditch.

The Oligarchy Ditch is located downstream of Breach 4, diverting water from the St. Vrain Creek to communities east of the creek. The diversion structure is located across the creek, diverting water from the left bank of the creek, just upstream of the 63rd Street Bridge. This diversion structure was rebuilt in 2014 by the ditch owner at a cost of approximately $1 million.

The North Branch Ditch is located south of the Hygiene Road Bridge, and diverts water eastward from the creek. The diversion structure is located on the left bank of the creek immediately downstream of the Hygiene Road Bridge. This ditch was impacted by the flood flows in the creek during the 2013 flood. Protection of this ditch should be considered during the design for restoration in the area of the Hygiene Road Bridge.

Protection of these ditches was considered in developing alternative designs for the site. Recommendations for improvements or modifications to the ditches or diversion structures to improve the overall stream function are discussed as part of the restoration alternatives (Section 4.0 of this report).

### 2.2.5 Ponds, Lakes, and Reservoirs

Multiple ponds, lakes, and reservoirs are present within the reach. The bodies of water that were impacted by the 2013 flooding include those discussed in Section 2.2.1 above; Lake 2, Lake 3, Lake 4, West Lake, A-Frame Lake, Ramey Pond, Hepp #1 Reservoir, Hepp #2 Reservoir, and Hepp #3 Reservoir. The only reservoir that was affected by flooding with storage water rights in the reach is Lake 4. The water rights for Lake 4 are divided evenly between the St. Vrain and Left Hand Water Conservancy District (SVLHWCD) and Boulder County.

Lake 2 restoration is addressed in this report as part of the restoration of Breach 2. Restoration of Lake 4, West Lake, A-Frame Lake are being addressed through separate projects. The restoration of Ramey Pond and the Hepp Reservoirs are discussed in this report as part of the restoration of Breaches 5 through 9.

## 2.3 Available Design Data

A combination of historical aerial imagery and digital terrain models was used in preparing a desktop study of the site. Historical aerial imagery was gathered from available online imagery through Google Earth. Digital terrain data dated 2011, 2013, and 2014 was gathered for the site from Boulder County's Geospatial Open Data Site. The 2011 data was used for the "Pre-Flood" condition, prior to the catastrophic flooding of 2013. The 2013 data collected in October of 2013, about one month after flooding occurred, was used as the "Post-Flood" condition of the site. The 2014 data collected subsequent to construction of the emergency temporary repairs (as described in Section 2.2.1), was used to represent the "Current" condition of the site.

In our modeling and design we used the design storm events for the project reach provided by the Colorado Department of Transportation (CDOT) in the document titled *Hydrologic Evaluation of the St. Vrain Watershed* (CDOT 2014). Based on the hydrologic information for the site, the maximum flows from the design storm event hydrographs used in our analyses (in cubic feet per second [cfs]) are approximately as follows:

- 2,212 cfs ~ 10% chance of exceedance, ~10 yr recurrence interval
- 4,912 cfs ~ 4% chance of exceedance, ~ 25 yr recurrence interval
- 12,268 cfs ~ 1% chance of exceedance, ~ 100 yr recurrence interval
- 26,984 cfs ~ 0.2% chance of exceedance, ~ 500 yr recurrence interval

These design flows and the storm hydrographs were used in the hydraulic, geomorphological, and sediment transport analyses, as well as the for the preliminary 30% design for the site.

## 2.4 Geotechnical Investigation

A geotechnical investigation was conducted at the site by EA on June 8 and 9, 2016. A total of eight geotechnical borings, labeled as B-1 through B-8, were drilled and sampled as part of the site assessment. Borings B-1 and B-2 were drilled along the crest of the Breach 1 emergency repair berm. Boring B-3 was drilled adjacent to the Breach 2 emergency repair berm in a location that did not appear to be disturbed or modified during the 2013 flood. Boring B-4 was drilled along the crest of the Breach 2 repair berm. Boring B-5 was drilled south of Breaches 5 and 6 in a location that did not appear to be disturbed or modified as a result of the 2013 flood. Borings B-6 and B-7 were drilled along the crest of the Breach 7a emergency repair berm. Boring B-8 was drilled adjacent to Breach 7b in a location that did not appear to be disturbed or modified as a result of the 2013 flood.

The existing on-site material generally consisted of alluvial sands and gravels with varying amounts of clay and silt, and is generally suitable for re-use. Off-site borrow clay material may be needed for the restoration design. Estimated quantities of required borrow material are included in the 30% design. A complete report of the geotechnical investigation is appended to this report (Appendix I).

## 2.5 Hydrologic and Hydraulic Assessment

The modeled terrain is based on digital terrain data for the site, as referenced in Section 2.3. Sections of the reach were surveyed for more accurate topographic information. The channel topography and surrounding terrain were optimized using a combination of digital terrain contours and site survey data.

Hydraulic modeling is conducted to simulate water flow through a river reach for various flow events. Unsteady flow analysis for the project reach was performed using the modeling program HEC-RAS for the design storm event hydrographs discussed in Section 2.3. Boundaries are used in a hydraulic model to define the project area within the model, and boundary conditions define the anticipated inflow and outflow of water through the river reach. The upstream boundary condition for the project is defined as the inflow of water in the St. Vrain Creek at the upstream boundary of our project area. The upstream boundary of the model is near the intersection of US Highway 36 and State Highway 66 at the St. Vrain Creek. The design inflow for the project was estimated using the outflow hydrographs provided by CDOT at 53rd Street. The downstream boundary represents the location for outflow of water on the downstream boundary of the project area. For our model, the downstream boundary is set as the intersection of Crane Hollow Road and the St. Vrain Creek.

The stream conditions were modeled in three terrain scenarios: Pre-Flood condition, Post-Flood condition, and Current condition, as discussed in Section 2.3. We compared various flow conditions for each of the three different terrain conditions to monitor the performance of the creek channel and floodplain under varied scenarios.

The models were analyzed for the amount of overtopping at each breach location in the Pre-Flood, Post-Flood, and Current terrain conditions. Tables 2-1 through 2-3 present the modeling results including the maximum flow over the breach locations in cubic feet per second (cfs), and the maximum water surface elevation (El.) in feet of the creek at the breach locations for flows at recurrence intervals of approximately 10 years (10% chance of exceedance), 100 years (1% chance of exceedance), and 500 years (0.2% chance of exceedance).

***Table 2-1*** *Flows through Breaches for 10-yr Recurrence (10% chance of exceedance)*

**Maximum Storm Flow = 2,212 cfs**

| Breach No. | Pre-Flood | | Post-Flood | | Current | |
|---|---|---|---|---|---|---|
| | Flow through Breach (cfs) | Water Surface Elevation in Channel (ft) | Flow through Breach (cfs) | Water Surface Elevation in Channel (ft) | Flow through Breach (cfs) | Water Surface Elevation in Channel (ft) |
| 1 | 0 | El. 5246 | 528 | El. 5250 | 0 | El. 5250 |
| 2 | 0 | El. 5198 | 1365 | El. 5193 | 0 | El. 5198 |
| 5&6 | 0 | El. 5123 | 2025 | El. 5118 | 2016 | El. 5118 |
| 7 | 0 | El. 5120 | 125 | El. 5116 | 0 | El. 5116 |
| 8&9 | 0 | El. 5114 | 2060 | El. 5113 | 2011 | El. 5113 |

***Table 2-2*** *Flows through Breaches for 100-yr Recurrence (1% chance of exceedance)*

**Maximum Storm Flow = 12,268 cfs**

| Breach No. | Pre-Flood | | Post-Flood | | Current | |
|---|---|---|---|---|---|---|
| | Flow through Breach (cfs) | Water Surface Elevation in Channel (ft) | Flow through Breach (cfs) | Water Surface Elevation in Channel (ft) | Flow through Breach (cfs) | Water Surface Elevation in Channel (ft) |
| 1 | 553 | El. 5252 | 5564 | El. 5253 | 1624 | El. 5254 |
| 2 | 889 | El. 5200 | 3184 | El. 5194 | 874 | El. 5199 |
| 5&6 | 114 | El. 5127 | 9119 | El. 5121 | 8319 | El. 5120 |
| 7 | 1225 | El. 5124 | 3692 | El. 5117 | 0 | El. 5119 |
| 8&9 | 3656 | El. 5119 | 8444 | El. 5117 | 8137 | El. 5118 |

***Table 2-3*** *Flows through Breaches for 500-yr Recurrence (0.2% chance of exceedance)*

**Maximum Storm Flow = 26,984 cfs**

| Breach No. | Pre-Flood | | Post-Flood | | Current | |
|---|---|---|---|---|---|---|
| | Flow through Breach (cfs) | Water Surface Elevation in Channel (ft) | Flow through Breach (cfs) | Water Surface Elevation in Channel (ft) | Flow through Breach (cfs) | Water Surface Elevation in Channel (ft) |
| 1 | 1387 | El. 5253 | 10703 | El. 5258 | 5661 | El. 5255 |
| 2 | 1303 | El. 5200 | 6430 | El. 5195 | 1851 | El. 5200 |
| 5&6 | 3878 | El. 5128 | 17459 | El. 5123 | 15938 | El. 5122 |
| 7 | 6212 | El. 5126 | 11742 | El. 5119 | 1438 | El. 5120 |
| 8&9 | 8119 | El. 5125 | 12946 | El. 5119 | 13926 | El. 5120 |

Inundation maps based on the modeling results, provided as Figures 2-2A, 2-2B, and 2-2C, show the extent of flooding for the 10-year and 100-year flow events for the Pre-Flood terrain, the immediate Post-Flood terrain, and the Current terrain, respectively. In reviewing the results in Tables 2-1 through 2-3 and the inundation mapping on Figures 2-2A through 2-2C, the modeling indicates that the Pre-Flood channel conveyed the majority of flows less than about 2,000 cfs within the channel, and for larger storm flows (greater than a 10-year storm), overtopping occurred. However, in the Post-Flood condition, significant overtopping occurs through the breaches with a 10-year flow event, indicating that the conditions of flow through the channel changed from Pre-Flood to Post-Flood because of the 2013 flood event. This overtopping occurs primarily through the Breach 1 area, inundating the floodplain to the southeast. When comparing the Pre-Flood and Current conditions, flow is generally maintained through the Current creek channel for a 10-year flow event, much like the Pre-Flood conditions in the areas of Breach 1 and Breach 2 where the temporary breach repairs are in place.

The results of the hydraulic analyses were used in preparing alternatives for the site and 30% designs. By comparing the Pre-Flood conditions with the Post-Flood conditions, we assessed the impact of “No Action” alternatives, in which the breaches would remain open as in the immediate Post-Flood condition. We then used the Pre-Flood and the Current conditions to assess the impact of flows in the Pre-Flood channel condition compared to the flows that occur currently with some breach repairs in place. Additional hydraulic modeling of the selected alternatives was also performed as part of the 30% design (presented in Section 5.0).

In addition to performing a hydraulic analysis of the reach, we also reviewed the Pre-Flood, Post-Flood, and Current conditions of the reservoirs in the project area. Based on our understanding of the size and capacity of the reservoirs in the project area, and our discussions with John Batka from the Colorado Department of Natural Resources Dam Safety Branch, the reservoirs are not currently jurisdictional dam structures and will likely be classified as low hazard or no public hazard dams. The final design for any proposed reservoirs resulting from the restoration should be reviewed by the state for a final hazard classification.

## 2.6 Sediment Analysis and Geomorphic Assessment

During the site visit on May 9, 2016, various locations of bank erosion and instability, and aggradational and degradational reaches were observed by Lidstone along with general geomorphic conditions. Lidstone conducted a sediment analysis at eight locations through the project area. The project area was geomorphically assessed to characterize bed and bank sediment and to identify changes to the stream alignment (planform), channel and bank stability, and vertical change. Restoration constraints such as property ownership, bridges, ditches, and rail lines were identified and photographed. Complete results of the geomorphic site assessment and sediment analysis are presented in the *Geomorphic Assessment* report, attached as Appendix II.

### 2.6.1 Stream Restoration Site Assessment

ERC performed a separate site assessment and used the information collected in the Geomorphic Assessment from Lidstone to develop an alternative restoration approach for the project. The first step in the ERC design process was to understand the natural, unimpacted state of the river. The project reach is roughly four miles and has a drop of 166 feet for an average slope of 0.8%. Its sinuosity, which is a measure of stream length over valley length, is approximately 1.14 over the full project length. The project reach is a low gradient, moderately sinuous stream. Review of current and historic aerial images suggests that land use practices such as gravel pit development, roads, and railroads have reduced the natural sinuosity.

ERC used the Rosgen and Montgomery-Buffington classification systems to determine the predominant bedform of the reach. Based on the characteristics of the creek and the criteria outlined in the classification systems, ERC determined that riffles and pools are the dominant form through the reach.

### 2.6.2 Preliminary Geomorphic Considerations for Design

Based on the findings of the geomorphic and sediment assessment, the following preliminary approaches for restoration were considered in developing design alternatives for the project.

Based on the information collected in Lidstone's report (Appendix II), damages from the 2013 flooding reportedly impacted the ability of the channel to efficiently convey sediment in certain reaches where the channel was widened, causing multiple low water braids to develop. Lidstone believes the sediment that was deposited in the project reach is poorly sorted, not armored, and is highly mobile under relatively low flow conditions and thus recommends that sediment storage capacity should be increased to remove some of the deposited sediment from the main channel and not move the problem downstream. Riverine structures such as vanes and cross vanes as described below are recommended to provide this function. Re-grading of the channel banks may be required to provide bank protection and/or improve habitat. Root wads may also be used to enhance habitat and provide bank stabilization.

Rock vanes transfer velocities away from the channel bank allowing sediment to settle on the lee side (downstream side). They prevent and in some cases heal bank erosion. This healing process allows natural development of vegetation and stabilization of the eroded bank in a natural fashion. The ability of a vane to collect sediment on the lee side provides critical permanent sediment storage sites within the riverine system. While there is no numerical calculation for determining the spacing between rock vanes, there are general rules of thumb that are followed during the design. Typically, this spacing equates to 50 feet, measured from the centerline of concurrent vanes, but varies based on local hydraulics, radius of curvature of the bend, and channel geometry goals. Each vane is keyed into the bank a distance ranging from 6 to 12 feet, and should not extend any further into the channel than 1/3 of the channel width. The purpose of this is to move the channel thalweg (lowest part of the channel) away from the bank without causing opposite bank erosion and unplanned sediment production. The rock vanes as proposed for St. Vrain Creek slope riverward from near bankfull height at the root to a lower flow stage height at the tip. This shape will result in pronounced scour at the tip and will establish a local thalweg at the location of the vane tip.

Cross vanes serve a critical function in the St. Vrain Creek set of plans. Cross vanes are a type of rock vane that spans the channel. In degradational reaches, such as Sub-Reach 2 as identified in the geomorphic assessment (Appendix II), grade control structures and cross vanes are used to prevent headcutting upstream and result in flow convergence immediately below the structure. Such structures are critical along straight but overly wide reaches and/or crossing reaches situated between two bends. With cross vanes channel grade is held as a riffle-pool sequence which assists in establishing backwater conditions immediately upstream. An important design use for the backwater component, for example, is at the mouth of Hepp #1 Reservoir where low flow backwater is important for ecological functioning. Cross vanes are also effective in increasing sediment conveyance. By placing cross vanes in areas where hydraulic constriction is required, the channel cross section is effectively narrowed. By narrowing the channel, flow depth increases thereby increasing the hydraulic forces on the sediment and inducing sediment movement.

Rock vanes and cross vanes are generally constructed of large natural boulders that will not be mobilized even during extreme large flow events. Chinking rock is typically placed in the gaps of the structures to prevent scour around or below the structure. Where keyed into the channel banks, the structures present opportunity for the use of large woody debris (LWD) to be incorporated into the structures. Typically, we prefer to add wood at locations between and adjacent to vane structures. In the same sense, topsoil is placed over the rock structures above the seasonal water lines and riparian plantings are introduced. Over the very near term these rock structures become well established vegetated and semi-permanent features within a hydraulically active environment rather than the temporal unstable landforms which existed prior to restoration. In a sensitive aquatic and terrestrial species area such as our project reach, bioengineering methods will provide habitat complexity by creating backwater and slackwater conditions, while stabilizing banks. The goal of the channel improvements through the use of riverine structures is to develop a main channel that adequately conveys the normal spring runoff events (approximately 1.5-year to 2-year flood event) by allowing a connection to the floodplain to allow flood relief. Additionally, this floodplain connection provides ecological values that only can be served by a well-connected stream.

Alternatively, ERC proposes a natural based improvement as opposed to structural control of the riverine system. ERC believes that a natural approach that uses channel shaping to provide low flow habitat is important for the project as this will allow the stream to continue to transport sediment through the project reach while providing deeper water for fish, which is particularly important in times of low flow. When compared to structural approaches, natural stream improvements are more sustainable, provide greater natural resource benefits, convey sediment in a natural manner, promote active recreation such as angling, passive recreation such as bird watching and relaxing, and result in a stream that is more aesthetically pleasing.

These preliminary approaches for restoration were used in developing alternatives for the project stream restoration (see Section 4.2).

## 2.7 Ecological Assessment

For the initial ecological assessment of the site, Ecos consulted numerous agency and public resources, and available literature and databases for scientific background data, as well as County and watershed data. The available resources and literature were reviewed to gather background information regarding the environmental setting of the project area and the St. Vrain Creek watershed.. Following the collection and review of background information, Ecos conducted an initial field reconnaissance survey of the creek corridor in May 2016 to document the stream reach characteristics (e.g. stream/in-stream features, vegetation, wildlife habitat) and take representative photographs. Significant features related to the areas of proposed construction were identified and located (via sketch map). Ecos also identified potential sources of native plant materials and performed an inventory of the ecological characteristics of the vegetation and habitat along the riparian corridor. Ecos performed a follow-up survey in October 2016 after the initial design alternatives and related impact areas were defined by the project team. This second, more detailed survey included: 1) identifying areas of opportunity within the breach repair work areas for restoration and enhancement of native vegetation, wetland, Preble’s meadow jumping mouse (PMJM), leopard frog, and fishery habitat; 2) performing a wetland delineation in the areas of proposed or potential construction-related impact; 3) performing a riparian assessment; 4) confirming sources of native materials; and 5) marking-up base maps to illustrate the approximate extent and location of any confirmed resources and habitat restoration opportunities. A complete discussion of the initial ecological assessment is presented in the *St. Vrain Breaches Restoration Project 30% Design – Basis of Design* technical memorandum prepared by Ecos, attached as Appendix III. The results of the site assessments and associated preliminary recommendations were used in preparing ecological restoration alternatives for the reach (Section 4.0) and the 30% design plans (Section 5.0). The following information summarizes Ecos' field notes and observations from the field assessments.

### 2.7.1 Vegetation

A composite list of the species observed during the field assessment is presented in Ecos' technical memorandum (Appendix III, Page 35). Based on Ecos' assessment of the availability of on-site and local plant and bioengineering materials, the following materials may be available for restoration activities:

- Significant number of plains and narrowleaf cottonwood seedlings and saplings that are regenerating may be viable for salvage and transplant from proposed impact areas.
- Plains and narrowleaf cottonwood, and coyote willow cuttings may be taken from proposed restoration/impact areas.
- Coyote willow clump transplants may be available for salvage and transplant from proposed restoration/impact areas.
- Salvage and transplant of other shrubs, saplings, and seedlings will be considered on an occurrence-specific basis once restoration/impact areas are better defined.
- BCPOS has a stockpile of root wads/trees removed from the creek corridor during Emergency Flood Response that need to be assessed for viability for bank/in-stream habitat restoration and/or use as woody debris/pollinator habitat/PMJM habitat.
- Ecos has utilized CDOT right of ways (ROWs) along Highway 66 for viable coyote willow cuttings and believes this source is still readily available.

### 2.7.2 Wetland Delineation and Riparian Assessment

Ecos performed the delineation of wetland habitat for the reach pursuant to the current USACE methodology. The delineation results generally yield an overall observation that herbaceous streamside wetland habitat is primarily absent post-flood and the more facultative, woody wetland habitat is dominant post-flood and regenerating throughout the reach. This observation assists in informing the design to target the restoration of herbaceous wetland habitat, particularly along steam and pond fringes that may support leopard frog habitat, nursery habitat for aquatic species, and habitat for other target species. Wetland delineation datasheets were developed by Ecos and are included in Appendix III. The wetland delineation boundaries are also shown on the 30% design plans (Appendix V). The vegetation data collected during the wetland delineation fieldwork was utilized to update the composite species list for the 30% Design; and the data will be used moving forward to identify areas of wetland habitat regeneration and to assist the Team in calculating impact areas based on the Project design.

Ecos performed a riparian assessment using the U.S. Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) Stream Visual Assessment Protocol Version 2 (SVAP2). SVAP2 is a national protocol that provides an initial evaluation of the overall condition of wadable streams, their riparian zones, and their instream habitats. It is designed to give a snapshot of wadable stream ecosystem conditions that allows planners and conservationists to determine the relative quality of stream habitat and identify potential improvement actions. SVAP2 lends itself to tracking trends in stream conditions over time, as well as identifying resource concerns and their potential causes. The vegetation data collected during the SVAP2 fieldwork will be utilized to inform riparian restoration and enhancement design moving forward and was utilized herein to update the composite species list for the Project.

### 2.7.3 Wildlife Habitat

Ecos noted the presence of good quality, but somewhat disconnected, PMJM habitat along the St. Vrain Creek corridor due to the effects of the 2013 floods. PMJM habitat along the riparian corridor may be optimized by enhancement and restoration measures, as well as via creating connectivity by filling in the barren voids in breach areas. PMJM habitat design will be focused on providing optimal tree and shrub coverage percentages and persistent seed food sources pursuant to the project examples provided in the complete assessment (Appendix III).

Instream fishery habitat is in relatively good condition as the flood enhances flow diversity, low-flow holding water, structural cover, and other in-stream habitat elements. Restoration of the riparian corridor and streambanks denuded and eroded by the 2013 floods will significantly improve fish habitat by restoring overhead cover (which moderates temperature and pH) and decreasing sediment input from eroded banks (which causes siltation in the stream bed therby impacting spawning areas and available aquatic invertebrates).

Ecos did not observe any nesting raptors or migratory birds directly adjacent to the breach repair locations during the initial field assessment. However, the initial desktop screening of raptors for the site indicates the potential presence of 24 raptors and birds and one Osprey nest location in the project vicinity. Therefore, a comprehensive nesting bird survey must be performed immediately prior to construction, including appropriate raptor buffers, in order to ensure compliance with the Migratory Bird Treaty Act (MBTA).

### 2.7.4 Preliminary Ecological Restoration Considerations for Design

Ecos identified certain areas of opportunity along the riparian corridor for native vegetation, wetland, PMJM, northern leopard frog, and fishery habitat restoration. Significant opportunities are available to restore riparian and wetland habitat in the flood scoured areas and reservoir bottoms downstream of each breach. These areas would significantly expand PMJM habitat and connection corridors laterally and longitudinally down the creek corridor. Numerous shallow water, palustrine emergent areas with high degree of edge effect/scalloping and saturated channels/swales are currently present upstream of currently existing open water areas that could be enhanced and revegetated to create amphibian and waterfowl habitat. Restoring or enhancing habitat in these areas is predicated on the reservoirs being maintained at the low pool elevations which exist today. Many of these potential forested, shrub-scrub, and herbaceous wetlands areas are already regenerating cottonwood, willow, sedge, and rush but could be augmented via grading, vegetation, and breach plugs designed to ensure periodic overtopping and sustaining hydrology to further accelerate the establishment and diversity of the riparian and wetland habitat. Creek-side banks, low benches, and point bars, especially in the downstream portions of the site (between Breaches 4 and 9) also provide opportunities for habitat development. Side channels/eroded gullies that formed during the flood leading from the channel and reservoir bottoms to the uplands could provide excellent forested and shrub cover and connector corridors to uplands. A preliminary plan detailing the existing conditions and identifying preliminary habitat restoration opportunities was developed by Ecos and is included in Appendix III. This preliminary plan was used through the design process and for discussions with stakeholders to develop the 30% design presented in Section 5.0, and should not be considered final. The proposed restoration planting and seeding plans are provided in the 30% design plans.

## 3.0 DESIGN CRITERIA

Multiple design criteria were referenced throughout the alternatives definition, alternatives analysis, and 30% design. The following guidelines are in addition to any federal, state, and local regulations set forth for the site area.

### 3.1 CDBG-DR Design Guidelines

The Community Development Block Grant Disaster Recovery Program (CDBG-DR) is established to rebuild affected areas and start the recovery process. The watershed planning grants under this fund are required to adhere to 30% design guidelines to ensure designs are compliant with the CDBG-DR grant requirements. This project should be designed in accordance with the *CDBG-DR 30% Design Guidelines* (EWP 2016, Appendix 2), and includes a science-based risk analysis for potential alternatives and identifies resilience performance standards in the design.

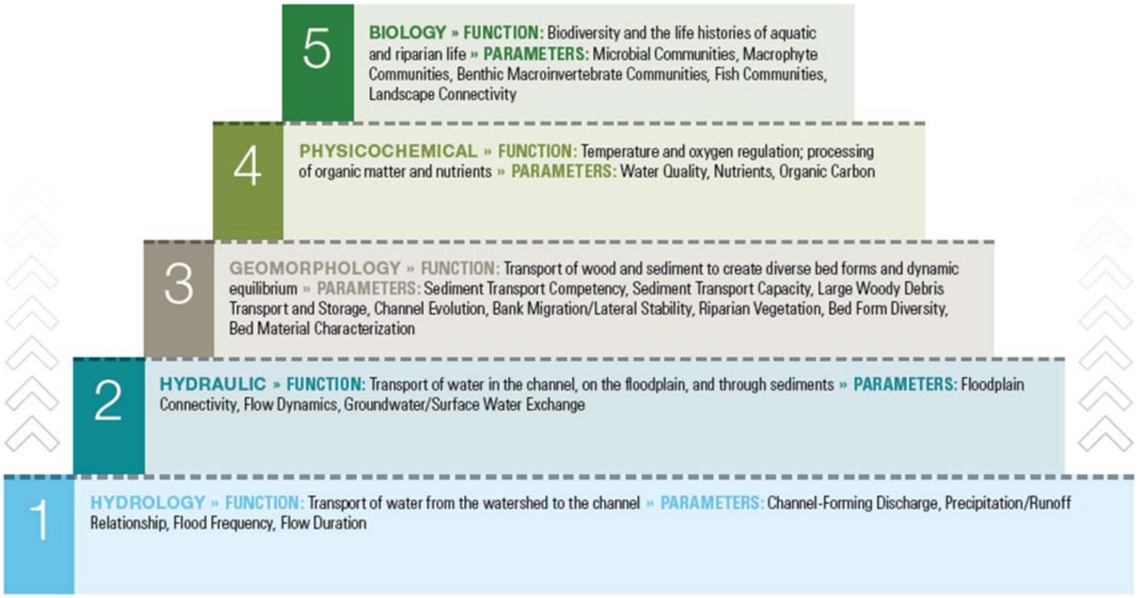
In addition to the design guidelines, the funding source requires a rapid final design and construction schedule to meet the deadlines necessary for funding. As a result, the proposed designs need to consider intricacy of design and timeframe required for final design plans and specifications, as well as the anticipated time for construction. Any alternatives that will not meet the required construction deadlines should not be considered as feasible for the site. Proper scheduling for design and construction is required, and anticipated construction schedule for the project will be provided as the design progresses. Additional details regarding construction considerations for the project are included in Section 5.1 below.

### 3.2 NRCS Emergency Watershed Protection Requirements

The NRCS Colorado Emergency Watershed Protection (EWP) Program Vision, and a main goal of the project, is “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.” The 30% design will be used for formal review of the project by the EWP. The design references the document titled *Project Engineering Guidance* prepared by the EWP for the 2013 Colorado Flood Recovery Phase 2 (EWP 2016). In accordance with these guidelines, the 30% design reduces threats to life or property by mitigating future flooding or erosion concerns caused by the 2013 flood event.

### 3.3 Colorado Parks and Wildlife Guidelines

Stream restoration design is in accordance with the document titled *Post-Flood Recovery Assessment and Stream Restoration Guidelines for the Colorado Front Range* (Richer et al. 2015) prepared by the Colorado Parks and Wildlife (CPW). As such, the goal of the project is to protect, restore, and reconnect the reach in accordance with the guidelines set by the CPW. The process for stream restoration design employs the guidelines detailed in the U.S. Environmental Protection Agency’s Stream Functions Pyramid (Harman et al. 2012), portraying the hierarchical nature of the stream functions.



*Stream Functions Pyramid (from Harman et al. 2012)*

This Stream Functions Pyramid was used in identifying the project approach to the restoration, and identifying the order in which the preliminary designs should progress. That is, initially looking at the hydrology and hydraulic function of any proposed alternatives, then proceeding on to the associated geomorphology, physiochemical, and biological considerations for each alternative. As such, the initial preliminary designs were focused on structural breach repair alternatives to meet the hydrology and hydraulic needs of the site. Once an alternative was selected that met the hydraulic needs of the site, the anticipated geomorphological design was detailed, and specific physiochemical and biological components along the reach were designed.

## 3.4 St. Vrain Creek Watershed Master Plan

The St. Vrain Creek Watershed Master Plan (SVMP) (Baker Team 2014) was initiated to provide long-term planning for the St. Vrain Creek at a watershed scale while integrating local needs and broader stakeholder interests for the approach to flood control and stream restoration. The SVMP combines restoration components, flood risk reduction, community resiliency, improved ecological function, and enhanced aesthetics. The purpose of the SVMP is to guide Boulder County, local municipalities, and individual landowners in the identification and prioritization of stream rehabilitation and restoration projects. A core objective of the SVMP is "to identify future flood risks and propose projects that both reduce flood risk and increase long-term watershed resilience (this includes engaging local stakeholders throughout the planning process to identify priorities, needs, and goals)". The SVMP provides recommendations and conceptual designs for Reach 3 of the St. Vrain Creek, which encompasses the project area. The SVMP was referenced throughout the design process, particularly during the initial site assessment and desktop study. Referencing the SVMP during restoration design ensures that the proposed design will incorporate the varied needs of stakeholders and fit within the vision for the watershed as a whole.

## 3.5 Flood Resilience

The 30% design is focused on resiliency of the St. Vrain Creek to future flooding events. Resiliency of the creek is defined as measures that improve the durability of the creek corridor, allow the corridor to be resistant to future flood events, and provide an overall stream health that is robust and quick to recover from future flooding. The flood events used for design are based on the CDOT design flow hydrographs referenced in Section 2.3. Streambanks will be designed to be restored using a combination of bioengineered and armored techniques (e.g., natural plantings, woody debris, engineered berms/armoring) to increase bank stability, reduce erosion, and maximize resiliency to a range of flood events. Enhanced bank stability will also improve the stream quality and riparian areas. Stream restoration may include streambank shaping, sediment removal, and debris removal along the reach.

The breach repairs are designed to resist flood flows and reduce underseepage and internal erosion during flood flows. The breach repairs will be founded on the undisturbed native soils below sediment and disturbed materials. The designs include impervious core materials extending at least 5 feet into the native soils.

The existing breach repairs at Breaches 1 and 2 were assessed for their suitability as permanent repairs. Additionally, the potential for re-purposing of the breach repair materials for use in the permanent repairs was evaluated. The breach repair at Breach 7a was assessed in accordance with the guidelines set by FEMA for removal of the temporary repair and replacement with a permanent solution. The breach restoration for all breaches in the reach considers the suitability of the restoration design for the site as a whole, the potential impacts upstream and downstream of the breaches in future flood events, and the resiliency against future flooding. Resiliency of the breach repairs will be accomplished using a combination of bioengineering techniques and hard armoring as necessary.

### 3.5.1 Bridges and Roads

Bridge structures of concern at the site include the N 51st Street Bridge, N 63rd Street Bridge, the Hygiene Road Bridge, and the Crane Hollow Road Bridge. The 30% design considers the resiliency of the bridges in relation to overall stream restoration, and any bridge improvements or modifications recommended to improve the overall stream function are discussed as part of the 30% design (Section 5.0 of this report). The design and construction of any bridge modifications is outside the scope of this project.

### 3.5.2 Diversion Structures and Diversion Ditches

A total of five diversion structures are located within the site, as referenced in Section 2.2. Design and construction of the diversion structures is outside the scope of this work, but the diversions should be designed to withstand the effects of large storm events. Restoration design along the reach considered the protection and improved resiliency of the ditches and diversion structures, and maintaining flow to the diversions. Any ditch and diversion structure improvements or modifications recommended to improve the overall stream function are discussed as part of the restoration alternatives (Section 4.0 of this report). Upstream and downstream restoration may be required to improve the resiliency and maintain flow.

## 3.6 Habitat Restoration

The data collected by Ecos during the data collection, desktop assessment, and field reconnaissance surveys form the basis of design of the proposed enhancement and restoration of native plant communities and wildlife habitat. A complete discussion of the basis of design for the development of enhancement and restoration plans for native plant communities and wildlife habitat within the project area is presented in Appendix III. Habitat restoration design is based on the guidelines provided by EWP (2016), CPW (Richer et al. 2015), SVCC (Baker Team 2014), the Boulder County Comprehensive Plan (BCLUD 2014), and federal, state, and local practices. Additional resources for habitat restoration design are presented in Appendix III.

## 3.7 State of Colorado Dam Safety Requirements

The Colorado Division of Water Resources sets forth guidelines on new and existing dams within the state. The reservoirs on site should be designed in accordance with these guidelines, and will be assessed for the dam safety hazard classification in accordance with the State Engineering Office (SEO) requirements. The existing reservoir structures present within the project area are not currently classified as dams. We do not anticipate that any of the reservoirs on site will be classified as jurisdictional dams according to the state requirements, but we will work cooperatively with the SEO to provide the documentation required for the non-jurisdictional reservoirs as the design progresses.

## 3.8 Recreational Aspects

Recreation is a desired component for the entire reach for the community. Recreation aspects are being addressed as part of BCPOS' master planning. Specific designs considering recreational aspects are outside the scope of this project. Preliminary plans for a BCPOS trail design through the project area envision the trail set back from the creek through this area, so the planned restoration activities should not impact any areas intended for future trail development.

## 4.0 RESTORATION AND BREACH REPAIR ALTERNATIVES

The overall project goal is to provide a 30% design level evaluation to mitigate the impacts of the 2013 flooding along the St. Vrain Creek and to reduce the impact of future flooding on life and property, while restoring the riparian and wildlife habitat throughout the reach. The alternatives for preliminary design should focus on resiliently restoring the creek channel, and restoring, enhancing, and promoting wildlife habitat. The restoration efforts include seeding and planting native grasses, wetland plants, and shrubs for wildlife, and restoring stream function to provide a resilient and connected riparian ecosystem. In restoring the creek channel and stream function, alternatives for potential permanent breach repairs were developed considering the impacts both upstream and downstream of the breaches, the impact on stream ecology and stream-associated infrastructure, the ability to reduce the impact of future flooding, and the potential for repair and/or redevelopment of disturbed areas.

The following proposed restoration alternatives have been reviewed and commented on by the BCPOS and local stakeholders, and the final alternatives presented herein have been revised to address these comments. The alternatives presented below are focused on restoring the stream through the reach and include ecological restoration (to restore and enhance vegetative and wildlife habitat), in-stream work (to enhance the health and resilience of the stream corridor), and breach repairs (to restore stream function and protect life and property from future flood events). The 30% design presented in Section 5.0 was developed for the selected alternatives along the reach.

### 4.1 Ecological Restoration

Ecos identified preliminary areas of opportunity along the riparian corridor for native vegetation, wetland, PMJM, leopard frog, and fishery habitat restoration and enhancement. These preliminary areas of opportunity were presented within Ecos' technical memorandum attached as Appendix III. These identified preliminary areas of opportunity were used in conjunction with the selected stream restoration and breach repair alternatives to refine the vegetation and habitat restoration in developing the 30% design presented in Section 5.0 of this report. As noted in Ecos' memorandum, significant opportunities are available to restore riparian and wetland habitat in the flood scoured areas and reservoir bottoms downstream of each breach where alluvial interflow is at or near the surface. These areas would significantly expand PMJM habitat and connection corridors laterally and longitudinally down the creek corridor. Numerous shallow water, palustrine emergent areas with high degree of edge effect/scalloping and saturated channels/swales are present upstream of currently existing open water areas that could be enhanced to create amphibian and waterfowl habitat. Restoring or enhancing habitat in these areas is predicated on the reservoirs being maintained at the low pool elevations which exist today. Many of these potential forested, shrub-scrub and herbaceous wetlands areas are already regenerating cottonwood, willow, sedge, and rush, but could be augmented via grading, vegetation, and low, leaky breach plugs to ensure periodic overtopping and sustaining hydrology to further accelerate the establishment and diversity of the riparian and wetland habitat. Creek-side banks, low benches, and point bars, especially in the downstream portions of the site (between Breaches 4 and 9) also provide opportunities for habitat development. Side channels/eroded gullies that formed during the flood leading from the channel and reservoir bottoms to the uplands could provide excellent forested and shrub cover and connector corridors to uplands.

Ecos defined innovative approaches to plant materials selection using ecotypic plant materials, live cuttings, broad-spectrum seed mixes, and companion crops in their basis of design (Appendix III). They also defined a native revegetation plan approach for restoration and enhancement, bioengineered and biotechnical stabilization, and staging and access areas. A Composite Species Inventory of native and naturalized plant species was provided by Ecos in Appendix III. This list was used for the selection of appropriate, native plant and seed materials for the planting and seeding plans presented in the 30% design (Section 5.0 of this report). A Composite Species Inventory of non-native and weed species was also provided by Ecos in Appendix III, and will be used to assist in the coordinated development of a maintenance and monitoring plan with BCPOS.

Riparian and wetland habitats will be the primary components of the overall vegetation and habitat restoration and enhancement approach for the reach based on the tremendous opportunities available. Wetland and riparian species will be used to assist in the following components of the project design and development, thus yielding functional, connected habitat throughout the reach:

- Restored and enhanced connectivity of PMJM habitat (shrub-scrub wetland habitat);
- Backwater wetland (emergent wetland habitat) areas that provide:
  - Nursery habitat and off-channel habitat for warm and cold-water fish;
  - Habitat for northern leopard frog; and
  - Habitat for other amphibians and aquatic species
- Bioengineered streambank restoration and stabilization;
- Biotechnical bank stabilization; and
- Inter-planting and “softening” of hard engineered structures (as necessary).

Additional criteria was presented by Ecos (in Appendix III) to incorporate specific design parameters for vegetation and habitat restoration to benefit the following sensitive wildlife species for the project.

- Preble’s meadow jumping mouse (*Zapus hudsonius preblei*)
- Northern leopard frog (*Lithobates pipiens*)
- Brassy minnow (*Hybognathus hankinsoni*)
- Common shiner (*Luxilus cornutus*)
- Stonecat (*Noturus flavus*)
- Stoneroller (*Campostoma anomalum*)
- Iowa darter (*Etheostoma exile*)
- Salmonids, primarily brown trout (*Salmo trutta*)
- Raptors and nesting migratory birds

## 4.2 Stream Restoration Alternatives

We developed three stream restoration alternatives through discussions with the BCPOS staff and local stakeholders regarding their preferred outcomes for the site. The alternatives were also assessed for their environmental impact, specifically in regards to increasing and enhancing riparian ecological habitat. Additional restoration details are included as part of the 30% design for the selected alternative.

As part of the design objectives, input from the affected individuals and communities was included throughout our alternative analysis. Once preliminary alternatives were developed, we collected comments and suggestions from local stakeholders including landowners, business owners, neighbors, and ditch owners. Comments received through the design process were used and addressed in preparing the final alternatives presented herein.

Based on the information collected during our site assessment and comments received from local stakeholders and BCPOS, we developed the following alternative designs for the stream restoration.

**Alternative 1 – *No Action***
**Alternative 2 – *Channel Improvements through Riverine Structures***
**Alternative 3 – *Natural Restoration through Channel Shaping***

We evaluated each stream restoration alternative based on the relative advantages and disadvantages. Additional details about each alternative and the recommended alternative are presented in the subsequent sections.

### 4.2.1 Alternative 1 – No Action

Alternative 1 consists of allowing the stream to continue a natural restoration process over time, without man-made intervention or modifications. Since the 2013 flood event and the emergency repairs performed in the reach, the creek has been naturally meandering and re-establishing through the damaged areas. As noted in the site assessment (Section 2.0), although significant changes in stream alignment were observed following the September 2013 flood, the St. Vrain Creek has returned to its original alignment through emergency flood restoration efforts with the exception of the alignment through the Hepp property, where the creek remains in the post-flood alignment through Hepp #1 Reservoir. Relatively steady state changes in aggradation and degradation in the reach were observed over the last 30 years, suggesting a consistent post flood re-establishment of the system. Alternative 1 suggests natural re-establishment of the creek without regard to enhancement of the stream stability or resiliency of the streambanks.

### 4.2.2 Alternative 2 – Channel Improvements through Riverine Structures

Alternative 2 consists of improvements to the channel through the use of riverine structures. Lidstone recommends the following stream restoration approach for the sub-reaches discussed in Appendix II:

- For Sub-Reach 1, banks should be laid back at a flatter slope where feasible, and channel narrowing should be employed to improve sediment conveyance through intermittent vanes. Riverine structures such as vanes and root wads and large woody debris (LWD) should be used to provide bank stabilization and sediment storage opportunities, construct slackwater areas, and improve habitat complexity. Rock vanes transfer velocities away from the channel bank allowing sediment to settle on the lee side (downstream side). They prevent and in some cases heal bank erosion. This healing process allows natural development of vegetation and stabilization of the eroded bank in a natural fashion. The ability of a vane to collect sediment on the lee side provides critical permanent sediment storage sites within the riverine system.
- For Sub-Reach 2, grade control may be achieved by using cross vanes to prevent head cutting upstream and limit degradation. Cross vanes through the reach should be designed to allow fish passage. Vanes and root wads can be used to provide bank stabilization, and LWD can be used to enhance habitat and provide slackwater areas. Cross vanes are a type of rock vane that spans the channel. In degradational reaches, cross vanes are used to prevent headcutting upstream and result in flow convergence immediately below the structure. Such structures are critical along straight but overly wide reaches. With cross vanes, channel grade is held as a riffle-pool sequence which assists in establishing backwater conditions immediately upstream. Cross vanes are also effective in increasing sediment conveyance. By placing cross vanes in areas where hydraulic constriction is required, the channel cross section is effectively narrowed. By narrowing the channel, flow depth increases thereby increasing the hydraulic forces on the sediment and inducing sediment movement.
- In Sub-Reach 3, consideration should be given to re-routing the stream channel through the pre-flood channel. Use of the post-flood channel through the Hepp #1 Reservoir for overflows could provide flood attenuation and backwater habitat. Bank stabilization can be achieved with the use of vanes and root wads, and habitat enhancements and slackwater areas can be created with LWD.

### 4.2.3 Alternative 3 – Natural Restoration through Channel Shaping

Alternative 3 uses the principles of natural channel design to guide restoration. The objective of stream restoration is to return riverine and adjacent riparian corridors to a more natural state, mitigating impacts of the 2013 floods and anthropogenic stressors. Alternative 3 consists of achieving the stream’s natural form, improving the function and resiliency of the system.

Based on alignment, gradient, and sediment composition, ERC believes the St. Vrain Creek through the project area is naturally a riffle/pool dominated system. Riffle/pool complexes are defined in the Clean Water Act 404(b)(1) guidelines at 40 CFR 230.45 (a) as:

> Steep gradient sections of streams are sometimes characterized by riffle and pool complexes. Such stream sections are recognizable by their hydraulic characteristics. The rapid movement of water over a coarse substrate in riffles results in a rough flow, a turbulent surface, and high dissolved oxygen levels in the water. Pools are deeper areas associated with riffles. Pools are characterized by a slower stream velocity, a steaming

flow, a smooth surface, and a finer substrate. Riffle and pool complexes are particularly valuable habitat for fish and wildlife.

In practice a riffle is identified as a faster moving, shallow area on a stream where water is aerated. Riffles are steeper than pools, runs, and glides but not as steep as cascades or steps. Pools are characterized by deeper, slower moving water. Riffle-pool complexes (also known as pool-riffle complexes) are areas in a stream where riffles and pools follow on another in sequence.

The idea that riffle/pool complexes are the natural form for this channel was confirmed by field evaluations. The most natural reach of the St. Vrain within the project area is the segment bounded upstream by Breach 3 and downstream by 63rd Street. Within this segment the channel exhibits a natural meander pattern and the bedform is dominated by riffle/pool complexes. Bankfull indicators are easily observed and the channel appears to overtop with flows accessing the floodplain during typical flood events. Bankfull widths in riffle sections within this reach were measured to generally be between 30 feet to 40 feet; bankfull widths in pool and glide sections typically ranged from 40 feet to 60 feet.

Given that riffle/pool complexes are the natural form for streams with the gradient and sediment gradation observed in the project area and the most natural stream section exhibits these features, meandering riffle/pool features were selected as Alternative 3 to be appropriate for natural restoration of the project reach.

### 4.2.4 Selected Stream Restoration Alternative

To promote natural channel design, and to meet our design objectives, Alternative 3 was selected for design. The principles of ERC’s natural restoration concept are that the restored channel should be self-sustaining, should not promote sediment degradation or aggradation, and should mimic natural channel functions. These principles typically require that restoration be continuous as opposed to occur only at isolated locations within a reach. For instance, to be most effective, the creation of a meandering thalweg requires channel shaping along the entire project length and not in one local area. ERC finds that this approach produces better, more stable results and can typically be less expensive than extensive large rock work in isolated locations. Less future maintenance will be required for a natural approach than the maintenance required for structural improvements.

Natural channel design for the St. Vrain Creek should therefore mimic features such as riffles, pools, and glides that provide habitat variety but are also effective at transporting sediment. This approach does not use drop structures, which disrupt the natural flow of sediment and can cause migration barriers. Constructed drops use the stream’s energy in a short distance immediately downstream from the drop. Flows upstream and downstream of the drop are made unnaturally slow due to the change in channel slope that the drop creates. ERC’s approach will incorporate features that would be found in a natural channel that do not hinder sediment transport. It includes items such as riffles, pools, glides, boulder habitat features, plunge features, woody debris, and vegetation. It does not include structural river control features such as rock weirs, arches, jetties, and vanes. We recommend Alternative 3, a natural approach to restoration design (natural channel design) that uses channel shaping to provide low flow habitat rather than a No Action (Alternative 1) or structural approach (Alternative 2).

## 4.3 Breach Repair Alternatives

We developed alternatives for repairs at the breach locations through discussions with the BCPOS staff and local stakeholders regarding their preferred outcomes for the site, along with modeling results and information collected during our site assessment. The models were used to estimate the impact of flooding in multiple design scenarios (no action, berms, etc.) for preliminary alternatives. The modeled flooding impact zones were then compared with the mapped locations of concern for public health and safety, particularly focused on impact to life and property, to analyze the economic and social impacts of each alternative design. The alternatives were also assessed for their environmental impact, specifically in regards to increasing riparian habitat and enhancing stream restoration for wildlife.

As part of the design objectives, input from the affected individuals and communities was included throughout our alternatives analysis. Once preliminary alternatives were developed, we collected comments and suggestions from local stakeholders including landowners, business owners, neighbors, and ditch owners. A public meeting presenting a draft version of the preliminary alternatives was presented with BPOS on July 12, 2016. The draft alternatives were also presented to the St. Vrain Creek Coalition (SVCC) on July 13, 2016. Comments received during these meetings, along with additional comments from the SVCC and the BCPOS project website, were used and addressed in preparing the final alternatives presented herein.

The following technical issues were established as minimum design evaluation criteria for each alternative for the project:

- Reduce hazards and protect life safety and property.
- Restore hydraulic capacity of channel based on pre-flood conditions
- Technically sound design.
- Meet the objectives of the Community Development Block Grant Disaster Recovery (CDBG-DR) Program.
- Meet the objectives of Natural Resources Conservation Service (NRCS) Emergency Watershed Protection (EWP) Program.

These mandatory criteria must be met for an alternative to be feasible for design. Each alternative was assessed on whether the minimum design criteria were fulfilled, and given a rating of yes or no.

In addition to required criteria for the project, other considerations used in comparing the alternatives include:

- Additional benefits of design
    - Improved habitat for threatened and endangered species
    - Provides for native fish passage
    - Maximizes riparian improvements
    - Maximizes bioengineering

  - Reconnects floodplain
  - Restores natural processes
  - Time to complete final design
- Construction considerations
  - Time for construction
  - Obstacles for timely implementation
  - Difficulty in meeting construction period
- Cost considerations
  - Construction cost
  - Operation and maintenance cost (O&M)
  - Lifecycle cost

For alternatives that met the minimum design criteria, further analysis of the alternative was assessed based on the above considerations. Each alternative was ranked based on the relative advantages and disadvantages, and given a ranking for each consideration from low to high relative to the other available alternatives. These rankings were compiled and the best rated alternatives were selected as having an edge over the other available alternatives. The comparative analysis rankings are included for each proposed breach repair alternative below.

Based on the information collected during our site assessment, modeling of preliminary alternatives, and comments received from local stakeholders and BCPOS, we developed the following alternative designs for the breach repairs.

**Breach 1, Alternative 1 – *No Action***
**Breach 1, Alternative 2 – *Gradual Low-Profile Setback Berm***
**Breach 1, Alternative 3 – *Maximum Floodplain Setback Berm***
**Breach 1, Alternative 4 – *Re-route Creek Channel***

**Breach 2, Alternative 1 – *No Action***
**Breach 2, Alternative 2 – *Berm and Downslope Grading***
**Breach 2, Alternative 3 – *Overflow Berm and Downslope Grading***

**Breaches 5-9, Alternative 1 – *No Action***
**Breaches 5-9, Alternative 2 – *Redirect Flow, Berm at Breach 7a***
**Breaches 5-9, Alternative 3 – *Overflow Berm at Breach 6, Berm at Breach 7a***

Additional details about each alternative and the comparative analysis of the alternatives are presented in the subsequent sections. As described in Section 2.2, Breach 3 and Breach 4 are outside the scope of this project, therefore, restoration alternatives for these breaches are not included in this report.

### 4.3.1 Breach 1 Alternatives

#### 4.3.1.1 Breach 1, Alternative 1 – *No Action*

Alternative 1 consists of removing the existing temporary berm. This alternative provides no protection to the CEMEX property, the rail line (that runs through the CEMEX property), the Foothills Reservoir Inlet Canal, or any properties further southeast along the floodplain, including the South Branch Diversion Ditch. These properties were all impacted by the flooding that occurred through Breach 1 in the 2013 event, and would be impacted by continued flooding through the breach if no repairs were installed. The diversion ditches further downstream would receive reduced flows with this alternative, and would likely not meet their full water right decrees. A depiction of Breach 1, Alternative 1 is shown on Figure 4-1A.

An assessment of whether or not Alternative 1 meets the key design criteria is outlined below:

- *Reduce hazards and protect life safety and property?* **No**
- *Restore hydraulic capacity of channel based on pre-flood conditions?* **No**
- *Technically sound?* **Yes**
- *Meets the objectives of CDBG-DR?* **No**
- *Meets the objectives of NRCS/EWP?* **No**

Alternative 1 does not reduce the threats to life or property of landowners and increases the hazard risk over the pre-flood and current condition, and thus does not meet the design objectives. While Alternative 1 would reconnect the maximum amount of the floodplain, and would maintain and encourage the natural redevelopment of riparian area in the floodplain, the future damages associated with frequent flooding, as well as the potential costs for these damages would be exorbitant. If this option were selected, large changes to the floodplain would occur. These changes to the floodplain would require the development of FEMA flood map revisions including a Conditional Letter of Map Revision (CLOMR) and a Letter of Map Revision (LOMR). A key component of the both the CDBG-DR and NRCS/EWP design objectives is to reduce threats to life and property by mitigating future risks from flooding, thus Alternative 1 does not meet these objectives, is not considered feasible, and was not explored further.

#### 4.3.1.2 Breach 1, Alternative 2 – Gradual Low-Profile Setback Berm

Alternative 2 consists of a low-profile berm gradually sloping away from the creek that maintains primary flows through the pre-flood channel, while directing overflows across the floodplain and back to the main channel. The berm will be designed to restore flows within the creek channel for flows less than 2,000 cfs (similar to the flow that conveyed through the channel prior to the 2013 flood event). The location and height of the berm was selected by modeling various flooding events through the channel and determining the berm elevation to limit flooding impacts on the left bank (north of the creek) and the location where the least amount of ground disturbance would be required for construction. A depiction of Breach 1, Alternative 2 is shown on Figure 4-1B.

For flood events greater than a 2,000 cfs, the repair berm will be designed to resiliently overtop (allowing overflows without damage to the berm) with the use of bioengineered armoring including specific seeding and planting designed to withstand overflows. These overflows will access the floodplain, and should return to the main creek channel further downstream. Several options for directing overflows across the floodplain were considered to limit impact or disturbance to the floodplain and provide protection to life and property. Overflows should be directed across the floodplain using the natural topography and limiting required grading. The project team evaluated several options for overflow routes in coordination with BCPOS staff. Option A would guide overflows through a more-defined “pilot channel,” directing flows from the east side of the CEMEX property through the area of the abandoned Lake 3, into Lake 4, and ultimately back into the St. Vrain Creek via the connected Lake 4, West Lake, and A-Frame Lake spillways. Option B considers redirecting overflows from the east side of the CEMEX property across the area of the abandoned Lake 3, and immediately returns the flows back into the main creek channel just south of Lake 2. Option C would take overflows from the east side of CEMEX, allow more access to the floodplain, and return flows to the main creek channel just upstream of the Hepp property. These three options are depicted on Figure 4-1B-1.

Option B is less controlled, has the longest flowpath, requires more extensive grading, and may impact the safety of some properties within the floodplain, thus Option B is less favorable than Option A. Option C would increase flows to the main creek channel in a section of the creek that is currently narrower and more constricted. Higher flows through a constricted section equates to higher stream velocity, which can lead to damages further downstream through bank erosion and channel avulsion. While Option C offers the most direct and shortest path for the overflows to return to the main creek channel, Option C is less favorable than Option A. Thus, Option A offers the most logical return flow path for Breach 1 repair berm overflows, and should be considered as part of the Breach 1, Alternative 2 design.

To carry overflows back to the main channel, the overflows will need to pass across the Foothills Inlet Canal Ditch and the South Branch Ditch. For this alternative, we recommend the overflows cross over the existing ditches to protect the ditches against future flood events. The location of these crossings will vary depending on the selected overflow path. We recommend passing a section of the Foothills Inlet Canal adjacent to the CEMEX property through a 52-inch Reinforced Concrete Pipe (RCP) to allow overflows to pass over the top of the canal to limit damages to the canal during flood events. Likewise, we recommend passing a section of the South Branch Ditch through a 36-inch HDPE inverted siphon to allow overflows to occur above the ditch, protecting the ditch and limiting damages during flood events.

The gradual low-profile setback berm with overflow route Option A provides protection to the CEMEX property and rail line, the Foothills Reservoir Inlet Canal, the South Branch Ditch, and properties southeast within the floodplain. Furthermore, this alternative allows for bank overflow from the primary channel to enhance floodplain vegetation and maximizes the potential to develop riparian habitat in the areas adjacent to the creek with the least amount of impact to existing riparian habitat. This alternative also minimizes the visual impact by having a low-profile berm. More frequent floodplain access through overflows will increase the riparian and wildlife habitat through a large area of open space. In designing the flow path for overflows, the

Foothills Inlet Canal and the South Branch Ditch will benefit from the additional safety provided by protecting sections of the ditches located within the overflow path against future flood events.

An assessment of whether or not Alternative 2 meets the key design criteria is outlined below.

- *Reduce hazards and protect life safety and property?* **Yes**
- *Restore hydraulic capacity of channel based on pre-flood conditions?* **Yes**
- *Technically sound?* **Yes**
- *Meets the objectives of CDBG-DR?* **Yes**
- *Meets the objectives of NRCS/EWP?* **Yes**

Alternative 2 reduces hazards and protects life and property, and restores the creek to pre-flood capacity. Additionally, the proposed elevation and location of the berm are considered technically sound based on the modeling performed. As such, the objectives of CDBG-DR and NRCS/EWP are met by Alternative 2, and the alternative was evaluated further. Additional benefits and considerations for the Alternative 2 design based on the criteria listed in Section 4.3 are discussed below.

- *Threatened and endangered species*
  Enhanced riparian habitat and bioengineering will benefit threatened and endangered species.

- *Native fish passage*
  No major in-stream grade changes will occur, thus maintaining native fish passage through this section of the reach.

- *Riparian improvements*
  The setback of the berm would allow for a wider low-flow floodplain, which would encourage enhanced riparian habitat adjacent to the creek.

- *Maximizes bioengineering*
  The setback berm will be designed and constructed to limit hard armoring and maximize the use of bioengineering for berm construction and across berm faces. In-stream structures will use bioengineering to encourage restoration of natural channel flow and to enhance “natural look” in the stream.

- *Reconnects floodplain*
  The setback of the berm will create a wider, low-flow floodplain adjacent to the creek, and the berm will be designed to resiliently overtop at flows greater than approximately 2,000 cfs, similar to the pre-flood condition. Flows greater than 2,000 cfs will reconnect to the larger floodplain.

- *Restores natural processes*
  In using a more natural, low-profile gradual slope rather than an abrupt, hard-armored berm (as the temporary berm currently exists), this alternative would encourage natural processes. The proposed design will restore the creek to maintain flows up to approximately 2,500 cfs, similar to the pre-flood condition, thus restoring the natural process of overtopping at higher flow events, but conveying low flow events. In-stream work would also maximize the use of bioengineering to encourage restoration

of natural channel flow. By using the natural channel sinuosity and bioengineering, erosion processes will be restored similar to pre-flood conditions.

- *Time to complete final design*
  Based on our experience with similar designs, Alternative 2 is considered moderately complex, and would require moderate time to complete the final design.
- *Time for construction*
  Based on our experience with similar projects, and similar complexity of design, we anticipate that construction of Alternative 2 can be completed within the required design and construction timelines.
- *Obstacles for timely implementation*
  Based on past experience and our understanding of the site conditions, we anticipate relatively few obstacles for timely implementation of Alternative 2 during construction.
- *Difficulty in meeting construction period*
  Based on past experience, we anticipate Alternative 2 to have low to moderate difficulty in meeting the required construction period relative to the other options.
- *Construction cost*
  Based on our planned design and our understanding of the current site conditions and the proposed construction, construction costs would be driven primarily by the required re-grading of the planned berm, as well as any import material that would be required for the berm construction, and is considered moderate in comparison to other alternatives.
- *Operation and maintenance cost (O&M)*
  The O&M costs are likely to be low for the setback berm, based on prior experience.
- *Lifecycle Cost*
  Lifecycle costs are also expected to be low for the setback berm, based on prior experience.

#### 4.3.1.3 Breach 1, Alternative 3 – Maximum Floodplain Setback Berm

This alternative provides the furthest location where a setback berm could be placed to protect the CEMEX property and rail line, the Foothills Reservoir Inlet Canal, and properties downstream. The location and configuration of Alternative 3 are dictated by the slope and grade of the current topography. As evidenced by the flood path during the 2013 event, the existing topography directs flows through Breach 1 southeastward across the floodplain, such that floodwater crosses the CEMEX property and rail line, the Foothills Inlet Canal, and the South Branch Diversion Ditch, and flows into Lake 3, Lake 4, West Lake, and A-Frame Lake, rather than flowing back to the creek channel. To protect these properties, this alternative uses a berm and a return flow channel to direct flood flows back to the St Vrain Creek west of the CEMEX property. Due to the existing topography of the floodplain, the return flow channel would need to be wide and shallow, passing through established riparian, rangeland, and upland habitat. A depiction of Breach 1, Alternative 3 is shown on Figure 4-1C.

An assessment of whether or not Alternative 3 meets the key design criteria is outlined below:

- *Reduce hazards and protect life safety and property?* **Yes**
- *Restore hydraulic capacity of channel based on pre-flood conditions?* **Yes**
- *Technically sound?* **Yes**
- *Meets the objectives of CDBG-DR?* **Yes**
- *Meets the objectives of NRCS/EWP?* **Yes**

Alternative 3 reduces hazards and protects life and property, and the location of the berm is considered technically sound based on the modeling performed. As such, the objectives of CDBG-DR and NRCS/EWP are met by Alternative 3, and the alternative was evaluated further. Additional benefits and considerations for the Alternative 3 design based on the criteria listed in Section 4.3 are discussed below.

- *Threatened and endangered species*
  Enhanced riparian habitat and bioengineering will benefit threatened and endangered species.

- *Native fish passage*
  No major in-stream grade changes will occur, thus maintaining native fish passage through this section of the reach.

- *Riparian improvements*
  Access to the full floodplain would encourage enhanced riparian habitat across a much larger area. A small amount of established riparian area would be disturbed during construction of the return flow channel, but the overall riparian area would be greater than the pre-flood condition.

- *Maximizes bioengineering*
  The berm will be designed and constructed to limit hard armoring and maximize the use of bioengineering for berm construction and across berm faces. In-stream structures will use bioengineering to encourage restoration of natural channel flow and to enhance “natural look” in the stream.

- *Reconnects floodplain*
  The maximum amount of floodplain would be connected to the creek in Alternative 3 while restoring the safety of life and property to the pre-flood condition for stakeholders further downstream of the floodplain berm.

- *Restores natural processes*
  By making significant changes to the floodplain access, and in creating a return flow at a defined point, Alternative 3 will modify the natural processes, and will not restore the stream to pre-flood conditions. In-stream work would maximize the use of bioengineering to encourage restoration of natural channel flow, but increased erosion may occur from modifying the flood flows and path of overflow returns.

- *Time to complete final design*
  Based on our prior experience, Alternative 3 is considered relatively complex and would require relatively significant time to complete the final design compared to other alternatives.
- *Time for construction*
  Based on our experience with similar projects, and similar complexity of design, we anticipate that construction of Alternative 3 will be complex and may not meet the required design and construction timelines.
- *Obstacles for timely implementation*
  Based on past experience and our understanding of the site conditions, we anticipate the potential for many obstacles to be encountered during construction that would impact timely implementation of Alternative 3.
- *Difficulty in meeting construction period*
  Alternative 3 is the most technically complicated option, and thus will have higher difficulty in meeting the required construction period relative to the other options.
- *Construction cost*
  Based on our planned design and our understanding of the current site conditions and the proposed construction, construction costs would be driven primarily by the required construction of the planned berm and re-grading in the return flow channel, and costs will likely be high in comparison to other alternatives.
- *Operation and maintenance cost (O&M)*
  The O&M costs are likely to be moderate for the length of the berm, in comparison to other alternatives.
- *Lifecycle cost*
  Due to the complexity of Alternative 3, lifecycle costs are expected to be high for Alternative 3, based on prior experience.

#### 4.3.1.4 Breach 1, Alternative 4 – *Re-route Creek Channel*

Alternative 4 consists of re-routing the main creek channel through the reach south of the existing creek channel, generally following the overland flow path from the 2013 flood event. The main river channel would be re-routed through Breach 1, passing across the CEMEX property and continuing southeastward through Lake 3, Lake 4, West Lake, and A-Frame Lake, connecting back into the existing main creek channel in the area of Breach 4. Secondary overflows would pass through the existing creek channel. A depiction of Breach 1, Alternative 4 is shown on Figure 4-1D.

By implementing a new flow path along the existing floodway, the creek would gain the resiliency of adjacent floodplain access and allow for natural channel movement through the reach. From a technical standpoint, a new creek flow path is feasible, and absent any existing site development, infrastructure and existing water uses, may be a preferred option. However, this alternative is inconsistent with the recommendations included in the recently completed St. Vrain Creek Watershed Master Plan (Baker Team 2014). The Master Plan suggests recommendations for restoration for the watershed as a whole, as opposed to looking at reaches separately, and does not recommend implementation of a new flow path for the reach.

This alternative would require construction of new ditch diversion structures and ditch connectors (impacting existing decreed water uses in this reach), at least one new bridge over the proposed main creek channel for CEMEX property access (including rail line access and conveyor access), and the redesign and reconstruction of the existing dams and spillways for Lake 4, West Lake, and A-Frame Lake. The spillways would need to be designed to withstand 100-year flow events, or more than 12,000 cfs. Some of the existing structures that would be impacted by the implementation of Alternative 4 include the following:

- CEMEX property – The access road, rail line, conveyor system, and associated equipment would be impacted by the re-routing of the river through the CEMEX property. At least one bridge would be required in this area.
- Foothills Reservoir Inlet Canal – The existing diversion structure would be abandoned, and a new diversion would be required along the proposed re-route.
- South Branch Diversion Ditch – The existing diversion structure would be abandoned and a new diversion structure would be required along the proposed re-route.
- Longmont Supply Diversion Ditch – A new diversion structure would be required along the proposed re-route, along with a new ditch to carry water from the re-route to the existing diversion structure.
- Oligarchy Ditch – A new diversion structure would be required along the proposed re-route, along with a new ditch to carry water from the re-route to the existing diversion structure.
- Lake 4, West Lake, and A-Frame Lake Dams – The proposed re-route would carry water through Lake 4, West Lake, and A-Frame Lake, and new spillways would be required to carry typical stream flows through the dams and back to the original channel. To accommodate such a move would require the redesign and reconstruction of the existing dams and spillways (Boulder County FEMA projects). The dams and spillways would need to be redesigned to withstand flood flows up to the 100-year event (peak flow greater than 12,000 cfs). The added cost for the implementation and addition of these structures in these Boulder County FEMA projects was not considered in the original assessment and would substantially exceed the current funding amounts.

BCPOS (the project sponsor) would need to secure land or easements to successfully move the creek through any new pathway, as they do not own all of the land that would be needed to accomplish this move. The impaired owners and holders of other property interests may not be cooperative to the effort, which may translate into years of negotiations and large sums of funds to acquire the necessary land. Relocation of three miles of a major Colorado waterway is a major undertaking that will take significant funding and will require many years of permitting and land acquisition. Re-routing the main creek channel would change the existing floodplain, shifting the main flood path south along the new creek alignment, and would likely require the development of FEMA flood map revisions including a Conditional Letter of Map Revision (CLOMR) and a Letter of Map Revision (LOMR) for the impacted floodplain. This may impact the flood mapping of adjacent landowners, which may have a negative impact on property values and lower the protection to said properties. A flood impact study would need to be performed to assess the impact of potential flooding on life and property based on the new alignment, with particular focus on the added potential for dam breach/failure by passing primary channel flows through the dams, and the impact of dam breach/failure on neighboring stakeholders. The construction costs associated with moving the main channel would be very expensive, and re-routing the entire stream through the reach would require a comprehensive Environmental Impact Statement, which would have its own additional expense and add months to the project timeline as well.

As part of our alternative analysis process, EA sought feedback from the project's local stakeholders, including ditch companies and ditch owners that are located in the affected project area. EA provided a plan for the proposed new primary creek channel to these stakeholders, including ditch companies and ditch owners, the St. Vrain Water Commissioner, and the SVLHWCD, which is a local district that serves as an advocate for all the various ditch companies and land owners along the St. Vrain Creek. While ditch companies and ditch owners were generally receptive to changes that would support life/property safety issues, they were not receptive to moving the entire stream reach, as the financial and administrative burden for moving this infrastructure would fall on these companies and owners. While some owners were receptive to an alternative stream channel as their diversions would be shortened, others were concerned by the additional maintenance, need for new easements that would take years to obtain, and additional costs that would be associated with lengthening their diversions to connect to the new channel to receive their full water right.

SVLHWCD, as the collective voice for water users, water uses, property uses and the health of the St. Vrain Creek, provided a response to the project team regarding Alternative 4. This response is attached as Appendix IV. In addition to comments received from ditch companies and the SVLHWCD, the St. Vrain Water Commissioner also expressed concerns for the impacts to ditch owners should a new primary creek channel be considered. The Water Commissioner emphasized that any move of the creek of this magnitude will need to go through water court to change the locations for the diversions, the need for additional maintenance and right-of-way agreements, and the creation of Lake 4 as an on-stream reservoir. We anticipate the water court determination process may take approximately 5 years. A copy of this correspondence is also attached in Appendix IV.

An assessment of whether or not Alternative 1 meets the key design criteria is outlined below:

- *Reduce hazards and protect life safety and property?* **Yes**
- *Restore hydraulic capacity of channel based on pre-flood conditions?* **Yes**
- *Technically sound?* **Yes**
- *Meets the objectives of CDBG-DR?* **Yes**
- *Meets the objectives of NRCS/EWP?* **Yes**

Alternative 4 can be designed to reduce hazards and protect life and property. As such, the objectives of CDBG-DR and NRCS/EWP are met by Alternative 4, and the alternative was evaluated further. It should be noted that this alternative may fall into the category of projects for which EWP Program funds may not be used in accordance with the EWP Engineering Guidance document (EWP 2016), specifically in reference to Part 511.4 Limitations, Section A of the EWP Program Manual.

Additional benefits and considerations for the Alternative 4 design based on the criteria listed in Section 4.3 are discussed below.

- *Threatened and endangered species*
  Re-routing the entire creek channel will negatively impact the existing threatened and endangered species. In the long term, providing a main channel and an overflow channel may increase the available riparian habitat and restore threatened and endangered species.
- *Native fish passage*
  By passing primary flows through a set of dams, native fish passage will be hindered along a significant portion of the reach.
- *Riparian improvements*
  By moving primary flows out of the existing creek channel, the existing developed riparian areas will be negatively impacted. In the long term, providing a main channel and an overflow channel may increase the available riparian habitat through the corridor.
- *Maximizes bioengineering*
  In-stream structures will use bioengineering to encourage restoration of natural channel flow and to enhance “natural look” in the stream. Bioengineering will be used as much as possible along the new creek channel, however, hard armoring will be required for the redesigned dam embankments and spillways.
- *Reconnects floodplain*
  By implementing a main channel and an overflow channel, the floodplain will be changed, but will remain relatively connected. A wider southern floodplain will likely develop as a result of the main channel shifting south from the existing channel.
- *Restores natural processes*
  By following the path of overland flow, the new creek channel will use the natural, sinuous alignment set by prior flooding. By using more natural channel sinuosity and bioengineering, erosion processes will be restored similar to pre-flood conditions.
- *Time to complete final design*

  Based on our experience with similar designs, Alternative 4 is considered the highest complexity, and would require significant time to complete the final design.
- *Time for construction*
  Based on our experience with similar projects, and similar complexity of design, we anticipate that construction of Alternative 4 may not be possible within the required design and construction timelines.

- *Obstacles for timely implementation*
  Based on past experience and our understanding of the site conditions, we anticipate the potential for many obstacles for timely implementation of Alternative 4 during construction.
- *Difficulty in meeting construction period*
  Based on the complexity of the project, we anticipate Alternative 4 to have high difficulty in meeting the required construction period relative to the other options.
- *Construction cost*
  Based on our planned design and our understanding of the current site conditions and the proposed construction, construction costs are considered to be very high in comparison to other alternatives.
- *Operation and maintenance cost (O&M)*
  The O&M costs are likely to be high for the proposed re-route, particularly considering the maintenance of the dam spillways to maintain flows.
- *Lifecycle cost*
  Lifecycle costs are also expected to be high for the proposed re-route, particularly as the channel naturally establishes, and new erosion patterns, split flows, and floodplains are established.

### 4.3.1.5 Breach 1 – Comparative Analysis

A comparative analysis of the alternatives with respect to the design criteria and additional design benefits, cost, and construction is provided in the following table. The "edge" column in the table indicates the relative most favorable alternative(s) for each evaluation criterion.

***Table 4-1*** *Breach 1 Alternatives Comparative Analysis*

| **Criteria** | | **Alternative #1** | **Alternative #2** | **Alternative #3** | **Alternative #4** | **Edge** |
|---|---|---|---|---|---|---|
| Design Evaluation Criteria | **Reduce hazards and protect life safety and property** | No | Yes | Yes | Yes | Alt 2 / 3 / 4 |
| | **Restore hydraulic capacity of channel based on pre-flood conditions** | No | Yes | Yes | Yes | Alt 2 / 3 / 4 |
| | **Technically sound** | Yes | Yes | Yes | Yes | Alt 2 / 3 / 4 |
| | **Meets objectives of CDBG-DR** | No | Yes | Yes | Yes | Alt 2 / 3 / 4 |
| | **Meets objectives of NRCS/EWP** | No | Yes | Yes | Yes | Alt 2 / 3 / 4 |
| Additional Benefits of Design | T&E species | - | Med | Med | Low | Alt 2 / 3 |
| | Native fish passage | - | Med | Med | Low | Alt 2 / 3 |
| | Riparian improvements | - | Med | High | Med | Alt 3 |
| | Maximizes bioengineering | - | High | High | Med | Alt 2 / 3 |
| | Reconnects floodplain | - | Med | High | Med | Alt 3 |
| | Restores natural processes | - | Med | Low | Med | Alt 2 / 4 |
| | Time frame for final design | - | Low | Med | High | Alt 2 |
| Cost Considerations | Initial cost | - | Low | Med | High | Alt 2 |
| | Lifecycle cost | - | Low | High | High | Alt 2 |
| | O&M cost | - | Low | Low | High | Alt 2 / 3 |
| Construction Considerations | Construction time | - | Low | Med | High | Alt 2 |
| | Obstacles for timely implementation | - | Low | Med | High | Alt 2 |
| | Difficulty in meeting construction period | - | Low | Med | High | Alt 2 |
| | | Overall Edge | | | | Alt 2 |

Note: No further analysis performed for alternatives not meeting minimum design evaluation criteria.

The Breach 1 alternative that meets the minimum design evaluation criteria and provides the most additional benefits of design and construction based on the above analysis, and is thus considered the recommended alternative, is Alternative 2, the Gradual Low-Profile Setback Berm. The overflow route follows existing floodway, providing natural resilience by taking advantage of the established floodway.

Rather than redirecting primary flows into a new channel (as discussed in Alternative 4), we recommend encouraging more frequent overflows (for storms greater than 2,000 cfs) over the Breach 1 repair berm, using the natural resilience provided within the existing floodway along the alignment denoted as the *South Branch Channel* in the 30% design plans, with overflows making their way back into the stream system via Lake 4, West Lake, and A-Frame Lake (as in Alternative 2). The South Branch Channel generally follows the path of the existing floodway, providing a primary flood path for the creek to limit damages to the surrounding area. By using the existing floodway for overflows, no special design or permitting will be required. In fact, using the existing floodway maintains and takes advantage of the natural resilience of a pre-existing flood path.

While a portion of the overflows will likely pass back to the stream system through Lake 4, West Lake, and A-Frame Lake, these lakes cannot be turned into riverine wetlands nor can the entire stream primary flow pass through the lakes as suggested in the comments and explored in our Alternatives Analysis. The current design for the new spillways for Lake 4, West Lake, and A-Frame Lake is on the order of 2,300 cfs. Lake 4 and West Lake have jurisdictional dams, and as such would be required to pass a minimum of the 100-year flow (>12,000 cfs) if the primary channel were to pass through the lakes. Thus, passing the primary channel through the lakes would require a costly redesign and construction that FEMA would be unwilling to fund. Additionally, Lake 4 is an augmentation pond with associated water rights that extend approximately 15 feet below the spillway of West Lake. Bypassing the live flow of the St. Vrain Creek through Lake 4 would deem this water unacceptable for augmentation and would result in loss of property to the SVLHWCD and Boulder County, as joint water rights owners. While moving the existing channel would create new riparian habitat, it would also take water away from the existing established riparian habitat adjacent to the existing primary channel; this would result in the loss of important habitat for species such as the PMJM. However, additional habitat may be achieved in the floodway resulting from more frequent floodplain access for storm events exceeding 2,000 cfs. Relocating the creek could be a viable option for this reach, if there was a longer project timeline to accommodate all of the constraints mentioned above, and all stakeholders were financially vested in this approach.

Based on the current feedback that EA has received from local stakeholders, the cost benefit analysis of Alternative 4, and the constraints mentioned above, we recommend Alternative 2 which maintains the creek within the existing primary creek channel and allows overflows into the existing floodway.

### 4.3.2 Breach 2 Alternatives

#### 4.3.2.1 Breach 2, Alternative 1 – *No Action*

Alternative 1 consists of removing the existing temporary berm. This alternative provides no protection to the Longmont Supply Diversion Ditch or to the neighboring properties. A depiction of Breach 2, Alternative 1 is shown on Figure 4-2A.

An assessment of whether or not Alternative 1 meets the key design criteria is outlined below:

- *Reduce hazards and protect life safety and property?* **No**
- *Restore hydraulic capacity of channel based on pre-flood conditions?* **No**
- *Technically sound?* **Yes**
- *Meets the objectives of CDBG-DR?* **No**
- *Meets the objectives of NRCS/EWP?* **No**

Alternative 1 does not reduce the threats to life or property of landowners and increases the hazard risk over the pre-flood and current condition, and thus does not meet the design objectives. By allowing unimpeded flow through Lake 2, regular flows through the main creek channel will be reduced, which will impact the flow to the Longmont Supply Diversion Ditch. While Alternative 1 would reconnect the floodplain by allowing regular access to Lake 2 for flood events, and would maintain and encourage the natural redevelopment of riparian area in the floodplain, the potential for future damages associated with frequent flooding into Lake 2 would be unacceptable. If this option were selected, large changes to the floodplain would occur and will require the development of a Conditional Letter of Map Revision (CLOMR) and a Letter of Map Revision (LOMR) for the impacted floodplain. A key component of both the CDBG-DR and NRCS/EWP design objectives is to reduce threats to life and property by mitigating future risks from flooding, thus Alternative 1 does not meet these objectives, is not considered feasible, and was not explored further.

#### 4.3.2.2 Breach 2, Alternative 2 – *Berm and Downslope Grading*

Alternative 2 consists of reconstructing the land in the Breach 2 area up to the pre-flood ground surface elevations to restore the creek to the pre-flood flow condition. To prevent further impacts from future flooding and overtopping, and to provide for additional habitat development, the downstream slope of the repair berm will be flattened and revegetated. This alternative will maintain primary flow through the creek channel, such that the Longmont Supply Diversion Ditch will receive its full allotment of water. Shoreline repairs will occur within Lake 2 as part of the re-grading, and erosion scars caused from the 2013 flooding will be filled and reinforced as part of the downslope improvements. We also recommend installation of a bifurcation structure just downstream of Breach 2 to redirect primary creek flows away from the Longmont Supply Diversion structure back to the original primary channel (current creek flows are passing to the Longmont Supply Diversion structure and back to the main creek channel through an overflow channel, rather than the original primary channel). By rebuilding a new berm with a flatter downslope, habitat regeneration will be encouraged. In-stream structures including cross vanes, vanes, and root wads will be used to encourage proper sediment deposition and prevent the sediment plug that occurred in the area of Breach 2 during the 2013 flooding. The bifurcation structure will enhance the safety and reduce maintenance of the Longmont Supply Diversion structure, as well as aid in restoring the riparian and wildlife habitat of the original primary channel. A depiction of Breach 2, Alternative 2 is shown on Figure 4-2B.

An assessment of whether or not Alternative 2 meets the key design criteria is outlined below:

- *Reduce hazards and protect life safety and property?* **Yes**
- *Restore hydraulic capacity of channel based on pre-flood conditions?* **Yes**
- *Technically sound?* **Yes**
- *Meets the objectives of CDBG-DR?* **Yes**
- *Meets the objectives of NRCS/EWP?* **Yes**

Alternative 2 reduces hazards and protects life and property, restores the creek to pre-flood capacity, and the berm is considered technically sound based on the modeling performed. As such, the objectives of CDBG-DR and NRCS/EWP are met by Alternative 2, and the alternative was evaluated further. Additional benefits and considerations for the Alternative 2 design based on the criteria listed in Section 4.3 are discussed below.

- *Threatened and endangered species*
  Enhanced riparian habitat and bioengineering will benefit threatened and endangered species.

- *Native fish passage*
  Any in-stream grade changes would be facilitated by the use of cross vanes that would be designed to maintain native fish passage through this section of the reach.

- *Riparian improvements*
  By rebuilding a new berm with a flatter downslope, habitat regeneration will be encouraged on the downslope side of the berm and into Lake 2.

- *Maximizes bioengineering*
  The berm will be designed and constructed to limit hard armoring and maximize the use of bioengineering for berm construction and across berm faces. In-stream structures will use bioengineering to encourage restoration of natural channel flow and to enhance “natural look” in the stream.

- *Reconnects floodplain*
  The berm will be designed to resiliently overtop at flows greater than approximately 2,500 cfs, similar to the pre-flood condition, which will reconnect to the larger floodplain including Lake 2.

- *Restores natural processes*
  This alternative will maintain primary flow through the creek channel, restoring the creek to maintain approximately 2,500 cfs, similar to the pre-flood condition, restoring the natural process of overtopping at higher flow events, but conveying low flow events. To prevent further impacts from future flooding and overtopping, the downstream slope of the repair berm will be flattened and revegetated. In-stream

structures including cross vanes, vanes, and root wads will be used to encourage proper sediment deposition.

- *Time to complete final design*
  Based on our experience with similar designs, Alternative 2 is considered relatively simple and would require low to moderate time to complete the final design.
- *Time for construction*
  Based on our experience with similar projects, and similar complexity of design, we anticipate that construction of Alternative 2 will be relatively simple, and will be feasible within the required design and construction timelines.
- *Obstacles for timely implementation*
  Based on past experience and our understanding of the site conditions, we anticipate relatively few obstacles for timely implementation of Alternative 2 during construction.
- *Difficulty in meeting construction period*
  Based on past experience, we anticipate Alternative 2 to have low to moderate difficulty in meeting the required construction period relative to the other options.
- *Construction cost*
  Based on our planned design and our understanding of the current site conditions and the proposed construction, construction costs would be driven primarily by the required re-grading of the planned berm, as well as any import material that would be required for the berm construction, and is considered low to moderate in comparison to other alternatives.
- *Operation and maintenance cost (O&M)*
  The O&M costs are likely to be low for the reconstructed berm, based on prior experience.
- *Lifecycle cost*
  Lifecycle costs are also expected to be low for the berm, based on prior experience.

#### 4.3.2.3 Breach 2, Alternative 3 – Overflow Berm and Downslope Grading

Alternative 3 is similar to Alternative 2, with the exception of the berm being designed with an armored low point for overflows into Lake 2. The low point will allow for the passage of more frequent flows and allow for sediment and flooding to exit the creek and deposit in Lake 2 or continue on towards Breach 3 and return to the creek. A depiction of Breach 2, Alternative 3 is shown on Figure 4-2C. The low point as shown on Figure 4-2C was determined based on the modeled creek flood elevations and the topography of the creek. To prevent further impacts from future flooding and overtopping, and to provide for additional habitat development, the downstream slope of the repair berm will be flattened and revegetated. Shoreline repairs will occur within Lake 2 as part of the re-grading, and erosion scars resulting from the 2013 flooding will be filled and reinforced as part of the downslope improvements. As in Alternative 2, we recommend installation of a bifurcation structure just downstream of Breach 2 to redirect primary creek flows away from the Longmont Supply Diversion structure back to the original primary channel. By rebuilding a new berm with a flatter downslope, habitat regeneration will be encouraged. In-stream structures including cross vanes, vanes, and root wads will be used to encourage proper sediment deposition and prevent the sediment plug that occurred in the area of Breach 2 during the 2013 flooding. The bifurcation structure will enhance the safety and reduce maintenance of the Longmont Supply Diversion structure, as well as aid in restoring the riparian and wildlife habitat of the original primary channel.

An assessment of whether or not Alternative 3 meets the key design criteria is outlined below:

- *Reduce hazards and protect life safety and property?* **Yes**
- *Restore hydraulic capacity of channel based on pre-flood conditions?* **Yes**
- *Technically sound?* **Yes**
- *Meets the objectives of CDBG-DR?* **Yes**
- *Meets the objectives of NRCS/EWP?* **Yes**

Alternative 3 reduces hazards and protects life and property, and restores the creek to pre-flood capacity. The height of the berm and the low point for overflow are considered technically sound based on the modeling performed. As such, the objectives of CDBG-DR and NRCS/EWP are met by Alternative 3, and the alternative was evaluated further. Additional benefits and considerations for the Alternative 3 design based on the criteria listed in Section 4.3 are discussed below.

- *Threatened and endangered species*
  Enhanced riparian habitat and bioengineering will benefit threatened and endangered species.

- *Native fish passage*
  No major in-stream grade changes will occur, thus maintaining native fish passage through this section of the reach.

- *Riparian improvements*
  Access to the full floodplain would encourage enhanced riparian habitat across a much larger area. A small amount of established riparian area would be disturbed during construction of the return flow channel, but the overall riparian area would be greater than the pre-flood condition.

- *Maximizes bioengineering*
  In addition to maintaining flows through the creek channel, this alternative encourages habitat growth in the downslope side of the berm and into Lake 2. The berm will be designed and constructed to limit hard armoring and maximize the use of bioengineering for berm construction and across berm faces. In-stream structures will use bioengineering to encourage restoration of natural channel flow and to enhance “natural look” in the stream.

- *Reconnects floodplain*
  The maximum amount of floodplain would be connected to the creek in Alternative 3 while restoring the safety of life and property to the pre-flood condition for stakeholders further downstream of the floodplain berm.

- *Restores natural processes*
  By making significant changes to the floodplain access, and in creating a return flow at a defined point, Alternative 3 will modify the natural processes, and will not restore the stream to pre-flood conditions. In-stream work would maximize the use of bioengineering to encourage restoration of natural channel flow, but increased erosion may occur by modifying the flood flows and path of overflow returns.

  One disadvantage of Alternative 3 is the reduction of flow that would occur in the main creek channel by encouraging overflows through Lake 2. By reducing flow through the main channel, total flows to the Longmont Supply Diversion Ditch would be reduced for larger flow events compared to the pre-flood condition, which may not be considered acceptable to the ditch owner.

- *Time to complete final design*
  Based on our prior experience, Alternative 3 is considered moderately complex, and would require moderate time to complete the final design compared to other alternatives.

- *Time for construction*
  Based on our experience with similar projects, and similar complexity of design, we anticipate that construction of Alternative 3 will be moderately complex, and will be able to meet the required design and construction timelines.

- *Obstacles for timely implementation*
  Based on past experience and our understanding of the site conditions, we anticipate relatively few obstacles for timely implementation of Alternative 3 during construction.

- *Difficulty in meeting construction period*
  Based on past experience, we anticipate Alternative 3 to have low to moderate difficulty in meeting the required construction period relative to the other options.

- *Construction cost*
  Based on our planned design and our understanding of the current site conditions and the proposed construction, construction costs would be driven primarily by the required re-grading of the planned berm, as well as any import material that would be required for the berm construction, and is considered moderate in comparison to other alternatives.

- *Operation and maintenance cost (O&M)*
  The O&M costs are likely to be moderate in comparison to other alternatives.

- *Lifecycle cost*
  Lifecycle costs are expected to be moderate for Alternative 3, based on prior experience.

#### 4.3.2.4 Breach 2 – Comparative Analysis

A comparative analysis of the alternatives with respect to the design criteria and additional design benefits, cost, and construction is provided in the following table.

***Table 4-2*** *Breach 2 Alternatives Comparative Analysis*

| **Criteria** | | **Alt #1 – No Action** | **Alt #2 – Berm and Downslope Grading** | **Alt #3 – Overflow Berm and Downslope Grading** | **Edge** |
|---|---|---|---|---|---|
| Design Evaluation Criteria | **Reduce hazards and protect life safety and property** | No | Yes | Yes | Alt 2 / 3 |
| | **Restore hydraulic capacity of channel based on pre-flood conditions** | No | Yes | Yes | Alt 2 / 3 |
| | **Technically sound** | Yes | Yes | Yes | Alt 2 / 3 |
| | **Meets objectives of CDBG-DR** | No | Yes | Yes | Alt 2 / 3 |
| | **Meets objectives of NRCS/EWP** | No | Yes | Yes | Alt 2 / 3 |
| Additional Benefits of Design | T&E species | - | Med | Med | Neutral |
| | Native fish passage | - | Med | High | Alt 3 |
| | Riparian improvements | - | Med | Med | Neutral |
| | Maximizes bioengineering | - | Med | Med | Neutral |
| | Reconnects floodplain | - | Low | Med | Alt 3 |
| | Restores natural processes | - | Low | Med | Alt 3 |
| | Time frame for final design | - | Med | Med | Neutral |
| Cost Considerations | Initial cost | - | Low | Med | Alt 2 |
| | Lifecycle cost | - | Low | Med | Alt 2 |
| | O&M cost | - | Low | Med | Alt 2 |
| Construction Considerations | Construction time | - | Med | Med | Neutral |
| | Obstacles for timely implementation | - | Med | Med | Neutral |
| | Difficulty in meeting construction period | - | Med | High | Alt 2 |
| | | | | Overall Edge | Alt 2 |

Note: No further analysis performed for alternatives not meeting minimum design evaluation criteria.

The Breach 2 alternative that meets the minimum design evaluation criteria and provides the most additional benefits of design and construction based on the above analysis, and is thus considered the recommended alternative is Alternative 2, the Berm and Downslope Grading option.

### 4.3.3 Breaches 5-9 Alternatives

#### 4.3.3.1 Breaches 5-9, Alternative 1 – *No Action*

Alternative 1 consists of maintaining the post-flood conditions by leaving Breaches 5, 6, 8, and 9 open and by removing the existing temporary berm at Breach 7a to return to the post-flood condition. This alternative provides no protection to nearby residents and adjacent communities and pertinent structures. Flows will likely lead to the development of additional breach(es). A depiction of Breaches 5-9, Alternative 1 is shown on Figure 4-3A.

An assessment of whether Alternative 1 meets the key design criteria needed to be considered a feasible approach is outlined below:

- *Reduce hazards and protect life safety and property?* **No**
- *Restore hydraulic capacity of channel based on pre-flood conditions?* **No**
- *Technically sound?* **Yes**
- *Meets the objectives of CDBG-DR?* **No**
- *Meets the objectives of NRCS/EWP?* **No**

Alternative 1 does not reduce the threats to life or property of landowners and increases the hazard risk over the pre-flood and current condition, and thus does not meet the design objectives. While Alternative 1 would reconnect the floodplain, and would maintain and encourage the natural redevelopment of riparian area in the floodplain, by allowing unimpeded flow through the breached areas, nearby neighbors and communities would be at risk in future flooding events as overtopping would occur repeatedly. Particularly, the City of Longmont would be at risk of flooding eastward through Breach 7, which is considered unacceptable for the safety of life and property. If this option were selected, large changes to the floodplain would occur and require the development of FEMA flood map revisions including a Conditional Letter of Map Revision (CLOMR) and a Letter of Map Revision (LOMR) for the impacted floodplain. A key component of the both the CDBG-DR and NRCS/EWP design objectives is to reduce threats to life and property by mitigating future risks from flooding, thus Alternative 1 does not meet these objectives, is not considered feasible, and was not explored further.

#### 4.3.3.2 Breaches 5-9, Alternative 2 – *Redirect Flow and Full Berm*

Alternative 2 includes the removal of the temporary breach repair at Breach 7a and replacement with a full berm east of Breach 7a across Hepp #2 Reservoir, re-grading and erosion protection to create a “permanent breach” at Breach 7b, a low-profile berm south of Breach 6 across Hepp #1 Reservoir to encourage more direct flows through Hepp #1 Reservoir, and some grading within the pre-flood channel to encourage overflows through the pre-flood alignment. Breach 5 will remain open as a backwater wetland area. Breaches 8 and 9 will remain open as a return flow location for flows through Hepp #1 to return to the main creek channel. The berm across Hepp #1 Reservoir will be designed to modify the post-flood creek channel flow through Hepp #1, and provide a more stable approach to the Hygiene Road Bridge. The island between Breaches 8 and 9 is also recommended for removal in this alternative as part of the modifications to the post-flood channel to provide more direct flows under the Hygiene Road Bridge. The berm across Hepp #2 Reservoir is set back from the creek to create more area for flood flows and increased riparian habitat area, and will be designed to prevent flows from the creek to communities east of the creek, including the City of Longmont. Natural split flows through Hepp #1 Reservoir, and overflows through the pre-flood channel will provide multiple locations for sediment deposition. Maintaining primary flows through Hepp #1 Reservoir and away from the pre-flood channel provides additional protection against flows heading eastward through Hepp #2 Reservoir, thus increasing resiliency of the Breach 7a repair. A depiction of Breaches 5-9, Alternative 2 is shown on Figure 4-3B.

An assessment of whether Alternative 2 meets the key design criteria needed to be considered a feasible approach is outlined below:

- *Reduce hazards and protect life safety and property?* **Yes**
- *Restore hydraulic capacity of channel based on pre-flood conditions?* **Yes**
- *Technically sound?* **Yes**
- *Meets the objectives of CDBG-DR?* **Yes**
- *Meets the objectives of NRCS/EWP?* **Yes**

Alternative 2 reduces hazards and protects life and property, and as such, the objectives of CDBG-DR and NRCS/EWP are met by Alternative 2, and the alternative was evaluated further. Additional benefits and considerations for the Alternative 2 design based on the criteria listed in Section 4.3 are discussed below.

- *Threatened and endangered species*
  Enhanced riparian habitat and bioengineering will benefit threatened and endangered species.
- *Native fish passage*
  No major in-stream grade changes will occur, thus maintaining native fish passage through this section of the reach.
- *Riparian improvements*
  Increased available floodplain and riparian area will be available through Hepp #1 Reservoir. Braided channels will be allowed to occur, which allows for enhanced riparian habitat. Grading within the pre-flood channel will encourage multiple flow paths through pre-flood and post-flood creek alignments. The pre-flood channel has already started a natural restoration of riparian habitat, and this would remain in place. The berm across Hepp #2 Reservoir is set back from the creek to create increased riparian habitat area.
- *Maximizes bioengineering*
  The berms will be designed and constructed to limit hard armoring and maximize the use of bioengineering for berm construction and across berm faces. In-stream structures will use bioengineering to encourage restoration of natural channel flow and to enhance “natural look” in the stream.
- *Reconnects floodplain*
  The larger floodplain through Hepp #1 Reservoir would be connected to the creek in Alternative 2, with a secondary floodplain through the pre-flood channel for higher

flow events. The berm across Hepp #2 Reservoir is set back from the creek to create more area for flood flows, and will be designed to protect communities to the east from future flooding across an area that is not defined as the natural floodplain.

- *Restores natural processes*
  Using a berm in Hepp #1 Reservoir will encourage natural re-routing of the primary flow path. Split flows through the reservoir would provide multiple locations for sediment deposition. However, Alternative 2 will modify the natural processes, changing the flow path, and will not restore the creek to pre-flood conditions. In-stream work would maximize the use of bioengineering to encourage restoration of natural channel flow, but increased erosion may occur by modifying the flow path.

- *Time to complete final design*
  To design a technically sound berm across Hepp #1 Reservoir will be complex because of the existing unconsolidated alluvial sediment in the reservoir. The berm would need to be designed to be founded on undisturbed native soil and/or bedrock. As a result, Alternative 2 is considered highly complex compared to other options, and would require relatively significant time to complete the final design.

- *Time for construction*
  The berm across Hepp #1 Reservoir will have higher likelihood of construction difficulties. To construct a technically sound berm, the foundation would need to be excavated to undisturbed native soil and/or bedrock, and the depth of excavation and difficulty of construction may be very high. We anticipate that construction of Alternative 2 will be complex, and may not meet the required construction timelines.

- *Obstacles for timely implementation*
  Based on our understanding of the site conditions, we anticipate the berm across Hepp #1 Reservoir will have higher likelihood of construction difficulties that would impact timely implementation of Alternative 2.

- *Difficulty in meeting construction period*
  Alternative 2 is the most technically complicated option, and thus will have higher difficulty in meeting the required construction period relative to the other options. We anticipate that construction of Alternative 2 will be complex, and may not meet the required construction timelines.

- *Construction cost*
  Based on our planned design and our understanding of the current site conditions and the proposed construction, to construct a technically sound berm across Hepp #1 Reservoir, the depth of excavation and cost of construction may be very high and overall construction cost for Alternative 2 will be higher in comparison to other alternatives.

- *Operation and maintenance cost (O&M)*
  The O&M costs are likely to be moderate in comparison to other alternatives.

- *Lifecycle cost*
  Lifecycle costs are expected to be higher for Alternative 2, specifically in regards to the potential for erosion and berm degradation for the berm across Hepp #1 Reservoir.

#### 4.3.3.3 Breaches 5-9, Alternative 3 – *Overflow Berm and Full Berm*

Alternative 3 includes the removal of the temporary breach repair at Breach 7a and replacement with a full berm east of Breach 7a across Hepp #2 Reservoir, re-grading and erosion protection to create a "permanent breach" at Breach 7b, a low-profile berm across Breach 6 to allow defined overflows, and grading to encouraging the primary flows through the pre-flood creek channel. Breach 5 will remain open as a backwater wetland area. Breaches 8 and 9 will remain open as a return flow location for overflows at the Breach 6 berm to return to the creek channel, and will also serve as a backwater wetland area along the right bank of the creek channel. The berm across Hepp #2 Reservoir is set back from the creek to create more area for flood flows and increased riparian habitat area, and will be designed to prevent flows from the creek to communities east of the creek, including the City of Longmont. Split flows through the pre-flood creek channel area will provide a location for sediment deposition and habitat restoration, while the overflow into Hepp #1 Reservoir will provide additional capacity for sediment deposition and an alternative location for riparian habitat development. A depiction of Breaches 5-9, Alternative 3 is shown on Figure 4-3C.

An assessment of whether Alternative 3 meets the key design criteria needed to be considered a feasible approach is outlined below:

- *Reduce hazards and protect life safety and property?* **Yes**
- *Restore hydraulic capacity of channel based on pre-flood conditions?* **Yes**
- *Technically sound?* **Yes**
- *Meets the objectives of CDBG-DR?* **Yes**
- *Meets the objectives of NRCS/EWP?* **Yes**

Alternative 3 reduces hazards and protects life and property, and restores the creek to pre-flood capacity. The height of the overflows across the Breach 6 berm, and the height of the berm required to prevent flows past Breach 7a are considered technically sound based on the modeling performed. The objectives of CDBG-DR and NRCS/EWP are met by Alternative 3, and the alternative was evaluated further.

Additional benefits and considerations for the Alternative 3 design based on the criteria listed in Section 4.3 are discussed below.

- *Threatened and endangered species*
  Enhanced riparian habitat and bioengineering will benefit threatened and endangered species.

- *Native fish passage*
  No major in-stream grade changes will occur, thus maintaining native fish passage through this section of the reach.

- *Riparian improvements*
  The berm across Hepp #2 Reservoir is set back from the creek and would allow for a wider low-flow floodplain, which would encourage enhanced riparian habitat adjacent to the creek, and the overflow into Hepp #1 Reservoir will provide additional capacity for sediment deposition and allow inundation of the Hepp #1 Reservoir creating additional riparian habitat area.

- *Maximizes bioengineering*
  The berms will be designed and constructed to limit hard armoring and maximize the use of bioengineering for berm construction and across berm faces. In-stream structures will use bioengineering to encourage restoration of natural channel flow and to enhance "natural look" in the stream.

- *Reconnects floodplain*
  The berm across Hepp #2 Reservoir is set back from the creek to create more area for flood flows and will be designed to prevent flood flows into communities east of the creek, including the City of Longmont. A low-profile berm across Breach 6 will allow defined overflows, and will be designed to resiliently overtop and inundate the Hepp #1 Reservoir as additional floodplain and riparian area.

- *Restores natural processes*
  Grading will encourage primary flows through the pre-flood creek channel, and overflows into Hepp #1 Reservoir will provide additional capacity for sediment deposition and an alternative location for riparian habitat development. In addition to restoring flows through the pre-flood creek channel, Alternative 3 provides additional resiliency against flows heading eastward through the Breach 7a repair berm by having the redundancy of a secondary overflow channel through Hepp #1 Reservoir.

  This alternative is also considered the most geomorphically stable option for sediment transport conveyance with low flows through the pre-flood channel, and overflows into Hepp #1 Reservoir. In-stream work would also maximize the use of bioengineering to encourage restoration of natural channel flow.

- *Time to complete final design*
  Based on our experience with similar designs, Alternative 3 is considered moderately complex, and would require moderate time to complete the final design compared to other options.

- *Time for construction*
  Based on our experience with similar projects, and similar complexity of design, we anticipate that construction of Alternative 3 will be moderately complex, but will be feasible within the required design and construction timelines.

- *Obstacles for timely implementation*
  Based on past experience and our understanding of the site conditions, we anticipate relatively few obstacles for timely implementation of Alternative 3 during construction.

- *Difficulty in meeting construction period*
  Based on past experience, we anticipate Alternative 3 to have low to moderate difficulty in meeting the required construction period relative to the other options.

- *Construction cost*
  Based on our planned design and our understanding of the current site conditions and the proposed construction, construction costs would be driven primarily by the required re-grading of the planned berm, as well as any import material that would be required for the berm construction, and is considered moderate in comparison to other alternatives.

- *Operation and maintenance cost (O&M)*
  The O&M costs are likely to be low to moderate for the overflow berm and full berm, based on prior experience.

- *Lifecycle cost*
  Lifecycle costs are also expected to be low for the overflow berm and full berm, based on prior experience.

### 4.3.3.4 Breaches 5-9 – Comparative Analysis

A comparative analysis of the alternatives with respect to the design criteria and additional design benefits, cost, and construction is provided in the following table.

***Table 4-3*** *Breaches 5-9 Alternatives Comparative Analysis*

| **Criteria** | | **Alt #1 – No Action** | **Alt #2 – Redirect Flow and Full Berm** | **Alt #3 – Overflow Berm and Full Berm** | **Edge** |
|---|---|---|---|---|---|
| Design Evaluation Criteria | **Reduce hazards and protect life safety and property** | No | Yes | Yes | Alt 2 / 3 |
| | **Restore hydraulic capacity of channel based on pre-flood conditions** | No | Yes | Yes | Alt 2 / 3 |
| | **Technically sound** | Yes | Yes | Yes | Alt 2 / 3 |
| | **Meets objectives of CDBG-DR** | No | Yes | Yes | Alt 2 / 3 |
| | **Meets objectives of NRCS/EWP** | No | Yes | Yes | Alt 2 / 3 |
| Additional Benefits of Design | T&E species | - | High | High | Neutral |
| | Native fish passage | - | High | High | Neutral |
| | Riparian improvements | - | Med | High | Alt 3 |
| | Maximizes bioengineering | - | High | High | Neutral |
| | Reconnects floodplain | - | Med | Med | Neutral |
| | Restores natural processes | - | Med | Med | Neutral |
| | Time frame for final design | - | High | Med | Alt 3 |
| Cost Considerations | Initial cost | - | High | Med | Alt 3 |
| | Lifecycle cost | - | High | Low | Alt 3 |
| | O&M cost | - | Med | Low | Alt 3 |
| Construction Considerations | Construction time | - | High | Med | Alt 3 |
| | Obstacles for timely implementation | - | High | Med | Alt 3 |
| | Difficulty in meeting construction period | - | High | Med | Alt 3 |
| | | | | Overall Edge | Alt 3 |

Note: No further analysis performed for alternatives not meeting minimum design evaluation criteria.

The Breaches 5-9 alternative that meets the minimum design evaluation criteria and provides the most additional benefits of design and construction based on the above analysis, and is thus considered the recommended alternative is Alternative 3, the Overflow Berm at Breach 6, and Berm at Breach 7a option.

The preferred alternative is to convey the main channel flows in the pre-flood channel. The capacity of this main channel will be based on the 2- and 5-year flow events (850 to 1,550 cfs).

Reestablishing the baseflow for the St. Vrain main channel in the pre-flood creek channel location will allow stable delivery of water and sediment yield below the Hygiene Road Bridge, successfully passing flood flows while maintaining the opportunity to establish a viable ecological habitat within the Hepp #1 Reservoir. The sediments deposited in the Hepp #1 Reservoir are a reflection of materials that were deposited during the recessional limb of the flood and as such will be easily mobilized under concentrated well-defined channel flows. Thus, to construct a berm across Hepp #1 Reservoir as suggested for Alternative 2 would require extensive excavation to reach stable subgrade materials. The preferred alternative requires less import of suitable materials, less import of rock to maintain a flood channel course, and less excavation within the Hepp #1 Reservoir to create a stable pilot channel with stable banks.

### 4.3.4 Selected Breach Repair Alternatives

Based on the comparative analysis discussed above, we recommend the following alternatives for each breach location. At Breach 1, we recommend the use of a gradual, low-profile setback berm to maintain primary flows through the main creek channel and overflows across the floodplain and back to the main channel via Lake 4 (Breach 1, Alternative 2). The selected breach repair option maximizes the riparian area adjacent to the creek, allows more frequent floodplain access, and restores the primary creek capacity to approximately the pre-flood capacity and increases the functionality and safety above the conditions that existed pre-flood with added resilience. More frequent floodplain access through overflows will increase the riparian and wildlife habitat through a large area of open space. The Foothills Inlet Canal and the South Branch Ditch will benefit from the additional safety provided by protecting sections of the canals (with below-grade pipes) located within the overflow path against future flood events. More frequent overflows (for storms greater than 2,000 cfs) over the Breach 1 repair berm would generally follow the path of the existing floodway, limiting damages to the surrounding area by maintaining and taking advantage of the natural resilience of a pre-existing flood path. By using the existing floodway for overflows, no special design or permitting will be required.

While a portion of the overflows will likely pass back to the stream system through Lake 4, West Lake, and A-Frame Lake, these lakes cannot be turned into riverine wetlands nor can the entire stream primary flow pass through the lakes as explored in Breach 1, Alternative 4. The current design for the new spillways for Lake 4, West Lake, and A-Frame Lake is on the order of 2,300 cfs. Lake 4 and West Lake have jurisdictional dams, and as such would be required to pass a minimum of the 100-year flow (>12,000 cfs) if the primary channel were to pass through the lakes. Thus, passing the primary channel through the lakes would require a costly redesign and construction. Additionally, Lake 4 is an augmentation pond with associated water rights that extend approximately 15 feet below the spillway of West Lake. Bypassing the live flow of the St. Vrain Creek through Lake 4 would deem this water unacceptable for augmentation and would result in loss of property to the SVLHWCD and Boulder County, as joint water rights owners. While moving the existing channel would create new riparian habitat, it would also take water away from the existing established riparian habitat adjacent to the existing primary channel; this would result in the loss of important habitat for species such as PMJM. However, additional habitat may be achieved in the floodway resulting from more frequent floodplain access for storm events exceeding 2,000 cfs.

At Breach 2, we recommend reconstructing a berm across the breach, with gradual downslope grading to maintain primary creek flow through the main creek channel, as well as establishing a more stable riparian environment in the restored Lake 2 (Breach 2, Alternative 2). The selected breach repair option for Breach 2 will restore the area downstream of the breach that was damaged in the 2013 flooding, and enhance the stability of the downstream slope to be more resilient against future flooding events. This will revitalize the natural riparian and wildlife habitat on the downstream slope and within the main creek channel, as well as resiliently restore the main creek channel. A restored Lake 2 will also take advantage of the natural flood resilience and additional flood capacity in the area of Breach 2. Flood flows that overtop the Breach 2 repair berm will access the flood capacity available in Lake 2 and return flows to the creek will follow the established floodway via the area of Breach 3. We also recommend installation of a bifurcation structure just downstream of Breach 2 to redirect primary creek flows away from the Longmont Supply Diversion structure and overflow back to the original primary channel. The bifurcation structure will enhance the safety and reduce maintenance of the Longmont Supply Diversion structure, as well as restore riparian habitat to the original primary channel. The final design elevation of the repair berm can be adjusted as the design progresses to allow more frequent overflows into Lake 2 if desired. This option would allow Lake 2 to provide flood relief to the main channel and would be available for additional off-channel sediment capacity for large flow events.

For the area of Breaches 5-9, we recommend keeping Breach 5 open as a backwater habitat, closing Breach 6 by constructing a low-profile overflow berm, closing Breach 7a with a full berm across the Hepp #2 Reservoir, maintaining a permanent breach at Breach 7b, and leaving Breaches 8 and 9 open to allow for outflows from the Hepp #1 Reservoir and additional backwater habitat area (Breaches 5-9, Alternative 3). Maintaining backwater area at Breach 5 will provide an opportunity for additional and enhanced riparian and wildlife habitat. The selected breach repair option for Breach 6 will restore primary creek flows to the pre-flood channel, restoring the hydraulic capacity of channel based on pre-flood conditions. The repair berm at Breach 6 will provide protection to life and property for local stakeholders downstream by providing additional flood control, while allowing defined overflows into Hepp #1 Reservoir for enhanced habitat opportunity. Overflows at the Breach 6 repair berm can take advantage of the natural resilience and additional flood capacity of the, before passing back to the main creek channel via Breaches 8 and 9. Hepp #1 Reservoir will also establish additional riparian and wildlife habitat area through more frequent flows. In addition to providing outflow for overflows from the Breach 6 repair berm, leaving Breaches 8 and 9 open will also serve to add backwater area for additional riparian and wildlife habitat in Hepp #1 Reservoir. By maintaining a connection between the primary creek channel and Hepp # 1 Reservoir at Breaches 8 and 9, the existing flood capacity of Hepp #1 Reservoir will protect downstream stakeholders.

The selected breach repair option for Breach 7a will create a larger floodplain adjacent to the primary creek channel, allowing for additional floodplain access and enhanced riparian and wildlife habitat area, in addition to. In restoring primary flows to the pre-flood creek channel with the Breach 6 repair berm, a resilient, engineered berm is necessary at Breach 7a to provide protection to stakeholders east of Hepp #2 Reservoir from future flood events. While Breach 7a will be designed to prevent overflows up to at least the 100-year event, based on the modeled conditions, we anticipate that flooding downstream of Hygiene Road may continue to spread across the floodplain, which encompasses Hepp #2 and Hepp #3 Reservoirs for large flood flows (greater than 100-year events). By re-grading and providing erosion protection at a "permanent breach" at Breach 7b, the areas of Hepp #2 Reservoir and Hepp #3 Reservoir will provide off-channel flood capacity for large flood events. Thus, the additional existing capacity of Hepp #2 and Hepp #3 Reservoirs will be accessible during large flood events to provide additional protection for stakeholders to the east and downstream, taking advantage of the existing resilience available in the reach.

Specific in-stream repairs, seeding and planting, and overall stream restoration along the entirety of the reach including details for the selected breach repairs are detailed in the 30% design plans (Appendix V) and discussed in Section 5.0 below.

# 5.0 30% DESIGN DEVELOPMENT

Preliminary restoration design was established for the entire project corridor based on the selected stream restoration alternatives. The restoration design includes in-channel structures and bioengineering work to improve geomorphology and sediment transport, ecological restoration within a restoration corridor adjacent to the channel, and preliminary grading and design plans for the proposed channel and breach repairs. In moving toward a 30% design for the project, the selected alternatives were refined with input from stakeholders and additional hydraulic modeling to maximize the benefits of the proposed stream restoration along the entirety of the reach. Construction considerations for the 30% design are summarized in Section 5.1 below. The hydraulic modeling is discussed in Section 5.2 below. Additional details regarding the 30% design plans are presented in Sections 5.3 through 5.6, and benefits of the proposed design are discussed in Section 5.7.

## 5.1 Construction Considerations

### 5.1.1 Construction and Revegetation Materials

Based on the geotechnical investigation conducted for the project, there are sufficient granular soils available on the project site for common fill and embankment construction. Portions of the site are overlain by one to three feet of sand, gravel, and cobble sediment deposited during the September 2013 flood event. In addition, extensive amounts of sand, gravel, and cobble sediment were deposited into Lake 2, Lake 3, and Lake 4 during the flood event. Sediment depths in the lakes are on the order of 5 to 20 feet deep.

Some of the construction materials will need to be obtained from off-site sources. These materials include riprap, riprap bedding, and boulders. These materials will be obtained from existing commercial quarries. Some riprap and riprap bedding from the temporary breach repairs is available and suitable for re-use.

In addition, clayey soils for the impervious zones of the breach repairs will need to be imported from off-site. There is an available source of clayey soils on Boulder County property in the Swede Lake footprint. Swede Lake is located approximately 9 miles south of the project. Clayey soils may also be imported from commercial sites. Estimated quantities of clayey material required for the restoration design is provided in the 30% design.

Stream and habitat restoration and revegetation materials will be obtained from local and on-site sources, commercial seed sources, commercial nurseries, and contract nurseries.

### 5.1.2 Construction Water

Non-potable water will be required for construction activities such as adding moisture to compacted fill embankments and for contractor irrigation of seeding areas, shrubs, and trees during the vegetation maintenance and warranty periods. Water rights for Lake 4 are evenly distributed to Boulder County and the SVLHWCD. Boulder County should work with SVLHWCD to secure water for use in construction and irrigation for the project. The construction contractor will be responsible for conveying water to construction and irrigation sites from these facilities.

### 5.1.3 Stream Diversion and Dewatering

Temporary facilities will be required to facilitate stream diversion and dewatering of the site during construction. These facilities will likely include cofferdams and pumps. Stream diversion and dewatering requirements will be significantly less after the spring runoff has occurred. Dewatering construction of instream vanes may be required.

### 5.1.4 Construction Operations

Construction of the breach repairs and stream restoration is anticipated to occur over approximately a 6-month period. Site reclamation and plantings will occur over approximately a 3- to 4-month period that will partially overlap construction operations. Additional details regarding construction timing will be included within the Implementation Plan and Timeline as we move toward 80% design.

Construction activities will be confined to the limits of disturbance. Construction limits will be shown on the construction drawings as the design progresses. The size of the contractor’s work force and equipment spread for construction will depend on the construction plan and schedule. Based on similar projects, we anticipate an average work force of 10 to 20 persons.

Wet concrete must be contained from live stream water, and water quality must not be impacted by construction operations involving the pouring of concrete in or near any channel.

Initial construction operations will include improving access roads, creating stockpile areas, and providing temporary erosion control. Access roads and staging areas need to be arranged with BCPOS staff. Locations for access roads and staging areas should document conservation measures to prevent impact to sensitive wildlife (e.g. PMJM) and riparian habitat. Materials trucked from off-site are expected to include clay for breach repairs, riprap and riprap bedding, boulders, and planting materials including seed, mulch, soil amendments, shrubs, and trees.

### 5.1.5 Construction Access and Staging Areas

As the design progresses from 30% to 80% design level, and comments are received on the preliminary design plans and changes to the preliminary design are finalized, we will coordinate with BCPOS to establish and define construction access and staging areas, with particular focus on protecting and maintaining existing wildlife and vegetation.

## 5.2 Hydraulic Modeling

The proposed design was used to generate a new terrain model for the site. We modeled the proposed terrain in HEC-RAS, using flow hydrographs and model parameters discussed in Sections 2.3 and 2.5, respectively, to estimate the hydraulic impact of the proposed restoration repairs on future flow events. We performed 1-dimensional and 2-dimensional models to analyze the amount of flow anticipated to overtop the breach repair berms under varying flow events. Where overtopping occurred, we also monitored the downslope velocities over the breach repair berms. These flow velocities will be used in developing the required downslope cover (e.g., vegetation, bioengineering, armoring) for the berms to be resilient against overtopping flows. The required downslope cover for the berms will be refined as the design progresses from 30% to 80% design.

Unsteady flow analysis for the reach was performed using HEC-RAS, using the flow hydrographs for 1-year, 10-year, and 100-year events. Tables 5-1 through 5-3 present the results of the modeled maximum flow over the breach repair locations in cubic feet per second (cfs), and the maximum water surface elevation (El.) in feet within the channel at the breach area, at recurrence intervals of approximately 1 year (~100% chance of exceedance), 10 years (10% chance of exceedance), and 100 years (1% chance of exceedance).

***Table 5-1*** *Flows over Proposed Breach Repairs for 1-yr Recurrence (~100% chance of exceedance)*

**Maximum Storm Flow = 550 cfs**

| Breach Area | Flow Over Proposed Breach Repair (cfs) | Water Surface Elevation in Channel (ft) | Peak Velocity Over Breach Repair (ft/s) |
|---|---|---|---|
| 1 | 0 | 5247 | - |
| 2 | 0 | 5196 | - |
| 6 | 0 | 5118 | - |
| 7 | 0 | 5116 | - |

***Table 5-2*** *Flows over Proposed Breach Repairs for 10-yr Recurrence (10% chance of exceedance)*

**Maximum Storm Flow = 2,112 cfs**

| Breach Area | Flow Over Proposed Breach Repair (cfs) | Water Surface Elevation in Channel (ft) | Peak Velocity Over Breach Repair (ft/s) |
|---|---|---|---|
| 1 | 0 | 5248 | - |
| 2 | 0 | 5198 | - |
| 6 | 425 | 5120 | 7 |
| 7 | 0 | 5118 | - |

***Table 5-3** Flows over Proposed Breach Repairs for 100-yr Recurrence (1% chance of exceedance)*

**Maximum Storm Flow = 12,268 cfs**

| Breach Area | Flow Over Breach Repair (cfs) | Water Surface Elevation in Channel (ft) | Peak Velocity Over Breach Repair (ft/s) |
|---|---|---|---|
| 1 | 2035 | 5251 | 5 |
| 2 | 855 | 5199 | 10 |
| 6 | 5620 | 5122 | 15 |
| 7 | 0 | 5119 | - |

Inundation maps based on the modeling results show the extent of flooding across the site area for the proposed design. Figures 5-1A, 5-1B, and 5-1C depict an overview of the site with the extent of flooding for the 1-year, 10-year, and 100-year flow events, respectively. Figures 5-2, 5-3, and 5-4 portray detailed views of the flooding extent for the proposed repairs at Breach 1, Breach 2, and Breaches 5 through 9, respectively. These inundation maps indicate that primary flows are maintained within the main channel for flows less than about 2,000 cfs with the proposed breach repair berms. The backwater areas that are designed to remain open for habitat restoration are activated under regular flow intervals, with water accessing Sadar Pond via Breach 5, and the Hepp #1 Reservoir through Breaches 8 and 9. The overflow at Breach 6 into Hepp #1 Reservoir is activated at flows greater than 2,000 cfs, further providing water to the Hepp #1 Reservoir for habitat development. For a large flow event greater than 12,000 cfs, flooding increases dramatically and overtopping is anticipated to occur over the repair berms at Breach 1, Breach 2, and Breach 6. However, no overtopping was observed in the modeled results for the Breach 7 repair at the 100-year event, as desired.

Based on the modeling performed for the 30% design terrain, the proposed repair berms at Breaches 1, 2, 6, and 7 are considered acceptable for the design goals as outlined above. Final berm elevations, channel grading, and streambank grading will be refined, and modeling will be revised as the design progresses from the 30% to 80% level and with further discussions with local stakeholders.

The bridges in the reach should be designed to withstand and convey a design flow equivalent to the 100-year storm event. Based on the modeled conditions for the reach, redesign and reconstruction of some of the bridge structures should be considered. The modeled maximum flow within the channel in cubic feet per second (cfs) and the maximum water surface elevation (El.) in feet for several bridge locations at a recurrence interval of approximately 100 years (1% chance of exceedance) are presented in Table 5-4. The current conveyance capacities of the bridges, as discussed in Section 2.2, are also listed in Table 5-4.

***Table 5-4*** *Flows at Bridge Locations for 100-yr Recurrence (1% chance of exceedance)*

**Maximum Storm Flow = 12,268 cfs**

| Bridge Location | Current Bridge Conveyance Capacity (cfs) | Maximum 100-year Storm Flow in Channel (cfs) | Water Surface Elevation in Channel (ft) | Peak Velocity (ft/s) |
|---|---|---|---|---|
| 63rd Street Bridge | 5,000 | 7,230 | 5141 | 20 |
| Hygiene Road Bridge | 5,200 | 10,130 | 5117 | 20 |
| Crane Hollow Bridge | 6,500 | 11,100 | 5103 | 15 |

The current bridge designs have insufficient capacity for the anticipated flood flow event. While the bridges are adequately sized for smaller storm events, a large storm event like a 100-year storm may result in overtopping or destruction of the current bridge design. While the redesign and reconstruction of bridges is outside the scope of this project, we recommend redesign of the bridges be considered as part of the larger St. Vrain Creek master planning efforts for long-term protection and resilience of the watershed.

## 5.3 30% Design Plans

The 30% design plan set was developed based on the analysis and evaluation of the selected alternatives. The 30% design plans for the project, attached as Appendix V, provide detailed site plans including overall proposed grading, stream restoration, and planting and seeding work, including details and cross sections, and general construction notes for the project. The 30% design plans should not be considered final and should not be used for construction.

## 5.4 Breach Repair Design

At Breach 1, we recommend the use of a gradual, low-profile setback berm to maintain primary flows through the main creek channel and overflows across the floodway (South Branch Channel). The temporary repair berm should be removed, and the breach should be repaired with a clay-core berm, with a maximum elevation of 5249 ft. The reconstructed berm should include a clay core and ensure proper construction techniques for long-term stability. The temporary berm materials can generally be reused for the proposed berm construction. The Foothills Inlet Canal and the South Branch Ditch will benefit from additional safety against future flood events provided by protecting sections of the canals within the South Branch Channel with below-grade pipes located within the overflow path. Additional details for the proposed below-grade pipes will be provided as the design progresses from 30% to 80%.

At Breach 2, we recommend reconstructing a berm across the breach, with gradual downslope grading to maintain primary creek flow through the main creek channel, as well as establishing a more stable riparian environment in the restored Lake 2. The temporary repair berm should be removed, and reconstructed with a maximum elevation of 5198 feet, and should include a clay core and be constructed in accordance with specified construction techniques to ensure long-term stability. The temporary berm materials can generally be reused for the proposed berm construction. Downslope grading and vegetative protection on the back side of the berm will restore damaged areas of Lake 2. We also recommend installation of a bifurcation structure just downstream of Breach 2 to redirect primary creek flows away from the Longmont Supply Diversion structure and overflow back to the original primary channel. A preliminary detail drawing for the bifurcation structure is included in the 30% design plans (Sheet C32). Additional details for the proposed bifurcation will be provided as the design progresses from 30% to 80%.

No repairs are required in the area of Breach 3. Restoration of Breach 4 is being addressed through separate projects for Lake 4 and 61st Street, and is not included within these 30% design plans.

We recommend keeping Breach 5 open as backwater habitat area. Minor grading and ecological restoration should be performed in the area of Breach 5 to improve the resilience of the backwater habitat area.

At Breach 6, we recommend constructing a permanent low-profile overflow berm designed to pass overflows for storm events greater than about 2,000 cfs. By constructing a new berm at Breach 6, the primary flow path will be redirected to the pre-flood channel alignment. The new berm at Breach 6 should be constructed with a clay core for long-term stability, and the berm should have a maximum elevation of 5119 feet.

The temporary berm at Breach 7a should be removed and a new permanent berm should be constructed across the Hepp #2 Reservoir. The new berm at Breach 7a should have a maximum elevation of 5124 feet to prevent overtopping and be constructed with a clay core. The temporary berm materials can generally be reused for the proposed berm construction.

We recommend maintaining a permanent breach at Breach 7b. Grading and seeding/planting will be required to improve the resilience and protect the breached area against further erosion.

Breaches 8 and 9 should be left open to allow for outflows from the Hepp #1 Reservoir and provide additional backwater habitat area. The area of Breaches 8 and 9 should be seeded and planted to improve resilience against future flood events.

Grading plans for the proposed breach repairs established using the above information are included in the 30% design plans (Sheets C27 through C30).

The clay cores should be keyed into the subgrade soil to a depth equivalent to a minimum of half the height of the total berm height to prevent seepage and erosion of the berm. The clay cores should have a minimum thickness of 10 feet. Based on the 30% design, a total of approximately 10,000 cubic yards of clay material are estimated to be required for construction of the clay cores (see Section 5.1).

The berm faces should be constructed with side slopes as shown in the detail drawings (Sheet C31), and should be designed to prevent erosion and protect the upstream and downstream faces from future flow events. The proposed plant and seed estimates provided in the 30% designs include vegetative cover of the berm faces and permanent breaches. Additional details for the breach repairs will be provided as the design progresses from 30% to 80%.

## 5.5 Stream Restoration Plans

The modeled inundation boundaries generated for the proposed design were used to establish stream restoration plans for the reach. The idea that riffle/pool complexes are the natural form for this channel was confirmed by field evaluations. The most natural reach of the St. Vrain within the project extents is the segment bounded upstream by Breach 3 and downstream by 63rd Street. Within this segment the channel exhibits a natural meander pattern and the bedform is dominated by riffle/pool complexes. Bankfull indicators are easily observed and the channel appears to overtop with flows accessing its floodplain during typical flood events. Bankfull widths in riffle sections within this reach were measured to generally be between 30 feet to 40 feet; bankfull widths in pool and glide sections typically ranged from 40 feet to 60 feet.

With an understanding that the objective of restoration was to replicate the natural riffle/pool complexes, ERC investigated the overall project segment. The intent of this evaluation was to determine current conditions of the different sub-reaches, identifying areas where restoration was required as well as locations where the stream is already in a natural state or trending that way on its own. Locations where the stream was observed to be in a good state or where signs indicate that trends are towards recovery, mechanical restoration was generally not recommended. Rather, the restoration recommendations focus on areas that do not show the desired natural feature and areas where instream improvements could complement other objectives such as breach repair or significant bank stabilization. The proposed restoration plans established using the above information are included in the 30% design plans (Sheets R1 through R14). A summary of the proposed improvements listed by station from upstream to downstream is given below. Stationing refers to the overall restoration design channel stationing as shown on the plan set.

- Station 208+00 to 220+00
  No instream restoration is suggested for this reach. While this area was impacted by the floods, riffle/pool complexes are naturally developing.

- Station 186+00 to 208+00
  Improvements are recommended in this area. Breach 1 is near the upstream end of this sub-reach and instream improvements near the upper end of this segment will complement grading work for the breach repair. This work is suggested to continue downstream to approximately Station 197+00. Work would pick back up near Station 192+50 and continue downstream to about Station 186+00. Work in this area would address the severe bank erosion that exists near Station 190+00 where the river is undermining the railroad. As part of bank stabilization, instream habitat will be improved.

- Station 148+00 to 186+00
  No instream restoration is suggested for this reach. Work at the Foothills Reservoir Inlet Canal and the South Branch Diversion Structure to improve fish passage, however, is suggested.

- Station 143+00 to 148+00
  Improvements are recommended in this area. Breach 2 is the identifying feature in this sub-reach. Restoration work and instream habitat improvements will complement grading work for the breach repair.

- Station 137+00 to 143+00
  No instream restoration is suggested for this reach. While this area was impacted by the floods, riffle/pool complexes are naturally developing.

- Station 117+00 to 137+00
  Improvements are recommended in this area. Upstream of the flow bifurcation, the channel is overly steep and appears unstable and erosion of the right bank is significant. Downstream of the bifurcation, stream modifications will allow flows to utilize the flow path to the right. At the far downstream extent of this segment the channel is impacted by the bridge crossing. Instream improvements are proposed for this entire segment. Riffle/pool complexes will provide improved habitat and work will also stabilize the bank and channel bed. It is also recommended that the Longmont Supply Diversion Structure be modified to facilitate fish passage.

- Station 72+00 to 117+00
  No instream restoration is suggested for this reach. This section of the St. Vrain Creek is currently believed to be functioning in a natural state and is used as the reference for improvements to areas where restoration is proposed. While instream work is not believed to be required, we do suggest that the Oligarchy Diversion Structure be modified for improved fish passage. We understand that this diversion structure is new and was intended to include fish passage but it is believed that modifying the channel slope downstream of the check structure would improve passage.

- Station 30+00 to 72+00
  This is the section of the St. Vrain Creek within the project reach that we believe will benefit the most from restoration and intensive channel improvements are proposed through this segment. Proposed improvements include stabilizing banks and reworking the stream alignment and profile to develop a more natural riffle/pool bedform. Grading work is intended to move the stream out of its current alignment yet preserve backwater conditions and allow peak flows to continue to access the Hepp #1 Reservoir. Improvements are intended to replicate the aquatic and riparian habitat that currently exists along Station 72+00 to 117+00 in this lower reach.

- Station 22+00 to 30+00
  Stabilization of the right bank is required in this area to preserve the diversion that is currently in jeopardy of being captured as the result of active lateral stream migration. Restoration work and instream habitat improvements will complement the required stabilization. Work to provide fish passage at the North Branch Diversion Structure is also recommended.

- Station 9+00 to 22+00
  No instream restoration is suggested for this reach. While this area was impacted by the floods as indicated by deposition on the overbanks, riffle/pool complexes are naturally developing.

## 5.6 Habitat Restoration and Revegetation Plans

The modeled inundation boundaries were also used to establish habitat restoration and revegetation plans for the reach. Ecos refined the original 300-foot vegetative buffer requested by BCPOS as a project boundary (300-foot offset from existing stream centerline) into a proposed restoration corridor based on the proposed grading, property lines, reservoir boundaries, existing buildings, roads, etc. to define revegetation zones for the project. Revegetation plans for the corridor were established using the following information:

- Information gathered from initial site assessment (existing vegetation, wetlands, and wildlife)
- Stream velocity and shear stresses
- Design water surface elevation contours and modeled inundation boundaries
- Proposed grading and breach repair berm designs
- Proposed stream restoration design

The proposed planting and seeding plans, details, planting schedules, and notes established using the above information are included in the 30% design plans (Sheets L1 through L17, LD1 and LD2, LS1 and LS2, and LN1 through LN3, respectively).

## 5.7 Benefits of Proposed Design

Benefits for the specific selected restoration alternatives are presented in Section 4.0. More broadly, however, the proposed restoration activities discussed above will restore riparian and wildlife habitat and reduce hazards and protect life and property from future flooding through the reach. The proposed design was selected based on the input and comments received throughout the design process from a combination of local stakeholders, Boulder County employees, and EWP employees. By working with property owners and community members to develop and select alternatives and incorporating stakeholder input throughout the design process, the design is based on protecting property owners while also maintaining consistency of the design approach with separate projects within and surrounding the project reach. The stream restoration approach and the breach repair designs are consistent with the larger vision for watershed and stream recovery as proposed within the St. Vrain Creek Watershed Master Plan.

The proposed design enhances stream stability through the use of natural stream restoration. Given that riffle/pool complexes are the natural form for streams with the gradient and sediment gradation observed in the project area and the most natural stream section exhibits these features, meandering riffle/pool features were selected as appropriate for natural restoration of the project reach. The stream restoration design uses the existing natural stream form as a basis for the proposed restoration activities, which will catalyze natural stream recovery, minimizing the need for operations and maintenance, and improve the structure and function of the stream corridor.

The proposed breach repairs are designed to prioritize protection of private property and public infrastructure by restoring the hydraulic capacity through the reach while being resilient to future flood events through a bioengineered system designed to withstand flood flows in overtopping scenarios: permanent engineered berms used concomitantly with protective vegetative covers for erosion protection.

The proposed stream restoration design will work in tandem with the wildlife and habitat restoration to maintain connectivity through the riparian habitat. This will benefit protected and sensitive species, including PMJM and native fish. The proposed planting plans will further enhance and promote wildlife and aquatic habitat through the riparian corridor.

The proposed restoration design will improve the natural stream flow of the creek and enhance floodplain connectivity, which will inherently promote wildlife habitat throughout the reach. Habitat restoration, stream restoration, and breach repairs, as proposed in the 30% design plans, are optimized to synergistically provide enhanced protection to property owners against regular flow events and reduce the impact of future flood events while benefitting ecological habitat throughout the reach.

## 5.8 Implementation Plan and Timeline

An implementation plan and timeline for the project will be developed in conjunction with the design progressing from 30% to 80% level design. The prioritization of the project elements will be coordinated with BCPOS based on the desired project outcomes. The implementation plan and timeline will describe the project element priority, identify limiting factors for construction, and provide an estimated timeline for construction.

## 5.9 Engineer’s Opinion of Probable Construction Costs

Our Engineer’s opinion of probable construction costs for the proposed design is provided under separate cover. These costs will continue to be modified and refined as the design progresses from 30% to 80% design level.

## 6.0 REFERENCES

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# FIGURES

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| | |
|---|---|
| PROJECT NO. | 110666 |
| DRAWN BY: | NRS |
| CHECKED BY: | LCB |
| DATE: | 7/1/16 |

OVERALL SITE PLAN
ST. VRAIN CREEK BREACHES RESTORATION
BASIS OF DESIGN

FIGURE
1-1

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CHECKED BY: LCB
DATE: 7/1/16

BREACH 1 SITE PLAN
ST. VRAIN CREEK BREACHES RESTORATION
BASIS OF DESIGN

**FIGURE**
**2-1A**

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DATE: 7/1/16

BREACH 2 & 3 SITE PLAN
ST. VRAIN CREEK BREACHES RESTORATION
BASIS OF DESIGN

FIGURE
2-1B

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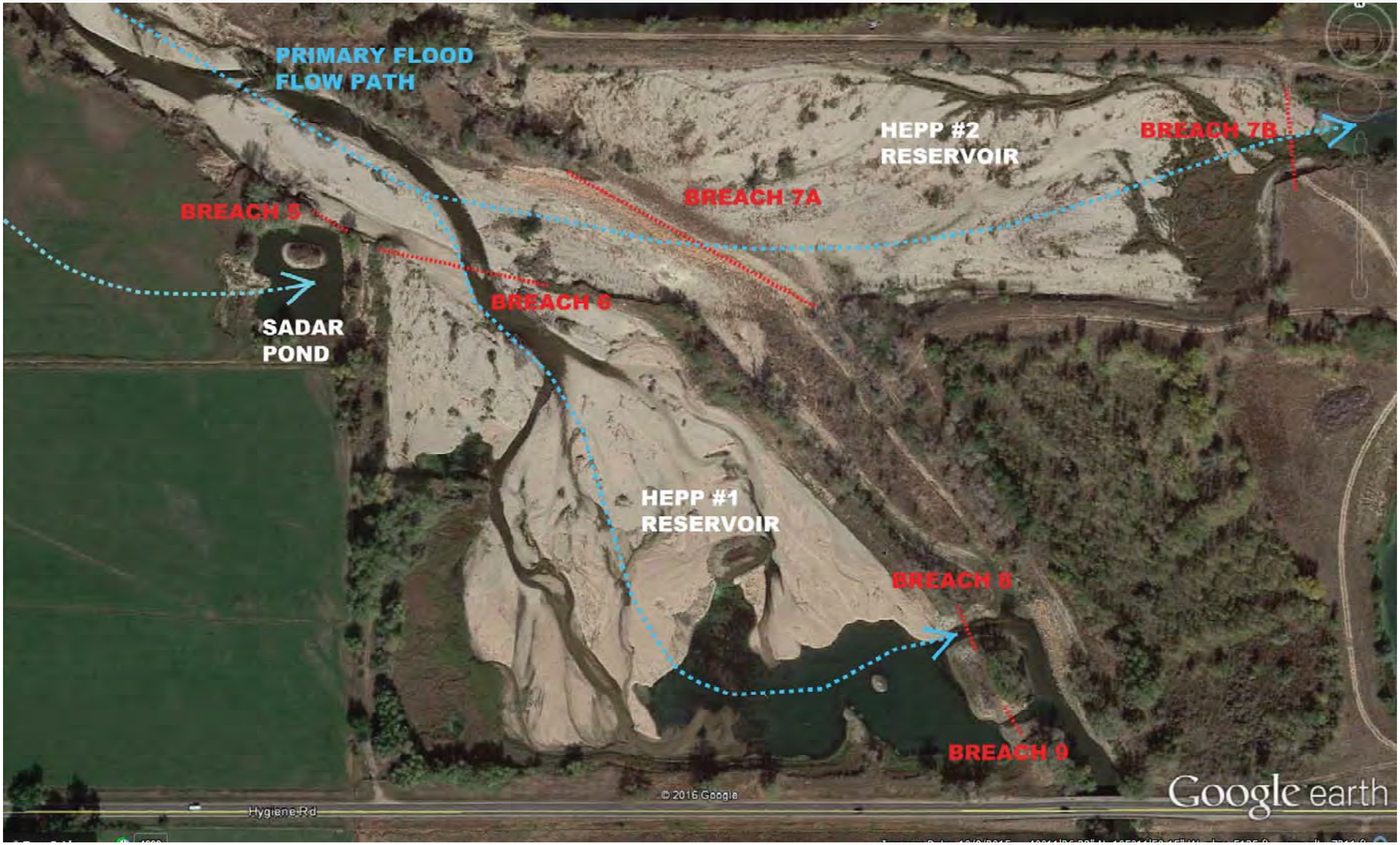
| | |
|---|---|
| PROJECT NO. | 110666 |
| DRAWN BY: | NRS |
| CHECKED BY: | LCB |
| DATE: | 7/1/16 |

BREACH 4 SITE PLAN
ST. VRAIN CREEK BREACHES RESTORATION
BASIS OF DESIGN

FIGURE
2-1C



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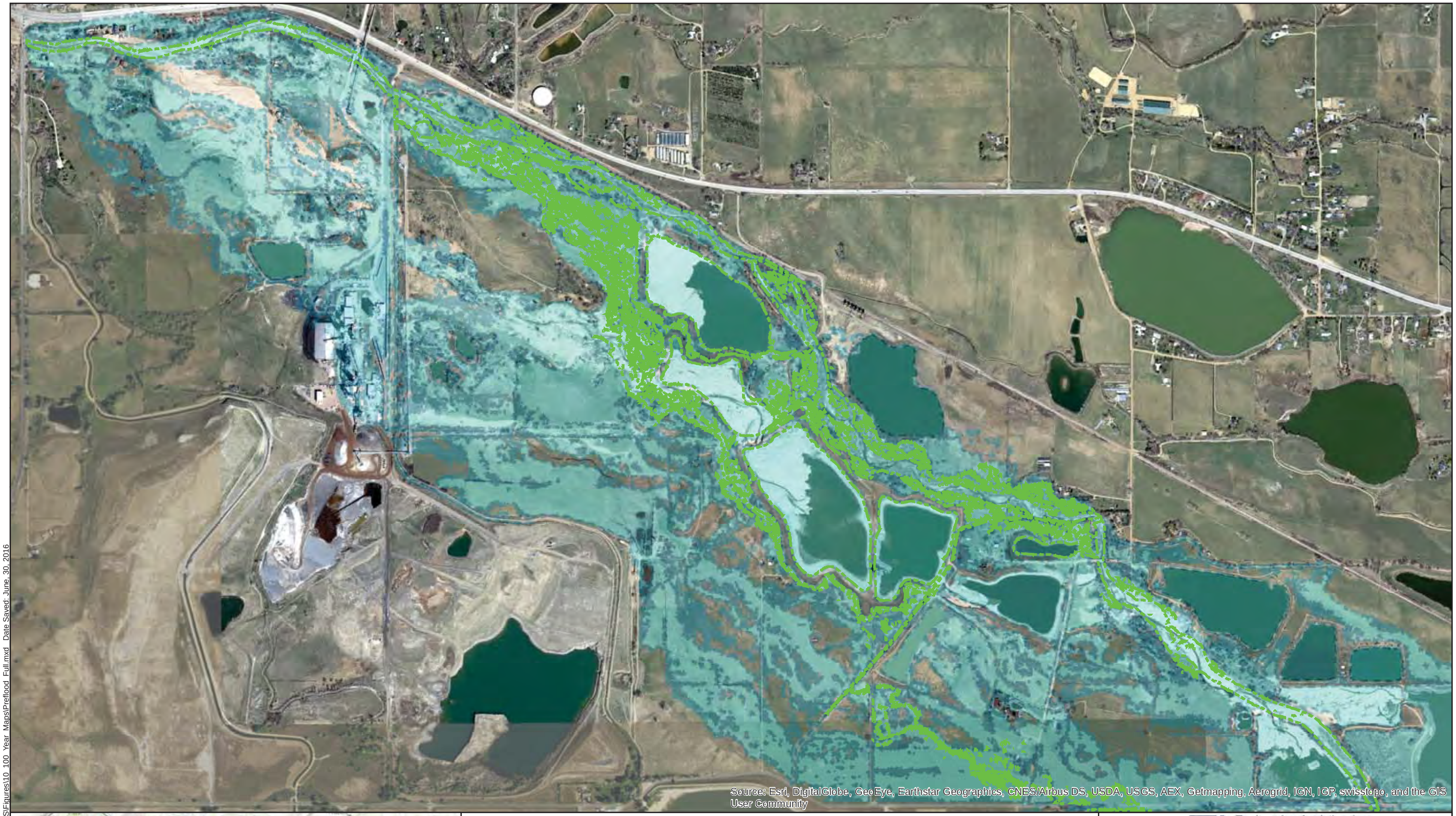
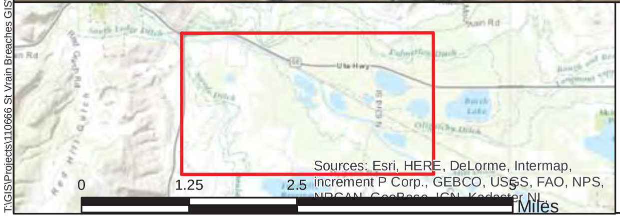
PROJECT NO. 110666
DRAWN BY: NRS
CHECKED BY: LCB
DATE: 7/1/16

BREACH 5, 6, 7, 8, & 9 SITE PLAN
ST. VRAIN CREEK BREACHES RESTORATION
BASIS OF DESIGN

FIGURE
2-1D


Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL

**EXPLANATION**

| | |
|---|---|
| ▨ | 100-Year Inundation Area |
| ☐ | 10-Year Inundation Area |

0 1,000 2,000 4,000
Feet
SCALE: 1" = 1,000'

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## ST. VRAIN CREEK BREACHES RESTORATION
## Pre-Flood Inundation Maps

| Date: July 2016 | Project No.: 110666 | Figure 2-2A |
|---|---|---|

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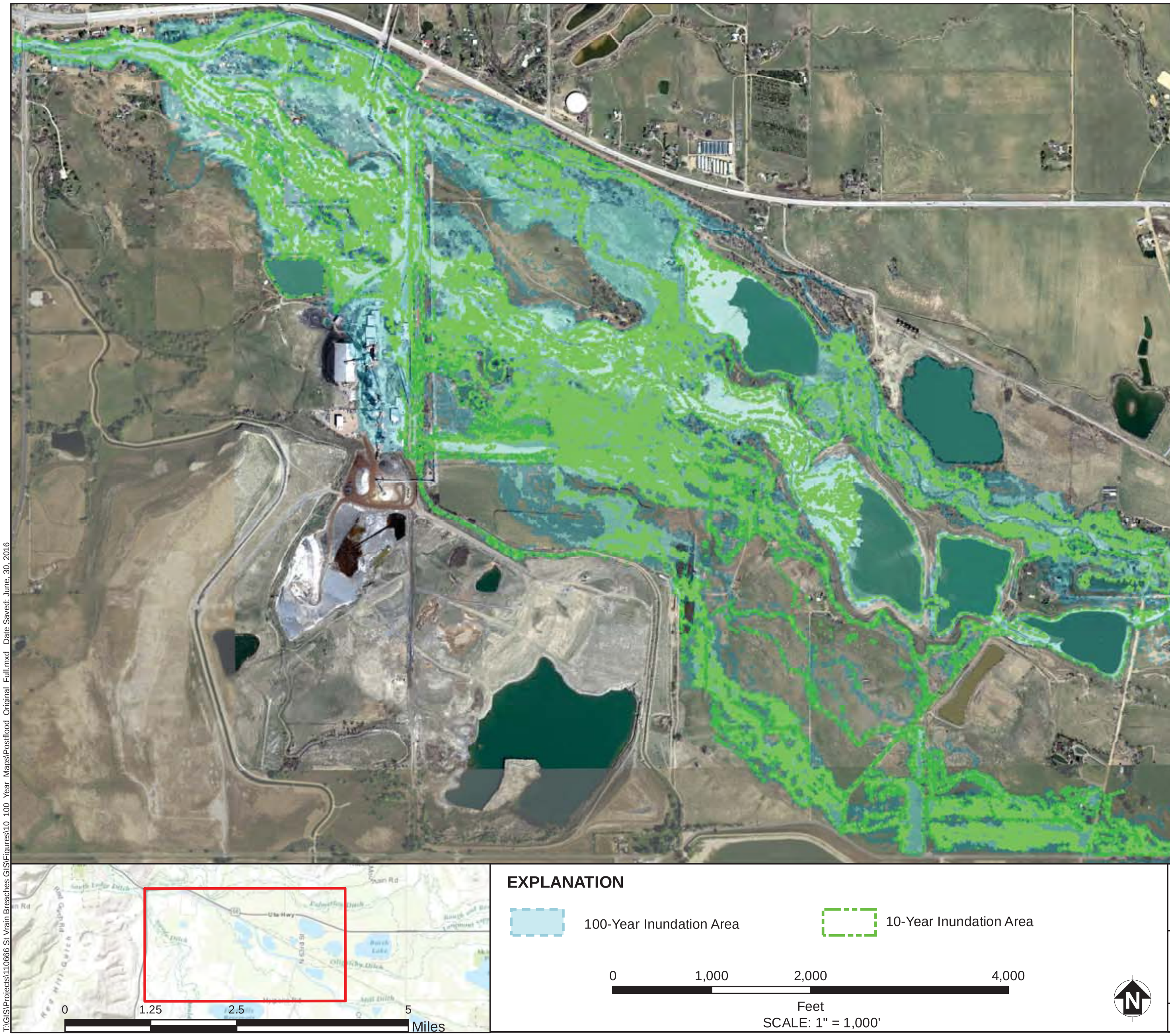

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**ST. VRAIN CREEK BREACHES RESTORATION**
**Post-Flood Inundation Maps**

Date: July 2016 | Project No.: 110666 | Figure 2-2B

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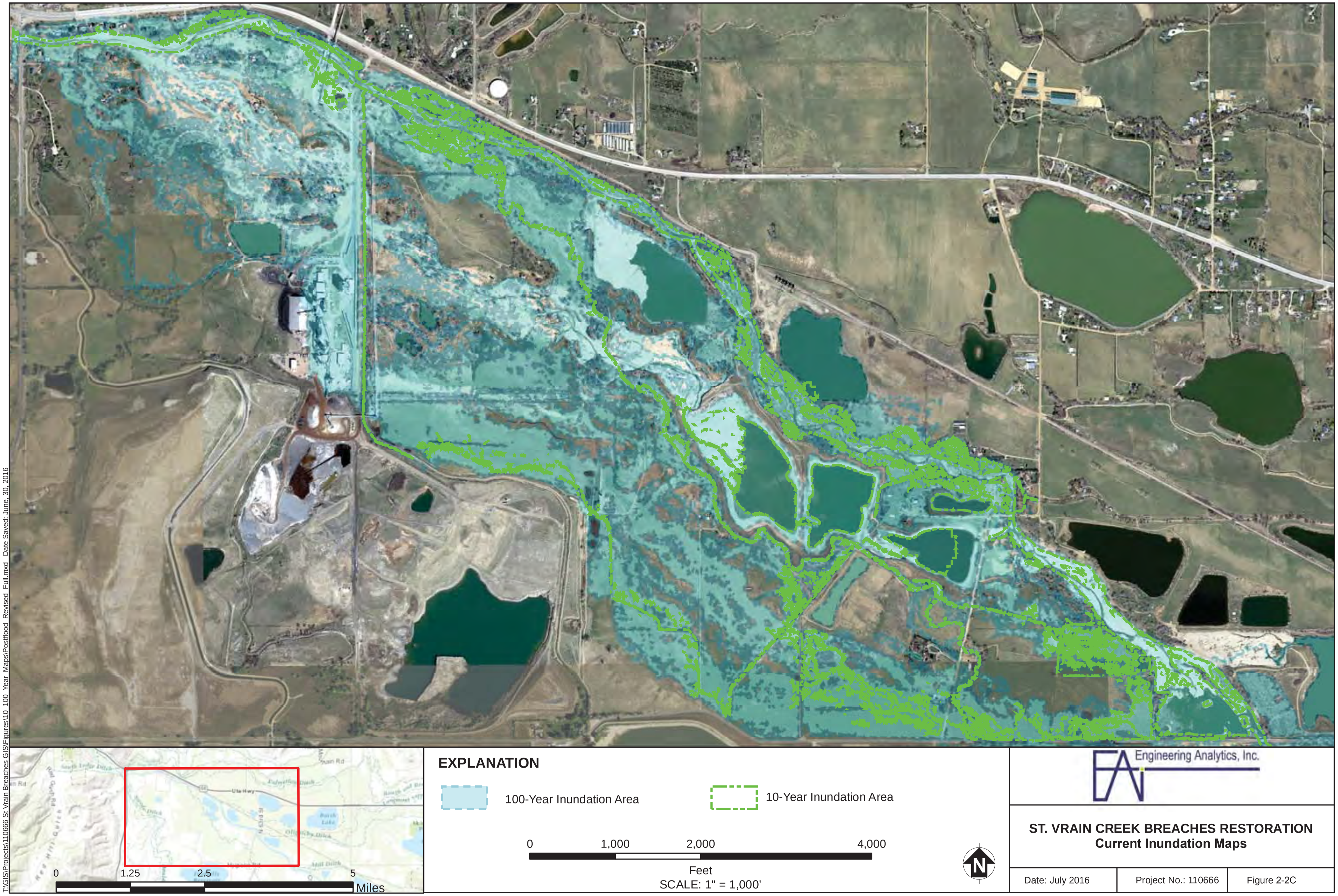

**EXPLANATION**

| | |
|---|---|
| ▨ | 100-Year Inundation Area |
| ▭ | 10-Year Inundation Area |

0 1,000 2,000 4,000
Feet
SCALE: 1" = 1,000'

Engineering Analytics, Inc.

**ST. VRAIN CREEK BREACHES RESTORATION**
**Current Inundation Maps**

| Date: July 2016 | Project No.: 110666 | Figure 2-2C |
|---|---|---|

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Project No. 110666

December 2016

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**FIGURE 4-1A**
**BREACH 1, ALTERNATIVE 1**
**NO ACTION**

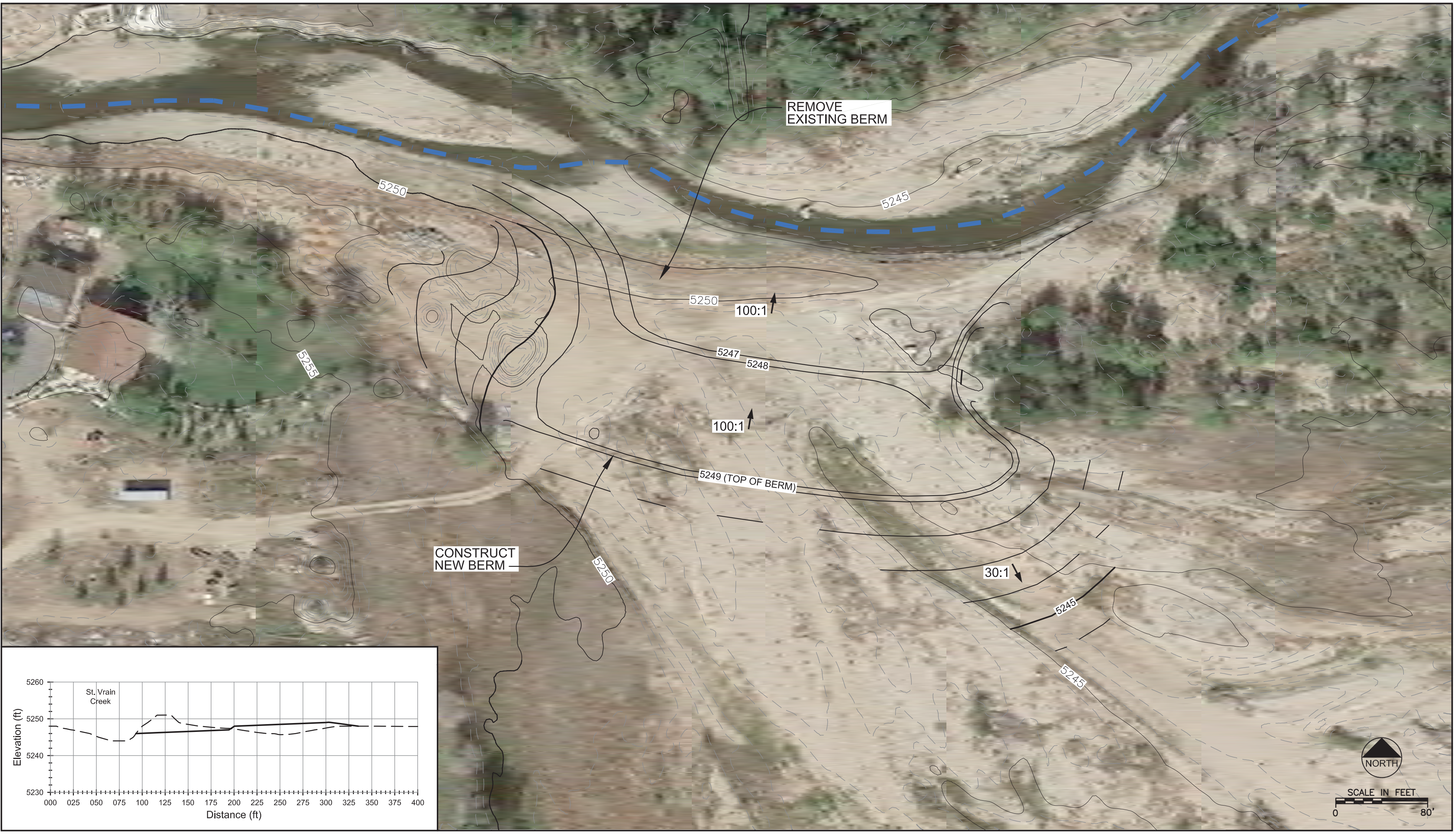

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**FIGURE 4-1B**
**BREACH 1, ALTERNATIVE 2**
**GRADUAL LOW-PROFILE SETBACK BERM**

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**FIGURE 4-1B-1**
**BREACH 1, ALTERNATIVE 2 - OVERFLOW ROUTE OPTIONS**
**GRADUAL LOW-PROFILE SETBACK BERM**

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NORTH

SCALE IN FEET
0 250'

**FIGURE 4-1C**
**BREACH 1, ALTERNATIVE 3**
**MAXIMUM FLOODPLAIN SETBACK BERM**

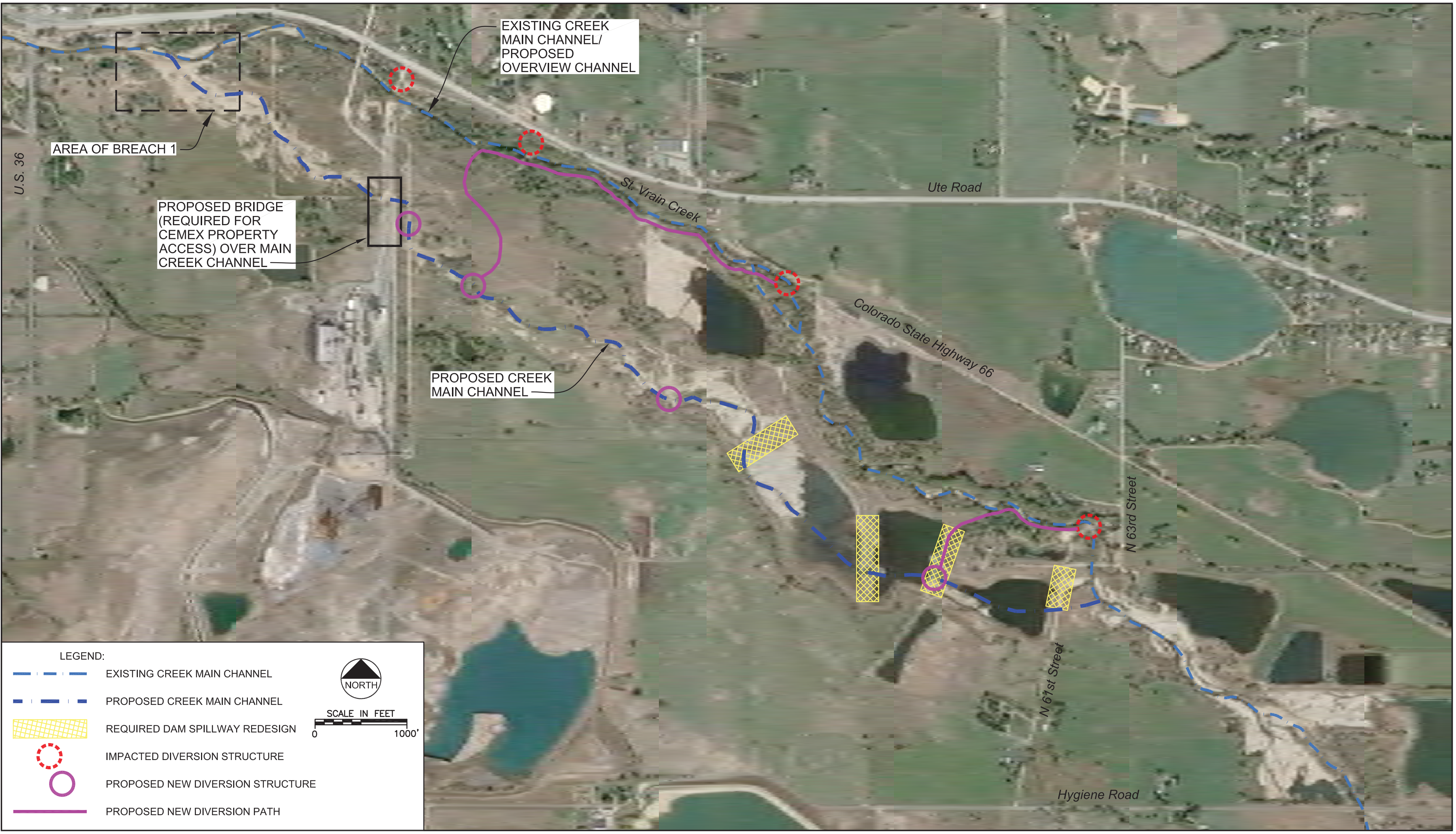

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**FIGURE 4-1D**
**BREACH 1, ALTERNATIVE 4**
**RE-ROUTE MAIN CREEK CHANNEL**

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**FIGURE 4-2A**
**BREACH 2, ALTERNATIVE 1**
**NO ACTION**

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**FIGURE 4-2B**
**BREACH 2, ALTERNATIVE 2**
**BERM AND DOWNSLOPE GRADING**

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**FIGURE 4-2C**
**BREACH 2, ALTERNATIVE 3**
**OVERFLOW BERM AND DOWNSLOPE GRADING**

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**FIGURE 4-3A**
**BREACHES 5-9, ALTERNATIVE 1**
**NO ACTION**

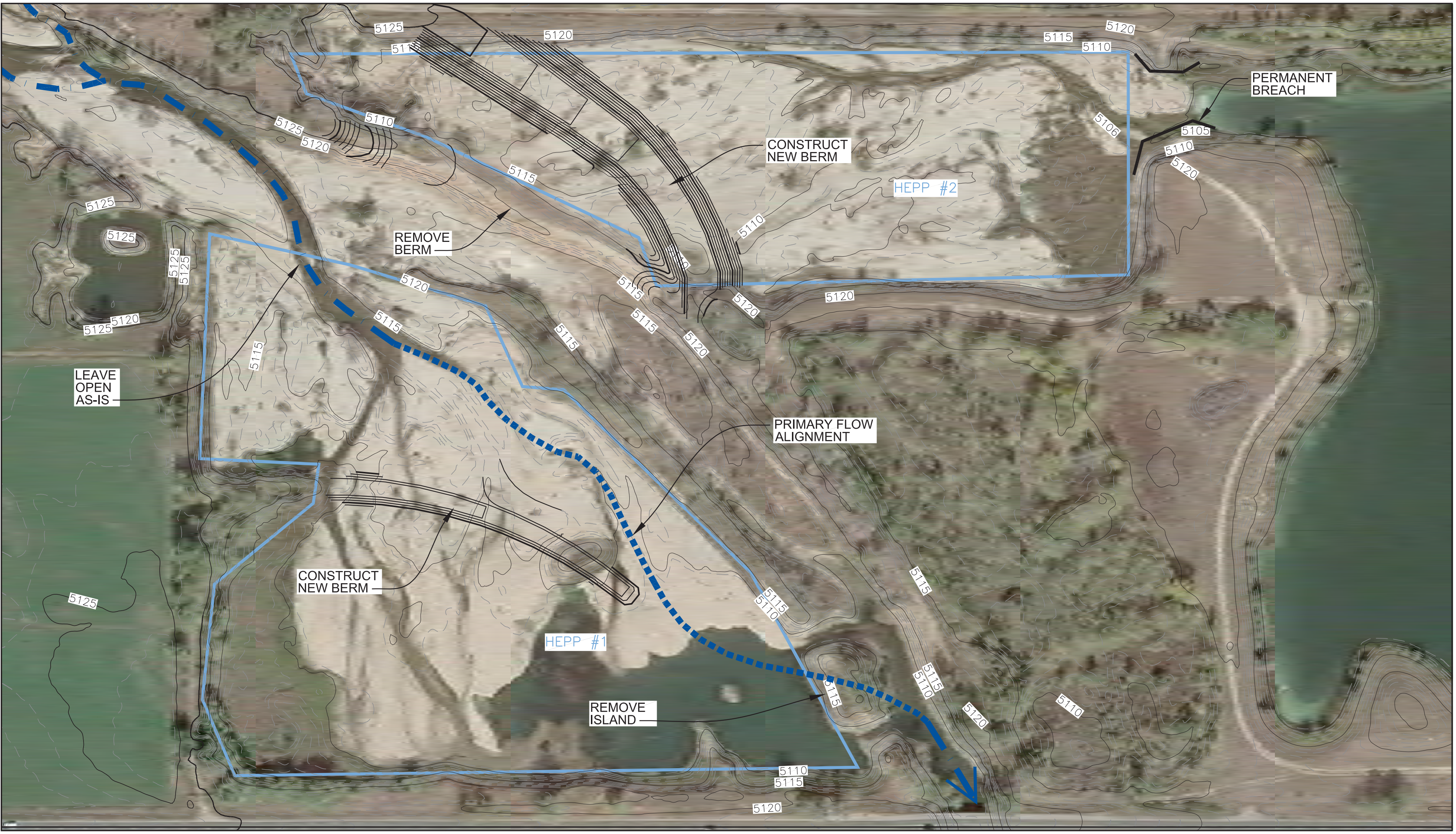

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**FIGURE 4-3B**
**BREACHES 5-9, ALTERNATIVE 2**
**REDIRECT FLOW AND FULL BERM**

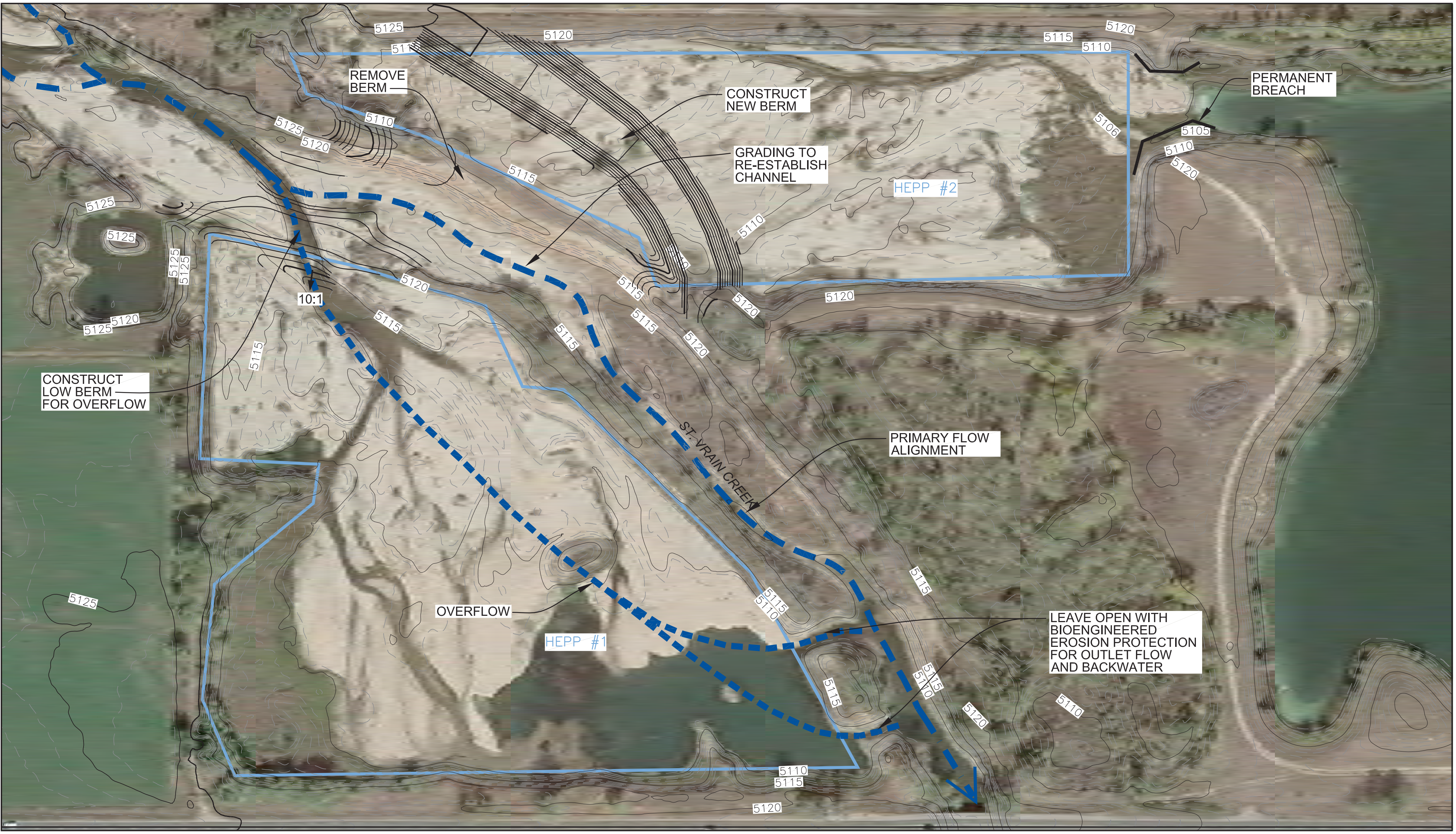

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**FIGURE 4-3C**
**BREACHES 5-9, ALTERNATIVE 3**
**OVERFLOW BERM AND LOW BERM**

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**FIGURE 5-1A**
**OVERVIEW PROPOSED CONDITION**
**INUNDATION MAP 1-YEAR EVENT**

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**FIGURE 5-1B**
**OVERVIEW PROPOSED CONDITION**
**INUNDATION MAP 10-YEAR EVENT**

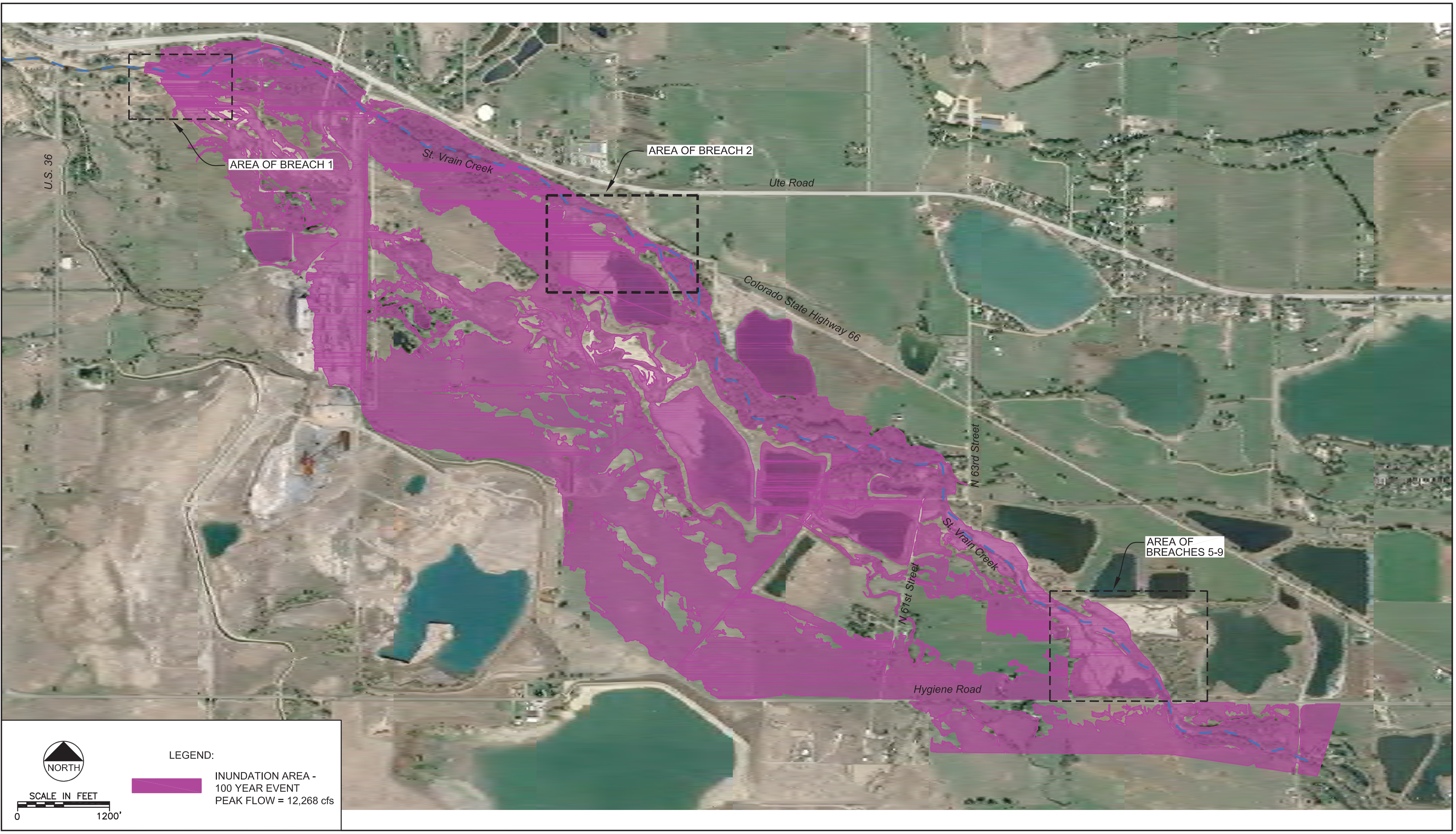

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**FIGURE 5-1C**
**OVERVIEW PROPOSED CONDITION**
**INUNDATION MAP 100-YEAR EVENT**

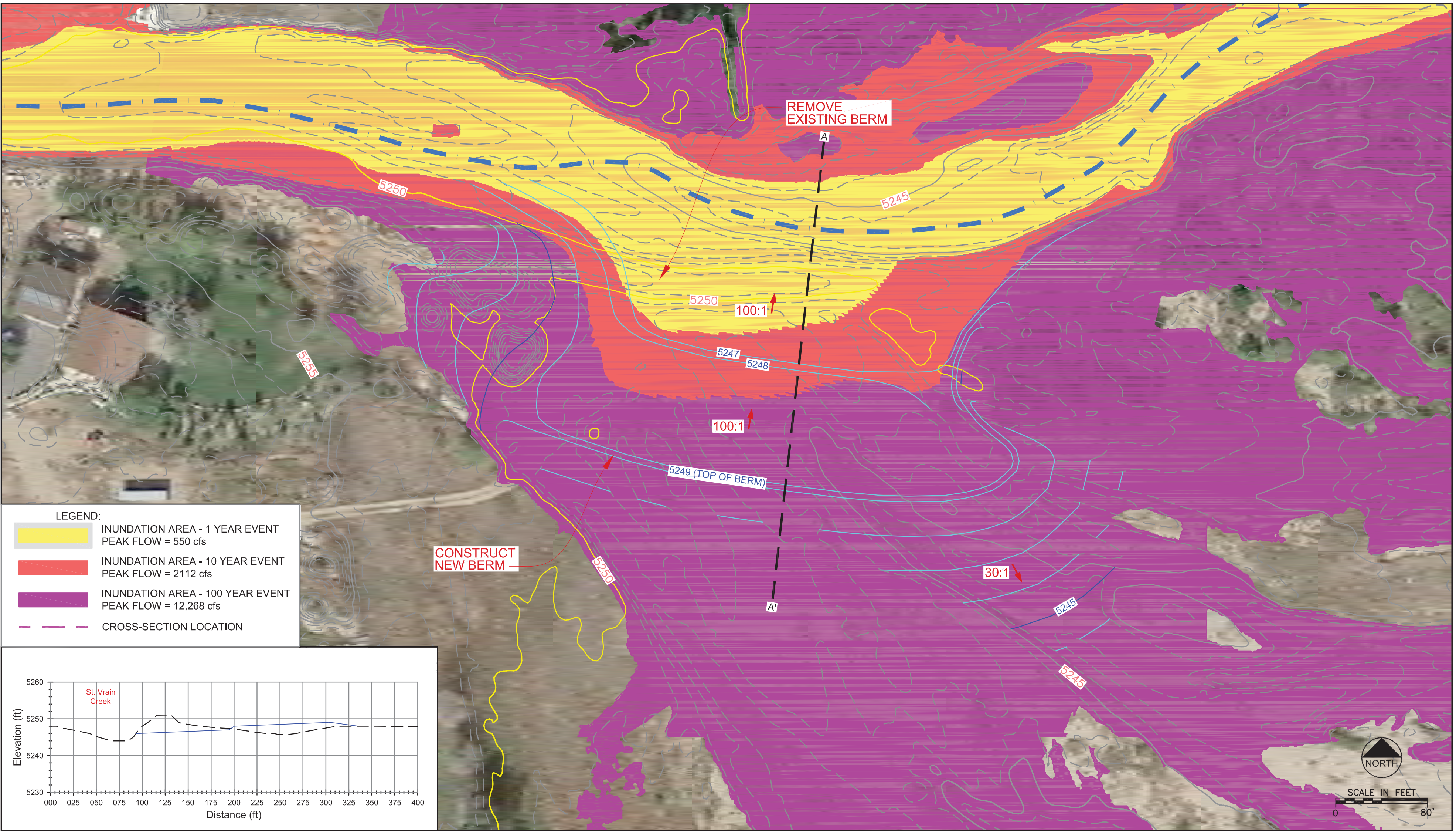

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**FIGURE 5-2**
**BREACH 1, PROPOSED CONDITION**
**INUNDATION MAP**

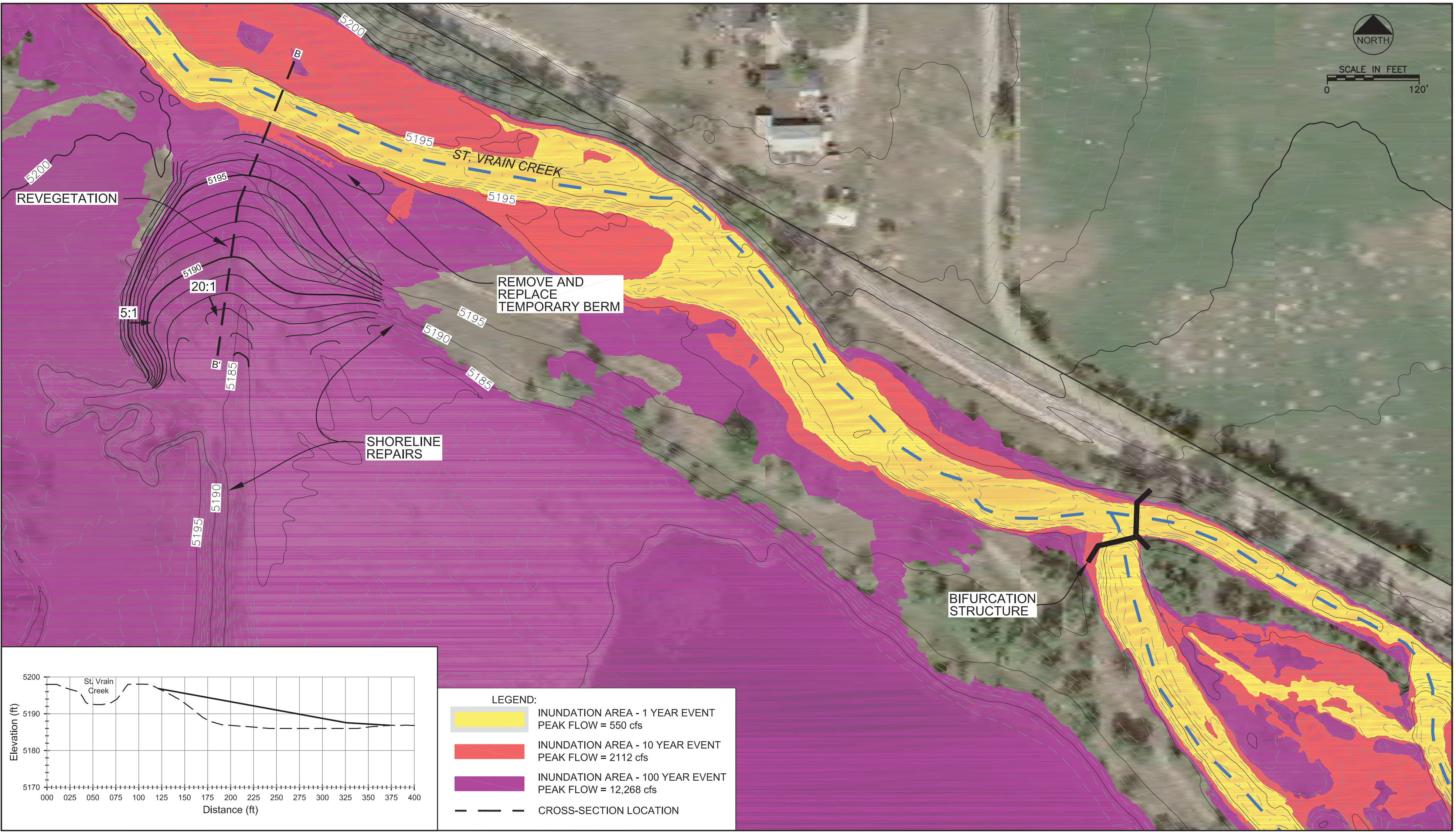

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**FIGURE 5-3**
**BREACH 2, PROPOSED CONDITION**
**INUNDATION MAP**

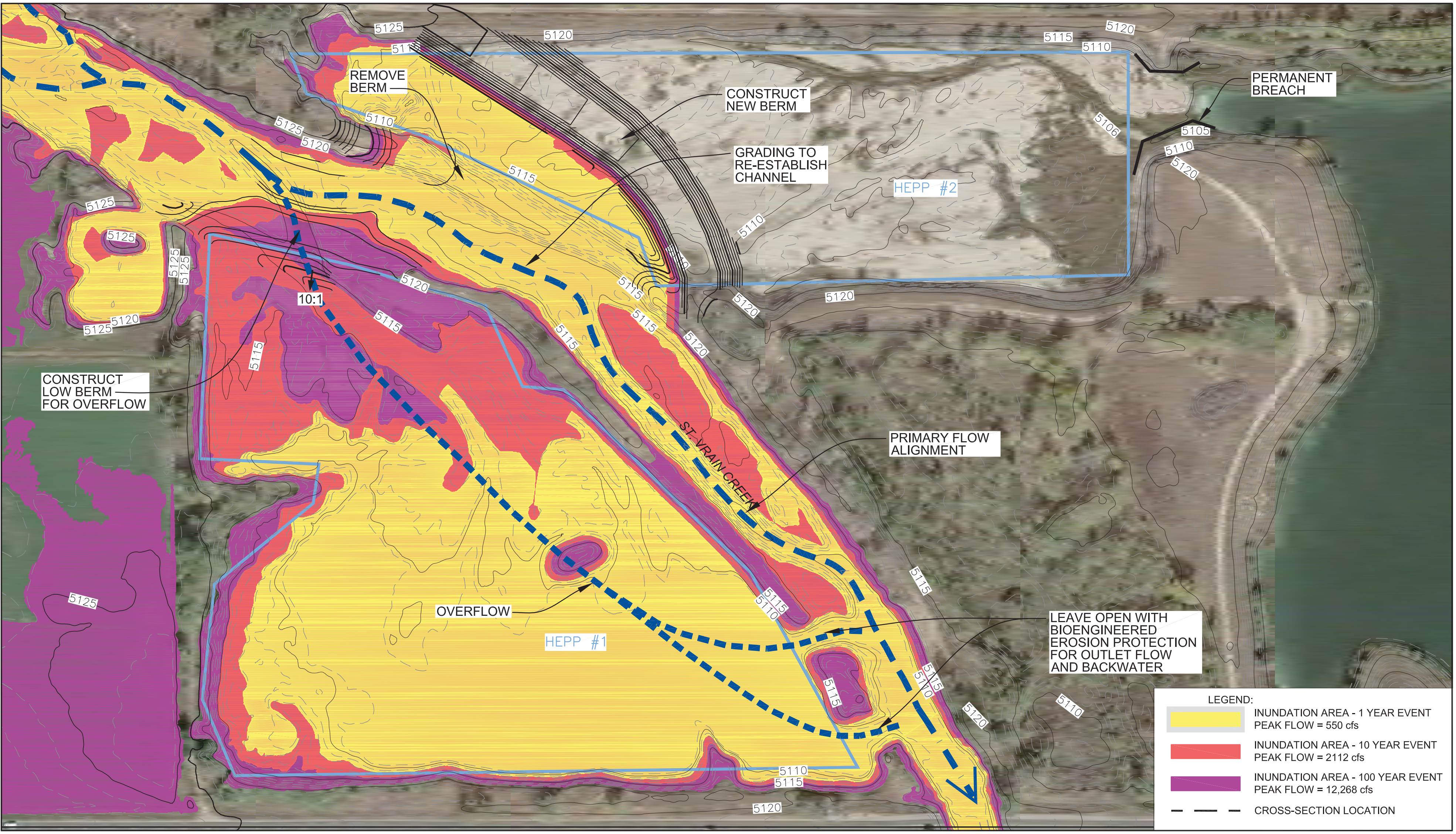

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**FIGURE 5-4**
**BREACHES 5-9, PROPOSED CONDITION**
**INUNDATION MAP**

# APPENDIX I
# EA GEOTECHNICAL INVESTIGATION

# Geotechnical Investigation
# St. Vrain Creek Breaches Restoration
# Highway 36 to Hygiene Road
# Boulder County, Colorado

*Prepared for:*

Boulder County Parks and Open Space
2025 14th Street
Boulder, Colorado 80302

*Prepared by:*

Engineering Analytics, Inc.

1600 Specht Point Road, Suite 209
Fort Collins, Colorado 80525
(970) 488-3111
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Project No. 110666

July 1, 2016

## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF APPENDICES

## 1.0 INTRODUCTION

Engineering Analytics, Inc. (EA) is pleased to present this report for the St. Vrain Breaches Restoration project in Boulder County, Colorado. This report presents the results of the geotechnical investigation, laboratory testing, and recommendations.

### 1.1 Scope of Work

The scope of work for this project included the following:

1. Advancement of 8 borings to explore subsurface soil and bedrock conditions at the site and to obtain soil samples.
2. Laboratory testing of select soil samples.
3. Recommendations for on-site material re-use and/or import fill material

### 1.2 Site Description

The project site is located in the foothills of the Rocky Mountains, approximately 0.25 miles east of the intersection of US Highway 36 East/N Foothills Highway and State Highway 66/Ute Highway in Boulder County, Colorado. The project area includes nine breaches along the St. Vrain Creek between US Highway 36 to Hygiene Road that occurred in the September 2013 flooding. Emergency, temporary repairs were installed at some of the breach locations.

Breach 1 occurred along the south stream bank over a length of approximately 1200 feet. A temporary breach repair berm was installed in the area of Breach 1. According to the information provided by Boulder County, we understand this berm consists of fill material derived from native on-site flood-deposited sand and cobbles capped with 12 inches of imported clay across the top, along the front slope, and extending 20 feet toward the stream channel from the toe of the slope. The front slope is dressed with type M and H sandstone riprap. The elevation ranges from approximately Elevation (El.) 5257 to 5251 feet above sea level along the length of the berm.

Breach 2 occurred along the south stream bank over a length of approximately 100 feet. A temporary breach repair berm was installed in the area of Breach 2. According to the information provided by Boulder County, we understand the berm at Breach 2 consists of a mix of about 60% fill material derived from native on-site sand and cobble materials with about 40% clay/loam materials, mixed and compacted in lifts, and the slope face dressed with sandstone rip-rap. An additional 2 to 3 feet of on-site material was added to the height of the breach repair in 2014, and was dressed with imported granite riprap and spillway. The elevation ranges from approximately El. 5203 to 5202 feet above sea level along the length of the berm.

Breach 3 is more accurately defined as the area where overland flow of water from Breach 2 returned to the creek channel. Restoration of Breach 3 will be addressed through ongoing restoration planning with the surrounding property’s mineral-rights owner.

The combined southeastward flow of water from Breach 1 and Breach 2 returned to the creek immediately downstream of the 63rd Street bridge at Breach 4. Breach 4 resulted in destruction of 61st Street, and the restoration of this Breach area is being addressed through separate projects.

A small amount of spatially varied flow from Breaches 1 and 2 continued overland south of the pre-flood channel and returned to the creek at Breach 5 through Ramey Pond. Breach 6 occurred along the south stream bank into Hepp #1 Reservoir. Return flow of the floodwater from Breach 6 to the pre-flood creek channel occurred through Breach 8. Additionally, a man-made cut, Breach 9, was excavated to enable water to return more directly to St. Vrain Creek. The current stream channel now passes through Breach 6 and Hepp #1 Reservoir, and returns to the pre-flood channel at Breaches 8 and 9.

Breach 7a occurred along the north stream bank into Hepp #2 Reservoir, where the floodwaters continued through Breach 7b to Hepp #3 Reservoir, and spatially varied overland flow occurred eastward. A temporary breach repair berm was installed in the area of Breach 7a. According to the information provided by Boulder County, we understand this berm consists of fill material derived from native on-site flood-deposited sand and cobbles capped with 12 inches of imported clay across the top, along the front slope, and extending 20 feet toward the stream channel from the toe of the slope. The front slope is dressed with type M and H sandstone riprap. The elevation ranges from approximately El. 5128 to 5125 feet above sea level along the length of the berm.

### 1.3 Report Layout

The purpose of this report is to present field observations, classification of the on-site soils, a summary of the laboratory testing, conclusions and recommendations. Figure 1 depicts the site location and the approximate locations of the borings explored by EA. The boring logs are included in Appendix A and show detailed descriptions of the subsurface conditions encountered. Appendix B contains the laboratory test results.

## 2.0 FIELD INVESTIGATION

The field investigation included the advancement and sampling of eight borings. The exploratory borings (B-1 through B-8) were drilled on June 8 and 9, 2016. The borings were advanced to depths ranging from about 18 to 23½ feet. EA logged the in-situ soil conditions, collected soil samples, and recorded groundwater conditions. The locations of the borings are described further in Section 2.2 below, and are shown on Figure 1. Logs of the borings are presented in Appendix A.

### 2.1 Exploration Procedures

Elite Drilling Services of Denver, Colorado performed the drilling, and the borings were advanced using a CME550 buggy rig with a 3 ¼” hollow-stem auger. EA personnel supervised the drilling and logged the materials in the boreholes.

EA collected samples using a Standard Penetration Test (SPT) sampler that consists of a 2-inch outside diameter split-barrel. The sampler was driven into the soil by a 140-pound manual (or rope) hammer falling 30 inches, and the number of blows required to drive the sampler 24 inches was recorded in four consecutive intervals of 6 inches.

SPT samples were collected at the ground surface and at approximately 5-foot intervals thereafter in each of the borings. Bulk samples of the auger cuttings were collected from two of the borings. The sampling depths and descriptions of the materials encountered in the borings are presented on the boring logs in Appendix A.

Select field samples were sent to the laboratory for analysis and field verification.

## 2.2 Subsurface Conditions

The following summarizes the soil conditions encountered during the field investigation. All depths are relative to the ground surface at the time of the investigation. The boring logs in Appendix A provide a more detailed description of the materials encountered during the field investigation.

### 2.2.1 Breach 1

Borings B-1 and B-2 were drilled along the crest of the Breach 1 repair berm.

*Sandy Clay/Clayey Sand:* A layer of sandy clay to clayey sand was encountered at the ground surface of borings B-1 and B-2 to depths of approximately 5 inches and 2 feet below grade, respectively. This layer was comprised of brown clay and sand. This clayey layer is likely representative of the “clay cap” that was installed for the breach repair section.

*Alluvial Soil:* Native alluvial soil was encountered immediately below the surface materials listed above. and fill comprised of native alluvial materials Due to the nature of the fill materials being comprised of native alluvial materials, it was difficult to discern a boundary between fill materials and native materials with the samples collected in the borings. Alluvial materials were encountered through the extent of borings B-1 and B-2. These alluvial materials generally consisted of loose to dense sand and gravel with varying fractions of silt and clay.

### 2.2.2 Breach 2

Boring B-3 was drilled adjacent to the breach repair section in a location that did not appear to be disturbed or modified during the 2013 flood. Boring B-4 was drilled along the crest of the Breach 2 repair berm.

*Topsoil:* Topsoil material was encountered at the surface of boring B-3 to about 1 foot below existing ground surface.

*Alluvial Soil:* Native alluvial soil was encountered immediately below the topsoil in B-3. Fill material comprised of native alluvial materials was encountered at the ground surface of boring B-4. Due to the nature of the fill materials being comprised of native alluvial materials, it was difficult to discern a boundary between fill materials and native materials with the samples collected in the borings. The alluvial materials were encountered to depths of approximately 8 feet and 13½ feet in borings B-3 and B-4, respectively. These alluvial materials generally consisted of loose to medium dense sand, gravel, and silty sand.

*Bedrock:* Shale bedrock was encountered in borings B-3 and B-4 at depths of approximately 8 and 13½ feet, respectively, through the extent of the borings. The shale was very dark gray to black and weak. The shale below 13 feet in boring B-3 exhibited a hydrocarbon odor.

### 2.2.3 Breach 5/Breach 6

Boring B-5 was drilled south of Breaches 5 and 6 in a location that did not appear to be disturbed or modified as a result of the 2013 flood.

*Topsoil:* Topsoil material was encountered at the surface of boring B-5 to about 3 feet below existing ground surface. This boring was drilled

*Alluvial Soil:* Native alluvial soil was encountered immediately below the topsoil layer through the extent of boring B-5. These alluvial materials generally consisted of stiff sandy clay, and very dense sand with varying fractions of gravel and clay.

### 2.2.4 Breach 7a

Borings B-6 and B-7 were drilled along the crest of the Breach 7a repair berm.

*Sandy Clay/Clayey Sand:* A layer of sandy clay was encountered at the ground surface of borings B-6 and B-7 to depths of approximately 4 inches. This layer was comprised of light brownish gray to olive-brown clay and sand. This clayey layer is likely representative of the “clay cap” that was installed for the breach repair section.

*Alluvial Soil:* Native alluvial soil and fill comprised of native alluvial materials was encountered immediately below the surface materials listed above. Due to the nature of the fill materials being comprised of native alluvial materials, it was difficult to discern a boundary between fill materials and native materials with the samples collected in the borings. The alluvial materials were encountered to a depth of approximately 23 feet below grade in boring B-6, and through the extent of boring B-7. These alluvial materials generally consisted of medium dense to very dense sand and gravel with varying fractions of clay.

*Bedrock:* Shale bedrock was encountered in boring B-6 at approximately 23 feet through the extent of the boring. The shale was dark gray to black and weak.

### 2.2.5 Breach 7b

Boring B-8 was drilled adjacent to Breach 7b in a location that did not appear to be disturbed or modified as a result of the 2013 flood.

Alluvial Soil: Native alluvial soil was encountered at the ground surface through the extent of boring B-8. These alluvial materials generally consisted of dense to very dense sand and gravel with varying fractions of clay.

### 2.2.6 Groundwater

Water was encountered during drilling at depths ranging from approximately 4 feet to 18 feet below grade in the borings, with the exception of boring B-3 where no water was encountered during drilling. Groundwater levels are known to fluctuate due to local and regional factors such as seasonal changes and storm events.

## 3.0 LABORATORY TESTING

Laboratory testing was conducted on selected samples obtained from the borings to determine engineering properties of the fill and native soils. The laboratory testing program included moisture content and dry density determination and grain size analyses. Smith Geotechnical Engineering Consultants (Smith) of Fort Collins, Colorado performed the laboratory testing. The laboratory results are summarized below and presented in Appendix B.

Moisture Content: Moisture content of select SPT samples was measured in accordance with test method ASTM D2216. The moisture contents of the samples ranged from 2.4% to 21.8%.

Grain Size Distribution: The grain size distribution was determined in accordance with ASTM D 422 and ASTM D 1140 for selected SPT samples. The percent passing the #200 sieve ranged from 3.6% to 70.1%.

## 4.0 CONCLUSIONS

We understand that the breach repairs that are currently in place at the project site were installed as part of FEMA emergency, temporary flood mitigation work during the winter of 2013/2014. We also understand that these temporary repairs need to be replaced with permanent solutions, and as such, may need to be re-constructed. Based on our understanding of the materials used for the temporary breach repairs, the conditions observed at the existing repair sections, and the materials encountered in our explorations, we anticipate that the existing on-site materials are generally suitable for re-use as fill for the permanent breach repairs. Additionally, the rip rap installed along the faces of the temporary breach repairs is generally in good condition and can be re-used for the permanent repairs.

## 5.0 RECOMMENDATIONS

### 5.1 Re-use of on-site material

Topsoil or surface materials containing rootlets or other deleterious materials should be removed within construction limits during site preparation. The native alluvial soils and fill comprised of native alluvial materials encountered on site are suitable for reuse as structural fill and general fill. The existing sandstone and granite rip rap is suitable for reuse. We recommend the on-site materials intended for reuse be sorted to remove oversized and/or deleterious materials. Specific recommendations for fill materials will be dependent on the final breach repair design selected for construction.

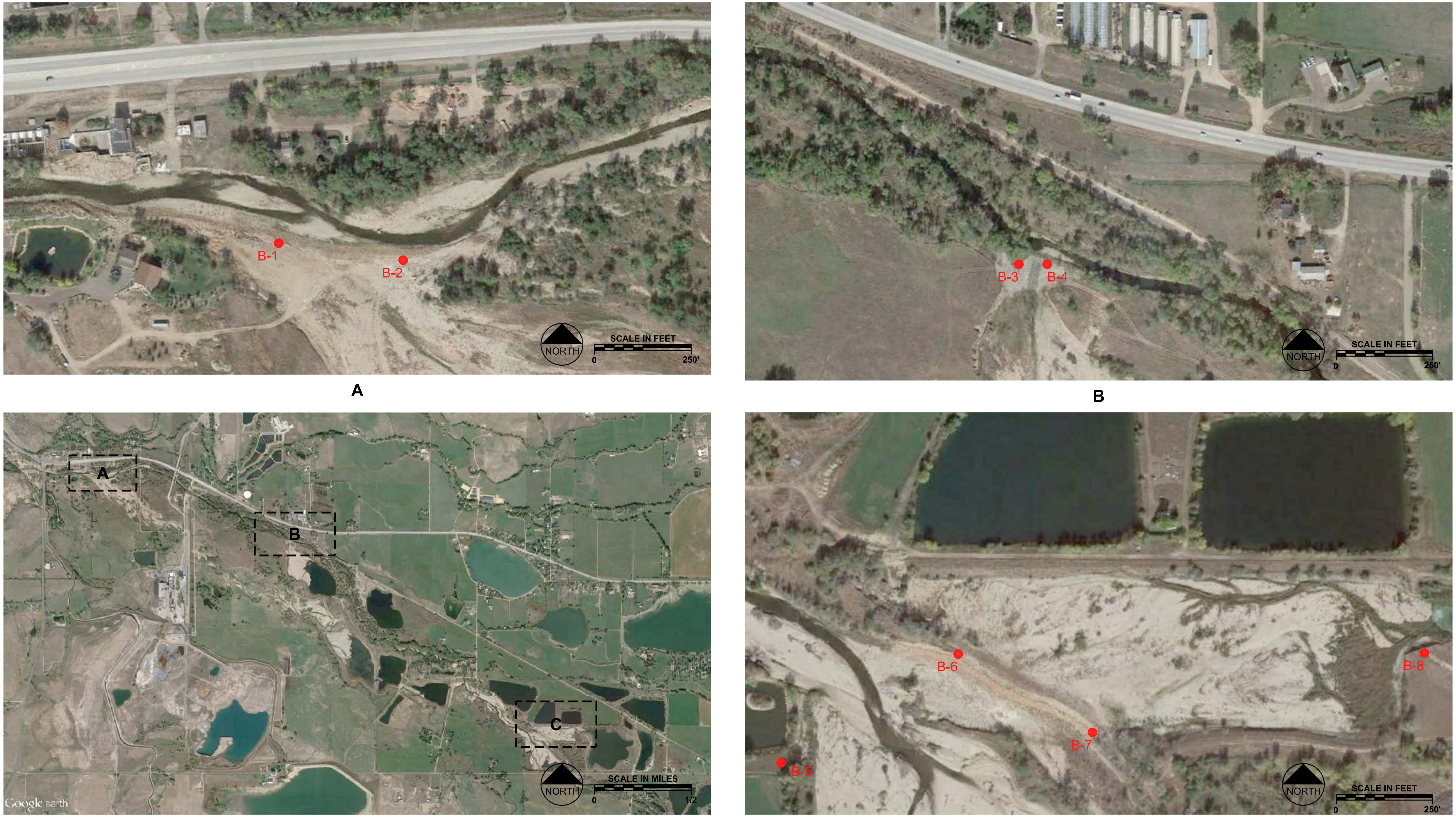
### 5.2 Anticipated need for import material

The material encountered in our explorations primarily consisted of coarse-grained sands and gravels, with minor amounts of silts and clays. For construction of the breach repairs and dams on site, we understand that additional clay soil may be required. We recommend allocating for the import of clay soil for use as select fill material in the breach repairs and/or dams. Quantities of import material will be dependent on the final breach repair design selected for construction.

## 6.0 STANDARD OF CARE

The information contained in this report represents our findings at the time and location as indicated in this report. The methods utilized are in accordance with currently accepted engineering and testing procedures and other than this, no warranty, either expressed or implied, is intended.

# FIGURES



A

B

OVERALL PLAN

C

**LEGEND:**

B-7 ● APPROXIMATE BORING LOCATION

T:\110666 St Vrain Breaches\Boring Locations.dwg SAVED: 6/29/16 PRINTED: 7/7/16

Project No. 110666

June 2016

Engineering Analytics, Inc.

**FIGURE 1**
**EXPLORATION LOCATION PLAN**
**ST. VRAIN CREEK BREACHES RESTORATION**
**US 36 TO HYGIENE ROAD**

# APPENDIX A
# BORING LOGS

Engineering Analytics, Inc.

# BOREHOLE LOG

**PAGE:** 1 OF 2

**DATE:** 6/8/2016

**BOREHOLE NO.:** B-1

## PROJECT INFORMATION

**PROJECT:** ST VRAIN BREACHES

**PROJECT NO.:** 110666

**CLIENT:** BOULDER COUNTY PARKS AND OPEN SPACE

**OWNER:** BOULDER COUNTY PARKS AND OPEN SPACE

**LOCATION:** BOULDER COUNTY

## BOREHOLE LOCATION

SEE FIGURE 1

## FIELD INFORMATION

**DATE & TIME ARRIVED:** 6/8/2016 8:00 AM

**BOREHOLE LOGGED BY:** NRS

**VISITORS:** N/A

**WEATHER:** SUNNY, 80°s

## DRILLING INFORMATION

**DRILLING COMPANY:** ELITE

**START TIME:** 9:05 AM

**BORING DEPTH:** 18'-5"

**BORING DIA.:** 3 ¼" I.D.

**DRILLING METHOD:** HOLLOW STEM AUGER

**SAMPLING METHOD:** SPT

**TIME DRILLING COMPLETE:** 10:00 AM

## BOREHOLE COMPLETION / ABANDONMENT INFORMATION

**START TIME:** 9:05 AM

**COMPLETE TIME:** 10:00 AM

**INSTRUMENTATION:** N/A

**BACKFILL:** CUTTINGS

**ELEVATION - TOP OF BORING:** APPROX. 5,255'

**NORTHING / WESTING:** 40°12'39.7"N / 105°14'38.7"W

## GROUNDWATER CONDITIONS

WATER WAS ENCOUNTERED AT APPROX. 8' BGS DURING DRILLING

## FOLLOWING FIELD WORK

**TIME OF CLEAN-UP COMPLETE:** 11:45 AM

**TIME LEFT SITE:** 12:00 PM

## NOTES:

Engineering Analytics, Inc.

# BOREHOLE LOG

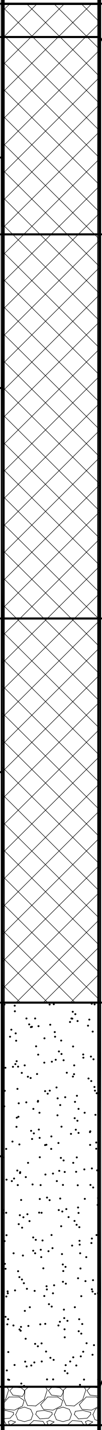
**PROJECT:** ST VRAIN BREACHES **PAGE:** 2 OF 2

**PROJECT NO.:** 110666 **DATE:** 6/8/2016

**BOREHOLE NO.:** **B-1**

| DEPTH (FT) | CORE RECOV. | DRIVE SAMPLES | | | ADD'L SAMPLES |
|---|---|---|---|---|---|
| | | SAMPLE TYPE | BLOWS (PER 6") | RECOV. | |
| 0 | | SPT | 4<br>24<br>14<br>6 | 12" | S1A<br>S1B |
| 3 | | SPT | 21<br>11<br>11<br>9 | 8" | S2 |
| 8 | | SPT | 8<br>11<br>20<br>20 | 18" | S3 |
| 13 | | SPT | 18<br>31<br>50/5" | 16" | S4 |
| 18 | | SPT | 50/5" | 3" | S5 |

LITHOLOGY GRAPHIC



**SOIL DESCRIPTION**

**CLAYEY SAND (0-APPROX. 5")**
SLIGHTLY MOIST, BROWN (10YR 4/3), LOOSE CLAYEY SAND

**GRAVEL WITH SAND (APPROX. 5"-APPROX. 3')**
DRY, PINKISH GRAY (7.5YR 6/2), DENSE POORLY GRADED GRAVEL WITH SAND, POSSIBLE FILL

**SAND WITH GRAVEL (APPROX. 3'-APPROX. 8')**
SLIGHTLY MOIST, REDDISH GRAY (5YR 5/2) TO GRAY (5YR 5/1), MEDIUM DENSE WELL GRADED SAND WITH GRAVEL, POSSIBLE FILL

**- (APPROX. 5'- APPROX. 7')** DRILLER REPORTED AUGER GRINDING, POSSIBLE GRAVEL / COBBLES

▼ **(APPROX. 8')** WATER ENCOUNTERED DURING DRILLING

**GRAVEL WITH SAND (APPROX. 8'-APPROX. 13')**
WET, BROWN (7.5YR 4/2), DENSE POORLY GRADED GRAVEL WITH SAND, FINE TO COARSE SAND, FINE TO COARSE GRAVEL, POSSIBLE FILL

**SAND WITH SILT AND GRAVEL (APPROX. 13'-APPROX. 18')**
WET, LIGHT BROWNISH GRAY (10YR 6/2), VERY DENSE WELL GRADED SAND WITH SILT AND GRAVEL

**GRAVEL WITH SILT AND SAND (APPROX. 18'-E.O.B.)**
WET, GRAYISH BROWN (2.5YR 5/2), VERY DENSE WELL GRADED GRAVEL WITH SILT AND SAND

E.O.B. = 18'-5"

Engineering Analytics, Inc.

# BOREHOLE LOG

**BOREHOLE NO.:** B-2

**PAGE:** 1 OF 2

**DATE:** 6/8/2016

## PROJECT INFORMATION

**PROJECT:** ST VRAIN BREACHES

**PROJECT NO.:** 110666

**CLIENT:** BOULDER COUNTY PARKS AND OPEN SPACE

**OWNER:** BOULDER COUNTY PARKS AND OPEN SPACE

**LOCATION:** BOULDER COUNTY

## BOREHOLE LOCATION

SEE FIGURE 1

## FIELD INFORMATION

**DATE & TIME ARRIVED:** 6/8/2016 8:00 AM

**BOREHOLE LOGGED BY:** NRS

**VISITORS:** N/A

**WEATHER:** SUNNY, 80°s

## DRILLING INFORMATION

**DRILLING COMPANY:** ELITE

**START TIME:** 10:30 AM

**BORING DEPTH:** 19'-3" **BORING DIA.:** 3 ¼" I.D.

**DRILLING METHOD:** HOLLOW STEM AUGER

**SAMPLING METHOD:** SPT

**TIME DRILLING COMPLETE:** 11:30 AM

## BOREHOLE COMPLETION / ABANDONMENT INFORMATION

**START TIME:** 10:30 AM **COMPLETE TIME:** 11:30 AM

**INSTRUMENTATION:** N/A **BACKFILL:** CUTTINGS

**ELEVATION - TOP OF BORING:** APPROX. 5,252' **NORTHING / WESTING:** 40°12'39.3"N / 105°14'34.5"W

## GROUNDWATER CONDITIONS

WATER WAS ENCOUNTERED AT APPROX. 4' BGS DURING DRILLING

## FOLLOWING FIELD WORK

**TIME OF CLEAN-UP COMPLETE:** 11:45 AM **TIME LEFT SITE:** 12:00 PM

## NOTES:

Engineering Analytics, Inc.

# BOREHOLE LOG

PROJECT: ST VRAIN BREACHES
PAGE: 2 OF 2
PROJECT NO.: 110666
DATE: 6/8/2016

BOREHOLE NO.: **B-2**

| DEPTH (FT) | CORE RECOV. | DRIVE SAMPLES | | | ADD'L SAMPLES | LITHOLOGY GRAPHIC | SOIL DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | SAMPLE TYPE | BLOWS (PER 6") | RECOV. | | | |
| 0 | | | | | | | **SANDY CLAY (0-APPROX. 2')**<br>SLIGHTLY MOIST, BROWN (2.5YR 5/2), VERY STIFF SANDY CLAY WITH TRACE GRAVEL, POSSIBLE FILL |
| 1 | | SPT | 3<br>6<br>11<br>17 | 12" | S1 | | |
| 2 | | | | | | | **SAND WITH GRAVEL (APPROX. 2'-APPROX. 9')**<br>MOIST TO WET, DARK REDDISH GRAY (5YR 4/2), MEDIUM DENSE WELL GRADED SAND WITH GRAVEL, POSSIBLE FILL<br>- **(APPROX. 2.5')** DRILLER REPORTED AUGER GRINDING |
| 3 | | | | | | | |
| 4 | | SPT | 17<br>14<br>15<br>12 | 8" | S2 | | ▼ **(APPROX. 4')** WATER ENCOUNTERED DURING DRILLING |
| 5 | | | | | | | |
| 6 | | | | | | | |
| 7 | | | | | | | |
| 8 | | | | | | | - **(APPROX. 8')** WET, REDDISH BROWN (5YR 5/2), MEDIUM DENSE WELL GRADED SAND WITH GRAVEL, FINE GRAVEL |
| 9 | | SPT | 5<br>6<br>12<br>20 | 20" | S3A<br>S3B | | **GRAVEL WITH SILT AND SAND (APPROX. 9'-APPROX. 18')**<br>WET, REDDISH BROWN (5YR 5/4), MEDIUM DENSE WELL GRADED GRAVEL WITH SILT AND SAND, FINE TO COARSE GRAVEL, POSSIBLE FILL |
| 10 | | | | | | | |
| 11 | | | | | | | |
| 12 | | | | | | | |
| 13 | | SPT | 50/4" | 4" | S4 | | - **(APPROX. 13')** WET, LIGHT OLIVE BROWNISH (2.5YR 5/3), VERY DENSE WELL GRADED GRAVEL WITH SILT AND SAND |
| 14 | | | | | | | |
| 15 | | | | | | | |
| 16 | | | | | | | |
| 17 | | | | | | | |
| 18 | | | | | | | **SAND WITH CLAY AND GRAVEL (APPROX. 18'-E.O.B.)**<br>WET, LIGHT YELLOWISH BROWN (2.5YR 6/3), VERY DENSE WELL GRADED SAND WITH CLAY AND GRAVEL, MEDIUM TO COARSE SAND |
| 19 | | SPT | 23<br>26<br>50/3" | 15" | S5 | | E.O.B. = 19'-3" |
| 20 | | | | | | | |

Engineering Analytics, Inc.

# BOREHOLE LOG

PAGE: 1 OF 2

DATE: 6/8/2016

BOREHOLE NO.: B-3

## PROJECT INFORMATION

PROJECT: ST VRAIN BREACHES

PROJECT NO.: 110666

CLIENT: BOULDER COUNTY PARKS AND OPEN SPACE

OWNER: BOULDER COUNTY PARKS AND OPEN SPACE

LOCATION: BOULDER COUNTY

## BOREHOLE LOCATION

SEE FIGURE 1

## FIELD INFORMATION

DATE & TIME ARRIVED: 6/8/2016 12:30 PM

BOREHOLE LOGGED BY: NRS

VISITORS: N/A

WEATHER: SUNNY, 80°s

## DRILLING INFORMATION

DRILLING COMPANY: ELITE

START TIME: 12:40 PM

BORING DEPTH: 18'-2"

BORING DIA.: 3 ¼" I.D.

DRILLING METHOD: HOLLOW STEM AUGER

SAMPLING METHOD: SPT

TIME DRILLING COMPLETE: 1:30 PM

## BOREHOLE COMPLETION / ABANDONMENT INFORMATION

START TIME: 12:40 PM

COMPLETE TIME: 1:30 PM

INSTRUMENTATION: N/A

BACKFILL: CUTTINGS

ELEVATION - TOP OF BORING: APPROX. 5,203'

NORTHING / WESTING: 40°12'23.0"N / 105°13'30.9"W

## GROUNDWATER CONDITIONS

NO WATER WAS ENCOUNTERED DURING DRILLING

## FOLLOWING FIELD WORK

TIME OF CLEAN-UP COMPLETE: 3:00 PM

TIME LEFT SITE: 3:30 PM

## NOTES:

Engineering Analytics, Inc.

# BOREHOLE LOG

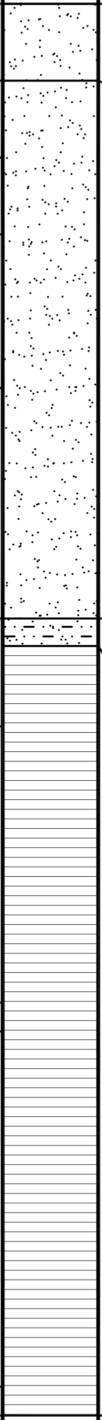
**PROJECT:** ST VRAIN BREACHES **PAGE:** 2 OF 2

**PROJECT NO.:** 110666 **DATE:** 6/8/2016

**BOREHOLE NO.:** B-3

| DEPTH (FT) | CORE RECOV. | DRIVE SAMPLES | | | ADD'L SAMPLES |
|---|---|---|---|---|---|
| | | SAMPLE TYPE | BLOWS (PER 6") | RECOV. | |
| 0–2 | | SPT | 5<br>6<br>7<br>7 | 22" | S1A<br>S1B |
| 3–5 | | SPT | 7<br>10<br>17<br>17 | 12" | S2 |
| 5–8 | | | | BAG 1 | |
| 8–9.4 | | SPT | 14<br>38<br>50/5" | 17" | S3 |
| 13 | | SPT | 50/2" | 2" | S5 |
| 18 | | SPT | 50/2" | 2" | S5 |

LITHOLOGY GRAPHIC



SOIL DESCRIPTION

**TOPSOIL (0-APPROX. 1')**

SLIGHTLY MOIST, BROWN (7.5YR 4/3), MEDIUM DENSE TOPSOIL, POORLY GRADED SAND WITH ROOTLETS, FINE SAND

**SAND (APPROX. 1'-APPROX. 8')**

SLIGHTLY MOIST, REDDISH BROWN (5YR 5/3), MEDIUM DENSE POORLY GRADED SAND, FINE SAND WITH TRACE ROOTLETS

- **(APPROX. 3')** DRY, DARK YELLOWISH BROWN (10YR 4/4), MEDIUM DENSE POORLY GRADED SAND WITH GRAVEL

- **(0-APPROX. 8')** BAG 1 CUTTING SAMPLE

**SILTY SAND WITH GRAVEL (APPROX. 8'-APPROX. 8'-3")**

MOIST, VERY DARK GRAYISH BROWN (10YR 3/2), SILTY SAND WITH GRAVEL

**SHALE (APPROX. 8'-3"-APPROX. E.O.B.')**

MOIST, VERY DARK GRAY (2.5YR 3/1), VERY DENSE SHALE

- **(APPROX. 13')** MOIST, BLACK (10YR 2/1), VERY DENSE WEAK SHALE, HYDROCARBON ODOR

E.O.B. = 18'-2"

Engineering Analytics, Inc.

# BOREHOLE LOG

**PAGE:** 1 OF 2

**DATE:** 6/8/2016

**BOREHOLE NO.:** B-4

## PROJECT INFORMATION

**PROJECT:** ST VRAIN BREACHES

**PROJECT NO.:** 110666

**CLIENT:** BOULDER COUNTY PARKS AND OPEN SPACE

**OWNER:** BOULDER COUNTY PARKS AND OPEN SPACE

**LOCATION:** BOULDER COUNTY

## BOREHOLE LOCATION

SEE FIGURE 1

## FIELD INFORMATION

**DATE & TIME ARRIVED:** 6/8/2016 12:30 PM

**BOREHOLE LOGGED BY:** NRS

**VISITORS:** N/A

**WEATHER:** SUNNY, 80°s

## DRILLING INFORMATION

**DRILLING COMPANY:** ELITE

**START TIME:** 1:45 PM

**BORING DEPTH:** 18'-1" **BORING DIA.:** 3 ¼" I.D.

**DRILLING METHOD:** HOLLOW STEM AUGER

**SAMPLING METHOD:** SPT

**TIME DRILLING COMPLETE:** 2:45 PM

## BOREHOLE COMPLETION / ABANDONMENT INFORMATION

**START TIME:** 1:45 PM **COMPLETE TIME:** 2:45 PM

**INSTRUMENTATION:** N/A **BACKFILL:** CUTTINGS

**ELEVATION - TOP OF BORING:** APPROX. 5,202' **NORTHING / WESTING:** 40°12'23.0"N / 105°13'30.0"W

## GROUNDWATER CONDITIONS

WATER WAS ENCOUNTERED AT APPROX. 13' BGS DURING DRILLING

## FOLLOWING FIELD WORK

**TIME OF CLEAN-UP COMPLETE:** 3:00 PM **TIME LEFT SITE:** 3:30 PM

## NOTES:

Engineering Analytics, Inc.

# BOREHOLE LOG

**PROJECT:** ST VRAIN BREACHES **PAGE:** 2 OF 2

**PROJECT NO.:** 110666 **DATE:** 6/8/2016

**BOREHOLE NO.:** **B-4**

| DEPTH (FT) | CORE RECOV. | DRIVE SAMPLES | | | ADD'L SAMPLES | LITHOLOGY GRAPHIC | SOIL DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | SAMPLE TYPE | BLOWS (PER 6") | RECOV. | | | |
| 0 | | | | | | | **GRAVEL WITH SAND (0-APPROX. 3')**<br>DRY, GRAYISH BROWN (10YR 5/2), MEDIUM DENSE WELL GRADED GRAVEL WITH SAND, POSSIBLE FILL |
| 1 | | SPT | 8<br>10<br>18<br>13 | 20" | S1 | | |
| 2 | | | | | | | |
| 3 | | | | | | | **SILTY SAND WITH GRAVEL (APPROX. 3'-APPROX. 9')**<br>MOIST, VERY DARK GRAYISH BROWN (10YR 3/2), LOOSE SILTY SAND WITH GRAVEL, TRACE ROOTLETS, MICACEOUS, POSSIBLE FILL |
| 4 | | SPT | 5<br>5<br>3<br>2 | 18" | S2 | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| 7 | | | | | | | |
| 8 | | | | | | | - **(APPROX. 8')** MOIST, VERY DARK GRAY (10YR 3/1), MEDIUM DENSE SILTY SAND WITH GRAVEL |
| 9 | | SPT | 17<br>11<br>7<br>3 | 14" | S3 | | **GRAVEL WITH SAND (APPROX. 9'-APPROX. 13')**<br>MOIST, GRAY (10YR 5/1), MEDIUM DENSE POORLY GRADED GRAVEL WITH SAND SAND |
| 10 | | | | | | | |
| 11 | | | | | | | |
| 12 | | | | | | | ▼ **(APPROX. 13')** WATER ENCOUNTERED DURING DRILLING |
| 13 | | SPT | 50/6" | 6" | S4 | | **SAND WITH GRAVEL (APPROX. 13'-APPROX. 13'-6")**<br>WET, BROWN (7.5YR 4/2), VERY DENSE WELL GRADED SAND WITH GRAVEL |
| 14 | | | | | | | **SHALE (APPROX. 13'-6"-APPROX. E.O.B.)**<br>WET, VERY DARK GRAY (7.5YR 3/1), VERY DENSE WEAK SHALE |
| 15 | | | | | | | |
| 16 | | | | | | | |
| 17 | | | | | | | |
| 18 | | SPT | 50/1" | 1" | S5 | | - **(APPROX. 18')** WET, BLACK (10YR 2/1), VERY DENSE WEAK SHALE<br>E.O.B. = 18'-1" |
| 19 | | | | | | | |
| 20 | | | | | | | |

Engineering Analytics, Inc.

# BOREHOLE LOG

PAGE: 1 OF 2

DATE: 6/9/2016

BOREHOLE NO.: **B-5**

## PROJECT INFORMATION

**PROJECT:** ST VRAIN BREACHES

**PROJECT NO.:** 110666

**CLIENT:** BOULDER COUNTY PARKS AND OPEN SPACE

**OWNER:** BOULDER COUNTY PARKS AND OPEN SPACE

**LOCATION:** BOULDER COUNTY

## BOREHOLE LOCATION

SEE FIGURE 1

## FIELD INFORMATION

**DATE & TIME ARRIVED:** 6/9/2016 12:15 PM

**BOREHOLE LOGGED BY:** NRS

**VISITORS:** N/A

**WEATHER:** SUNNY, 90°s

## DRILLING INFORMATION

**DRILLING COMPANY:** ELITE

**START TIME:** 12:30 PM

**BORING DEPTH:** 20'

**BORING DIA.:** 3 ¼" I.D.

**DRILLING METHOD:** HOLLOW STEM AUGER

**SAMPLING METHOD:** SPT

**TIME DRILLING COMPLETE:** 1:15 PM

## BOREHOLE COMPLETION / ABANDONMENT INFORMATION

**START TIME:** 12:30 PM

**COMPLETE TIME:** 1:15 PM

**INSTRUMENTATION:** N/A

**BACKFILL:** CUTTINGS

**ELEVATION - TOP OF BORING:** APPROX. 5,134'

**NORTHING / WESTING:** 40°11'27.5"N / 105°12'07.2W

## GROUNDWATER CONDITIONS

WATER WAS ENCOUNTERED AT APPROX. 13' BGS DURING DRILLING

## FOLLOWING FIELD WORK

**TIME OF CLEAN-UP COMPLETE:** 1:45 PM

**TIME LEFT SITE:** 2:00 PM

## NOTES:

Engineering Analytics, Inc.

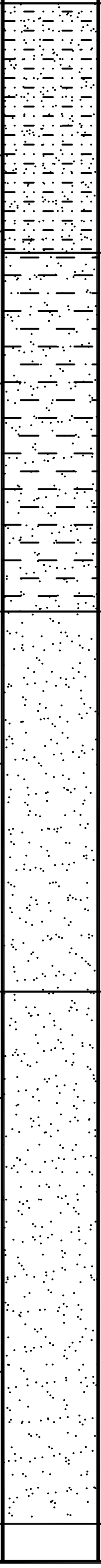
# BOREHOLE LOG

PROJECT: ST VRAIN BREACHES
PAGE: 2 OF 2
PROJECT NO.: 110666
DATE: 6/9/2016

BOREHOLE NO.: B-5

| DEPTH (FT) | CORE RECOV. | DRIVE SAMPLES SAMPLE TYPE | DRIVE SAMPLES BLOWS (PER 6") | DRIVE SAMPLES RECOV. | ADD'L SAMPLES |
|---|---|---|---|---|---|
| 1 | | SPT | 3<br>3<br>2<br>2 | 18" | S1 |
| 4 | | SPT | 4<br>4<br>5<br>7 | 24" | S2 |
| 9 | | SPT | 20<br>50/6" | 12" | S3 |
| 14 | | SPT | 13<br>17<br>50/5" | 17" | S4 |
| 19 | | SPT | 15<br>30<br>38<br>25 | 20" | S5 |

LITHOLOGY GRAPHIC



SOIL DESCRIPTION

**TOPSOIL (0-APPROX. 3'-3")**
MOIST, DARK REDDISH BROWN (5YR 3/2), LOOSE TOPSOIL, SILTY SAND WITH ROOTLETS

**SANDY CLAY (APPROX. 3'-3"-APPROX. 13')**
MOIST, DARK YELLOWISH BROWN (10YR 4/6) TO DARK GRAYISH BROWN (10YR 4/2), STIFF SANDY CLAY, FINE GRAINED SAND, MOTTLED, MICACEOUS

**SAND WITH GRAVEL (APPROX. --'-APPROX. --')**
SLIGHTLY MOIST, GRAY (7.5YR 5/1), VERY DENSE WELL GRADED SAND WITH GRAVEL, FINE TO COARSE SAND, FINE TO COARSE GRAVEL

**- (APPROX. 11')** DRILLER REPORTED AUGER GRINDING, POSSIBLE GRAVEL / COBBLES / BOULDERS

▼ **(APPROX. 13')** WATER ENCOUNTERED DURING DRILLING

**SAND WITH CLAY AND GRAVEL (APPROX. 13'-E.O.B.)**
WET, OLIVE GRAY (5Y 5/2), VERY DENSE POORLY GRADED SAND WITH CLAY AND GRAVEL

**- (APPROX. 18')** WET, DARK GRAYISH BROWN (10YR 4/2), VERY DENSE POORLY GRADED SAND WITH CLAY AND GRAVEL

E.O.B. = 20'

Engineering Analytics, Inc.

# BOREHOLE LOG

**PAGE:** 1 OF 3

**DATE:** 6/9/2016

**BOREHOLE NO.:** B-6

## PROJECT INFORMATION

**PROJECT:** ST VRAIN BREACHES

**PROJECT NO.:** 110666

**CLIENT:** BOULDER COUNTY PARKS AND OPEN SPACE

**OWNER:** BOULDER COUNTY PARKS AND OPEN SPACE

**LOCATION:** BOULDER COUNTY

## BOREHOLE LOCATION

SEE FIGURE 1

## FIELD INFORMATION

**DATE & TIME ARRIVED:** 6/9/2016 8:00 AM

**BOREHOLE LOGGED BY:** NRS

**VISITORS:** N/A

**WEATHER:** SUNNY, 90°s

## DRILLING INFORMATION

**DRILLING COMPANY:** ELITE

**START TIME:** 9:45 AM

**BORING DEPTH:** 23'-6" **BORING DIA.:** 3 ¼" I.D.

**DRILLING METHOD:** HOLLOW STEM AUGER

**SAMPLING METHOD:** SPT

**TIME DRILLING COMPLETE:** 10:45 AM

## BOREHOLE COMPLETION / ABANDONMENT INFORMATION

**START TIME:** 9:45 AM **COMPLETE TIME:** 10:45 AM

**INSTRUMENTATION:** N/A **BACKFILL:** CUTTINGS

**ELEVATION - TOP OF BORING:** APPROX. 5,127' **NORTHING / WESTING:** 40°11'30.3"N / 105°12'01.3W

## GROUNDWATER CONDITIONS

WATER WAS ENCOUNTERED AT APPROX. 13' BGS DURING DRILLING

## FOLLOWING FIELD WORK

**TIME OF CLEAN-UP COMPLETE:** 12:00 PM **TIME LEFT SITE:** 12:00 PM

## NOTES:

Engineering Analytics, Inc.

# BOREHOLE LOG

**PROJECT:** ST VRAIN BREACHES **PAGE:** 2 OF 3

**PROJECT NO.:** 110666 **DATE:** 6/9/2016

**BOREHOLE NO.:** **B-6**

| DEPTH (FT) | CORE RECOV. | DRIVE SAMPLES<br>SAMPLE TYPE | <br>BLOWS (PER 6") | <br>RECOV. | ADD'L SAMPLES | LITHOLOGY GRAPHIC | SOIL DESCRIPTION |
|---|---|---|---|---|---|---|---|
| 0 | | | | | S1a | | **SANDY CLAY (0-APPROX. 4")**<br>DRY, LIGHT BROWNISH GRAY (2.5YR 6/2), STIFF SANDY CLAY, WITH ROOTLETS |
| 1 | | SPT | 7<br>7<br>8<br>7 | 18" | S1b | | **SAND WITH GRAVEL (APPROX. 4"-APPROX. 13')**<br>SLIGHTLY MOIST, BROWN (7.5YR 4/2), MEDIUM DENSE WELL GRADED SAND WITH GRAVEL, POSSIBLE FILL |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | SPT | 6<br>11<br>11<br>7 | 10" | S2 | | |
| 5 | | | | | | | **- (APPROX. 5.5')** DRILLER REPORTED AUGER GRINDING, ROUNDED GRAVEL, COBBLES IN CUTTINGS |
| 6 | | | | | | | |
| 7 | | | | | | | |
| 8 | | | | | | | |
| 9 | | SPT | 11<br>17<br>16<br>16 | 16" | S3 | | **- (APPROX. 5.5')** DRY, LIGHT BROWNISH GRAY (10YR 6/2), DENSE POORLY GRADED SAND WITH GRAVEL, COARSE GRAVEL |
| 10 | | | | | | | |
| 11 | | | | | | | |
| 12 | | | | | | | ▼ **(APPROX. 13')** WATER ENCOUNTERED DURING DRILLING |
| 13 | | | | | | | **GRAVEL WITH SAND (APPROX. 13'-APPROX. 18'-6")**<br>WET, BROWN (10Y 4/3), MEDIUM DENSE WELL GRADED GRAVEL WITH SAND, FINE TO COARSE SAND, FINE TO COARSE GRAVEL |
| 14 | | SPT | 5<br>6<br>6<br>5 | 1" | S4 | | |
| 15 | | | | | | | |
| 16 | | | | | | | |
| 17 | | | | | | | |
| 18 | | | | | S5A | | **(APPROX. 18')** WET, DARK GRAYISH BROWN (10YR 4/2), VERY WELL GRADED GRAVEL WITH SAND |
| 19 | | SPT | 25<br>25<br>50/6" | 22" | S5B | | **CLAYEY GRAVEL WITH SAND (APPROX. 18'-6"-APPROX. 23')**<br>WET, GRAYISH BROWN (2.5Y 5/2), VERY DENSE CLAYEY GRAVEL WITH SAND, FINE TO COARSE SAND, FINE TO COARSE GRAVEL |
| 20 | | | | | | | |

Engineering Analytics, Inc.

# BOREHOLE LOG

PROJECT: ST VRAIN BREACHES PAGE: 3 OF 3

PROJECT NO.: 110666 DATE: 6/9/2016

BOREHOLE NO.: B-6

| DEPTH (FT) | CORE RECOV. | DRIVE SAMPLES | | | ADD'L SAMPLES | LITHOLOGY GRAPHIC | SOIL DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | SAMPLE TYPE | BLOWS (PER 6") | RECOV. | | | |
| 20 | | | | | | | **CLAYEY GRAVEL WITH SAND (APPROX. 18'-6"-APPROX. 23')**<br>(SEE DESCRIPTION ON PREVIOUS PAGE) |
| 21 | | | | | | | |
| 22 | | | | | | | |
| 23 | | SPT | 50/6" | 6" | S6 | | **SHALE (APPROX. 23'-E.O.B.)**<br>MOIST, DARK GRAY (7.5Y 4/1) TO BLACK (7.5Y 2.5/1), VERY DENSE WEAK SHALE<br>E.O.B. = 23'-6" |
| 24 | | | | | | | |
| 25 | | | | | | | |
| 26 | | | | | | | |
| 27 | | | | | | | |
| 28 | | | | | | | |
| 29 | | | | | | | |
| 30 | | | | | | | |
| 31 | | | | | | | |
| 32 | | | | | | | |
| 33 | | | | | | | |
| 34 | | | | | | | |
| 35 | | | | | | | |
| 36 | | | | | | | |
| 37 | | | | | | | |
| 38 | | | | | | | |
| 39 | | | | | | | |
| 40 | | | | | | | |

Engineering Analytics, Inc.

# BOREHOLE LOG

**PAGE:** 1 OF 2

**DATE:** 6/9/2016

**BOREHOLE NO.:** B-7

## PROJECT INFORMATION

**PROJECT:** ST VRAIN BREACHES

**PROJECT NO.:** 110666

**CLIENT:** BOULDER COUNTY PARKS AND OPEN SPACE

**OWNER:** BOULDER COUNTY PARKS AND OPEN SPACE

**LOCATION:** BOULDER COUNTY

## BOREHOLE LOCATION

SEE FIGURE 1

## FIELD INFORMATION

**DATE & TIME ARRIVED:** 6/9/2016 8:00 AM

**BOREHOLE LOGGED BY:** NRS

**VISITORS:** N/A

**WEATHER:** SUNNY, 90°s

## DRILLING INFORMATION

**DRILLING COMPANY:** ELITE

**START TIME:** 11:00 AM

**BORING DEPTH:** 20'

**BORING DIA.:** 3 ¼" I.D.

**DRILLING METHOD:** HOLLOW STEM AUGER

**SAMPLING METHOD:** SPT

**TIME DRILLING COMPLETE:** 11:45 AM

## BOREHOLE COMPLETION / ABANDONMENT INFORMATION

**START TIME:** 11:00 AM

**COMPLETE TIME:** 11:45 AM

**INSTRUMENTATION:** N/A

**BACKFILL:** CUTTINGS

**ELEVATION - TOP OF BORING:** APPROX. 5,125'

**NORTHING / WESTING:** 40°11'28.3"N / 105°11'56.8W

## GROUNDWATER CONDITIONS

WATER WAS ENCOUNTERED AT APPROX. 9.5' BGS DURING DRILLING

## FOLLOWING FIELD WORK

**TIME OF CLEAN-UP COMPLETE:** 12:00 PM

**TIME LEFT SITE:** 12:00 PM

## NOTES:

Engineering Analytics, Inc.

# BOREHOLE LOG

**PROJECT:** ST VRAIN BREACHES **PAGE:** 2 OF 2

**PROJECT NO.:** 110666 **DATE:** 6/9/2016

**BOREHOLE NO.:** **B-7**

| DEPTH (FT) | CORE RECOV. | DRIVE SAMPLES |  |  | ADD'L SAMPLES | LITHOLOGY GRAPHIC | SOIL DESCRIPTION |
|---|---|---|---|---|---|---|---|
|  |  | SAMPLE TYPE | BLOWS (PER 6") | RECOV. |  |  |  |
| 0 |  |  |  |  |  | ▨ | **SANDY CLAY WITH GRAVEL (0-APPROX. 4")**<br>MOIST, OLIVE-BROWN (2.5YR 4/4), STIFF SANDY CLAY WITH GRAVEL, WITH ROOTLETS |
| 1 |  | SPT | 11<br>6<br>11<br>16 | 20" | S1a<br>S1b | ▨ | **SAND WITH GRAVEL (APPROX. 4"-APPROX. 8')**<br>SLIGHTLY MOIST, BROWN (10YR 5/3), MEDIUM DENSE WELL GRADED SAND WITH GRAVEL |
| 2 |  |  |  |  |  | ▨ |  |
| 3<br>4 |  | SPT | 5<br>7<br>5<br>5 | 6" | S2 | ▨ |  |
| 5<br>6<br>7 |  |  |  |  |  | ▨ | - **(APPROX. 6')** DRILLER REPORTED AUGER GRINDING, ROUNDED TO SUB-ANGULAR GRAVEL AND COBBLES IN CUTTINGS |
| 8<br>9 |  | SPT | 14<br>28<br>24<br>19 | 17" | S3 | ▨ | **GRAVEL WITH SAND (APPROX. 8'-APPROX. 13')**<br>MOIST TO WET, DARK YELLOWISH BROWN (10YR 4/4), VERY DENSE POORLY GRADED GRAVEL WITH SAND<br>▼ **(APPROX. 9.5')** WATER ENCOUNTERED DURING DRILLING |
| 10<br>11<br>12 |  |  |  |  |  | ▨ | - **(APPROX. 11.5')** DRILLER REPORTED AUGER GRINDING |
| 13 |  | SPT | 50/6" | 6" | S4 | ░ | **SAND WITH CLAY AND GRAVEL (APPROX. 13'-APPROX. 18')**<br>WET, LIGHT BROWNISH GRAY (2.5Y 6/2) TO LIGHT OLIVE BROWN (2.5Y 5/3), VERY DENSE POORLY GRADED SAND WITH CLAY AND GRAVEL |
| 14<br>15<br>16<br>17 |  |  |  |  |  | ░ | - **(APPROX. 16.5')** ROUNDED COBBLES AND GRAVEL IN CUTTINGS |
| 18<br>19 |  | SPT | 20<br>28<br>35<br>21 | 18" | S5 | ▒ | **CLAYEY GRAVEL WITH SAND (APPROX. 18'-E.O.B.)**<br>WET, PALE BROWN (10YR 6/3) TO LIGHT BROWNISH GRAY (10YR 6/3), VERY DENSE CLAYEY GRAVEL WITH SAND, MEDIUM TO COURSE SAND, FINE TO COARSE GRAVEL |
| 20 |  |  |  |  |  |  | E.O.B. = 20' |

Engineering Analytics, Inc.

# BOREHOLE LOG

**PAGE:** 1 OF 2

**DATE:** 6/9/2016

**BOREHOLE NO.:** B-8

## PROJECT INFORMATION

**PROJECT:** ST VRAIN BREACHES

**PROJECT NO.:** 110666

**CLIENT:** BOULDER COUNTY PARKS AND OPEN SPACE

**OWNER:** BOULDER COUNTY PARKS AND OPEN SPACE

**LOCATION:** BOULDER COUNTY

## BOREHOLE LOCATION

SEE FIGURE 1

## FIELD INFORMATION

**DATE & TIME ARRIVED:** 6/9/2016 8:00 AM

**BOREHOLE LOGGED BY:** NRS

**VISITORS:** N/A

**WEATHER:** SUNNY, 90°s

## DRILLING INFORMATION

**DRILLING COMPANY:** ELITE

**START TIME:** 8:30 AM

**BORING DEPTH:** 19'-4" **BORING DIA.:** 3 ¼" I.D.

**DRILLING METHOD:** HOLLOW STEM AUGER

**SAMPLING METHOD:** SPT

**TIME DRILLING COMPLETE:** 9:30 AM

## BOREHOLE COMPLETION / ABANDONMENT INFORMATION

**START TIME:** 8:30 AM **COMPLETE TIME:** 9:30 AM

**INSTRUMENTATION:** N/A **BACKFILL:** CUTTINGS

**ELEVATION - TOP OF BORING:** APPROX. 5,127' **NORTHING / WESTING:** 40°11'30.3"N / 105°11'45.7W

## GROUNDWATER CONDITIONS

WATER WAS ENCOUNTERED AT APPROX. 18' BGS DURING DRILLING

## FOLLOWING FIELD WORK

**TIME OF CLEAN-UP COMPLETE:** 12:00 PM **TIME LEFT SITE:** 12:00 PM

## NOTES:

Engineering Analytics, Inc.

# BOREHOLE LOG

**PROJECT:** ST VRAIN BREACHES
**PAGE:** 2 OF 2
**PROJECT NO.:** 110666
**DATE:** 6/9/2016

**BOREHOLE NO.:** **B-8**

| DEPTH (FT) | CORE RECOV. | DRIVE SAMPLES | | | ADD'L SAMPLES | LITHOLOGY GRAPHIC | SOIL DESCRIPTION |
|---|---|---|---|---|---|---|---|
| | | SAMPLE TYPE | BLOWS (PER 6") | RECOV. | | | |
| 0 | | SPT | 12<br>16<br>14<br>16 | 15" | S1 | | **SAND WITH CLAY AND GRAVEL (0-APPROX. 3')**<br>DRY, BROWN (10YR 5/3), DENSE POORLY GRADED SAND WITH CLAY AND GRAVEL, FINE TO MEDIUM SAND, FINE TO COARSE GRAVEL, ROOTLETS IN UPPER 4" |
| 2 | | | | | | | |
| 3 | | SPT | 25<br>25<br>33<br>40 | 16" | S2 | | **SAND WITH GRAVEL (APPROX. 3'-APPROX. 9')**<br>DRY, GRAY (5YR 6/1) TO LIGHT BROWNISH GRAY (10YR 6/2), VERY DENSE POORLY GRADED SAND WITH GRAVEL, FINE TO MEDIUM SAND, FINE TO COARSE GRAVEL<br>- **(APPROX. 5')** DRILLER REPORTED AUGER GRINDING, POSSIBLE GRAVEL / COBBLES |
| 5 | | | | | | | |
| 8 | | SPT | 17<br>30<br>50/5" | 14" | S3 | | - **(APPROX. 8')** SLIGHTLY MOIST, LIGHT OLIVE BROWN (2.5Y 5/3), VERY DENSE POORLY GRADED SAND, MEDIUM SAND |
| 9 | | | | | BAG 1 | | **GRAVEL WITH SAND (APPROX. 9'-APPROX. 18')**<br>DRY, GRAYISH BROWN (2.5Y 5/2), VERY DENSE POORLY GRADED GRAVEL WITH SAND<br>- **(APPROX. 10'- APPROX. 12')** BAG 1 CUTTINGS |
| 13 | | SPT | 50/5" | 5" | S4 | | |
| | | | | | | | - **(APPROX. 14')** DRY, LIGHT BROWNISH GRAY (2.5Y 6/2), VERY DENSE POORLY GRADED GRAVEL WITH SAND<br>▼ **(APPROX. 18')** WATER ENCOUNTERED DURING DRILLING |
| 18 | | SPT | 20<br>25<br>50/4" | 18" | S5 | | **SAND WITH CLAY AND GRAVEL (APPROX. 18'-E.O.B.)**<br>WET, LIGHT OLIVE BROWN (2.5YR 5/4), VERY DENSE WELL GRADED SAND WITH CLAY AND GRAVEL |
| | | | | | | | E.O.B. = 19'-4" |
| 20 | | | | | | | |

# APPENDIX B
# LABORATORY TEST RESULTS

# SUMMARY OF LABORATORY TEST RESULTS

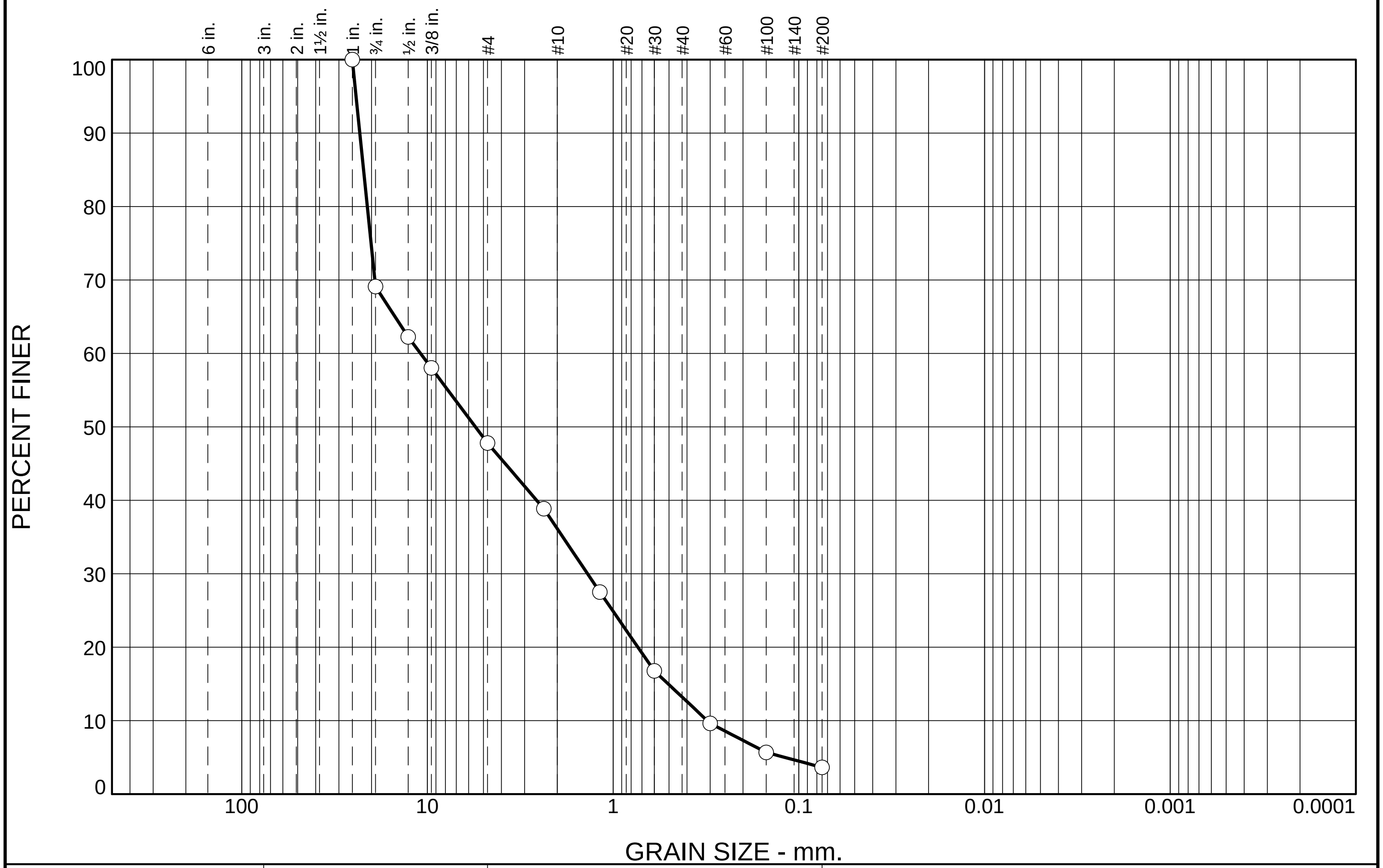
JOB NAME: EA-110666-St. Vrain Breaches JOB NUMBER: 16.037T Date: June-2016

| Depth (ft) | Sample Type | Moisture (%) | Dry Density (pcf) | Atterberg Limits LL / PL / PI * | % Passing 200 Sieve (Wash) | Grain Size Analysis | Hydrometer | Standard Proctor Max γ (pcf) / Opt. w (%) |
|---|---|---|---|---|---|---|---|---|
| **B-1** | | | | | | | | |
| 8-10 | Bag | 8.9 | | | 3.6 | (1) | | |
| **B-2** | | | | | | | | |
| 0-2 | Bag | 12.7 | | | 65.8 | (1) | | |
| **B-2** | | | | | | | | |
| 18-19.25 | Bag | 15.5 | | | 8.5 | (1) | | |
| **B-3** | | | | | | | | |
| 3-5 | Bag | 2.4 | | | 5.3 | (1) | | |
| **B-4** | | | | | | | | |
| 8-10 | Bag | 12.4 | | | 24.8 | (1) | | |
| **B-5** | | | | | | | | |
| 3-5 | Bag | 21.8 | | | 53.5 | (1) | | |
| **B-5** | | | | | | | | |
| 13-14.42 | Bag | 20.1 | | | 7.3 | (1) | | |
| **B-6** | | | | | | | | |
| 0-4 | Bag | 11.8 | | | 70.1 | (1) | | |
| **B-6** | | | | | | | | |
| 18.5-19.5 | Bag | 13.0 | | | 20.2 | (1) | | |
| **B-7** | | | | | | | | |
| 8-10 | Bag | 5.3 | | | 5.6 | (1) | | |
| **B-7** | | | | | | | | |
| 13-13.5 | Bag | 15.1 | | | 8.6 | (1) | | |
| **B-8** | | | | | | | | |
| 18-19.33 | Bag | 13.5 | | | 7.3 | (1) | | |

*LL = Liquid Limit PL = Plastic Limit PI = Plasticity Index N.P. = Non Plastic

(1) See Attached

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 30.9 | 21.3 | 11.7 | 22.9 | 9.6 | 3.6 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1 | 100.0 | | |
| .75 | 69.1 | | |
| .5 | 62.3 | | |
| .375 | 58.0 | | |
| #4 | 47.8 | | |
| #8 | 38.9 | | |
| #16 | 27.5 | | |
| #30 | 16.8 | | |
| #50 | 9.6 | | |
| #100 | 5.7 | | |
| #200 | 3.6 | | |

* (no specification provided)

### Material Description

Poorly graded gravel with sand

### Atterberg Limits

PL= LL= PI=

### Coefficients

| | | |
|---|---|---|
| $D_{90}$= 23.1416 | $D_{85}$= 22.0888 | $D_{60}$= 10.8948 |
| $D_{50}$= 5.5167 | $D_{30}$= 1.3736 | $D_{15}$= 0.5053 |
| $D_{10}$= 0.3111 | $C_u$= 35.02 | $C_c$= 0.56 |

### Classification

USCS= GP AASHTO=

### Remarks

M%= 8.9

**Source of Sample:** B-1 **Depth:** 8'-10'
**Sample Number:** S3

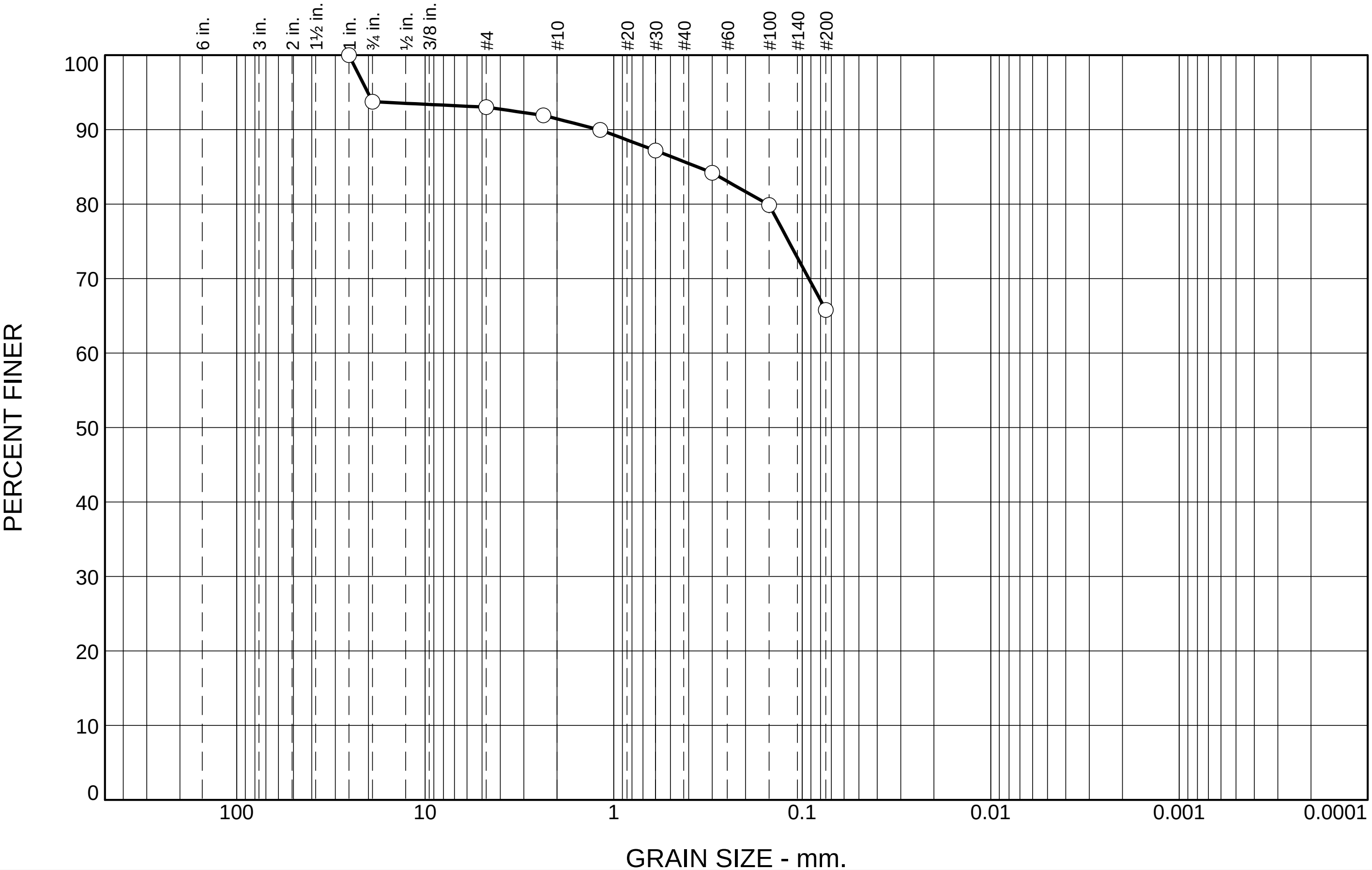
**Date:** 6/21/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 6.2 | 0.8 | 1.5 | 5.8 | 19.9 | 65.8 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1 | 100.0 | | |
| .75 | 93.8 | | |
| #4 | 93.0 | | |
| #8 | 91.9 | | |
| #16 | 90.0 | | |
| #30 | 87.2 | | |
| #50 | 84.2 | | |
| #100 | 79.9 | | |
| #200 | 65.8 | | |

* (no specification provided)

**Material Description**

Sandy clay

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{90}$= 1.1963 $D_{85}$= 0.3602 $D_{60}$=
$D_{50}$= $D_{30}$= $D_{15}$=
$D_{10}$= $C_u$= $C_c$=

**Classification**

USCS= CL AASHTO=

**Remarks**

M%= 12.7

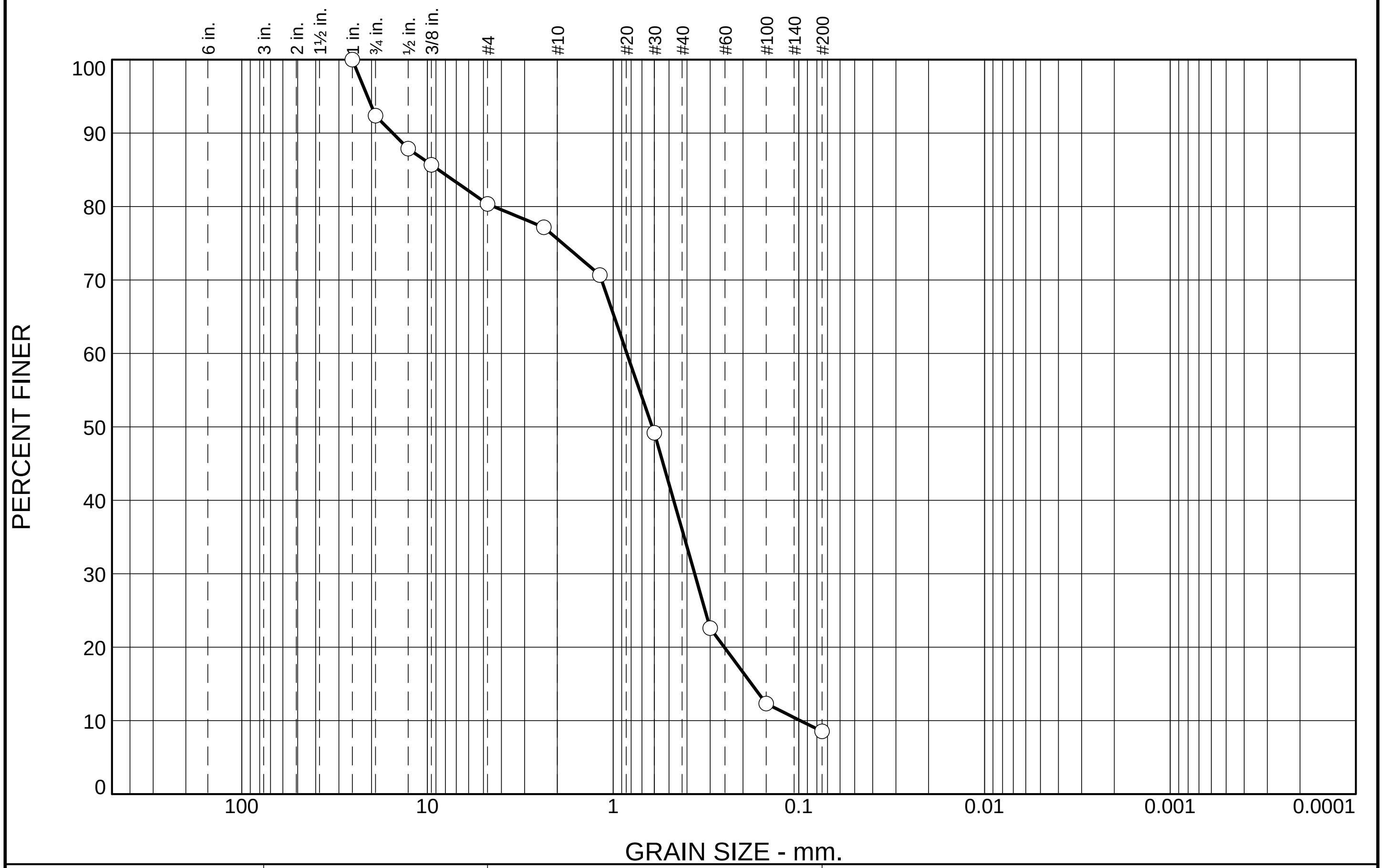
**Source of Sample:** B-2 **Depth:** 0'-2'
**Sample Number:** S1 **Date:** 6/21/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 7.6 | 12.0 | 4.8 | 39.6 | 27.5 | 8.5 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1 | 100.0 | | |
| .75 | 92.4 | | |
| .5 | 87.9 | | |
| .375 | 85.7 | | |
| #4 | 80.4 | | |
| #8 | 77.2 | | |
| #16 | 70.7 | | |
| #30 | 49.2 | | |
| #50 | 22.6 | | |
| #100 | 12.3 | | |
| #200 | 8.5 | | |

* (no specification provided)

**Material Description**

Well graded sand with clay and gravel

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{90}$= 15.3720 $D_{85}$= 8.7162 $D_{60}$= 0.8431
$D_{50}$= 0.6154 $D_{30}$= 0.3638 $D_{15}$= 0.1797
$D_{10}$= 0.0980 $C_u$= 8.60 $C_c$= 1.60

**Classification**

USCS= SW-SC AASHTO=

**Remarks**

M%= 15.5

**Source of Sample:** B-2 **Depth:** 18'-19.25'
**Sample Number:** S5

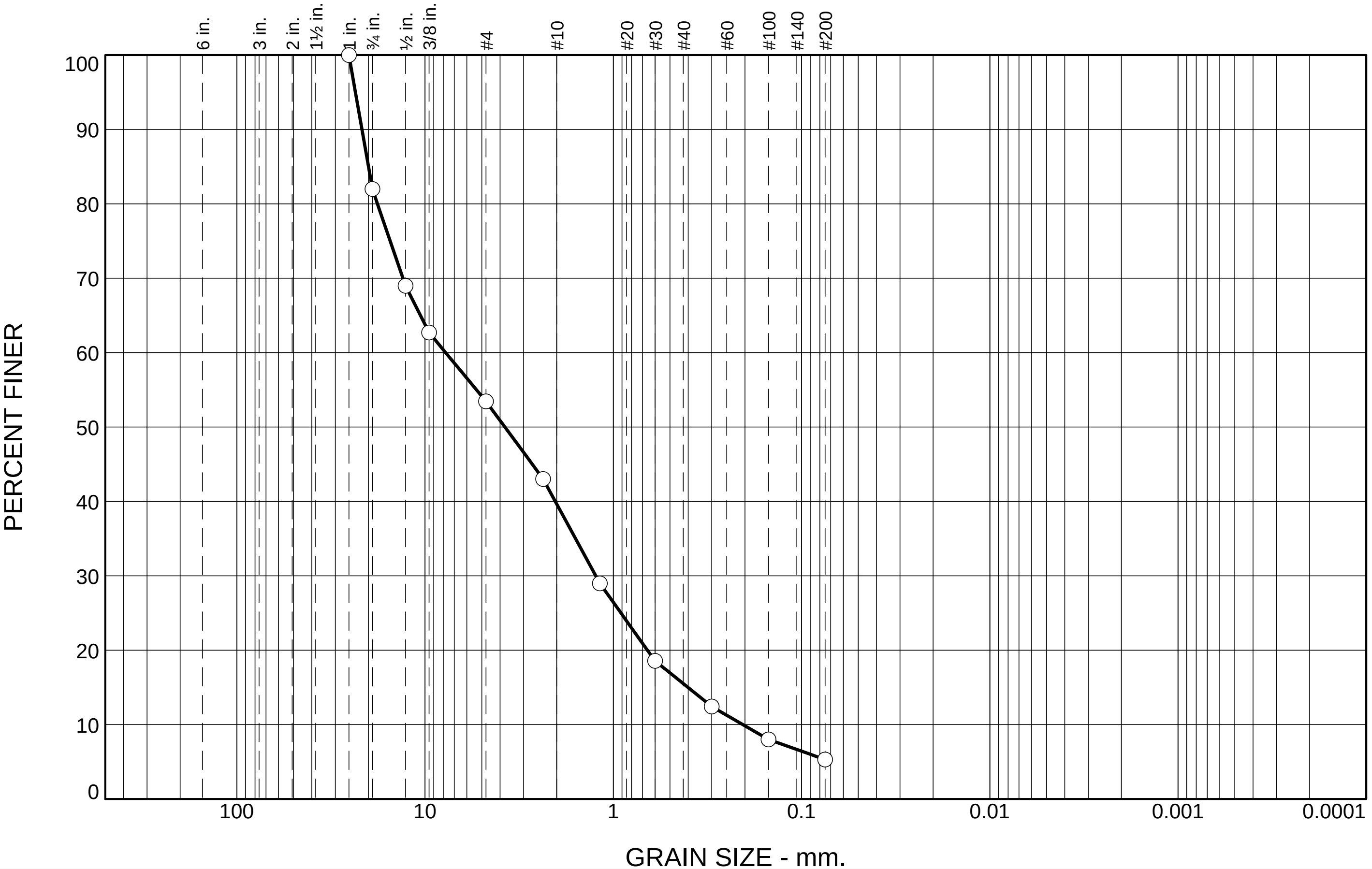
**Date:** 6/21/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 18.0 | 28.5 | 13.8 | 24.2 | 10.2 | 5.3 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1 | 100.0 | | |
| .75 | 82.0 | | |
| .5 | 69.0 | | |
| .375 | 62.7 | | |
| #4 | 53.5 | | |
| #8 | 43.0 | | |
| #16 | 29.0 | | |
| #30 | 18.6 | | |
| #50 | 12.4 | | |
| #100 | 8.0 | | |
| #200 | 5.3 | | |

* (no specification provided)

## Material Description

Poorly graded sand with gravel

## Atterberg Limits

PL= LL= PI=

## Coefficients

$D_{90}$= 21.6497 $D_{85}$= 19.9876 $D_{60}$= 7.7679
$D_{50}$= 3.7674 $D_{30}$= 1.2405 $D_{15}$= 0.4012
$D_{10}$= 0.2050 $C_u$= 37.88 $C_c$= 0.97

## Classification

USCS= SP AASHTO=

## Remarks

M%= 2.4

**Source of Sample:** B-3 **Depth:** 3'-5'
**Sample Number:** S2

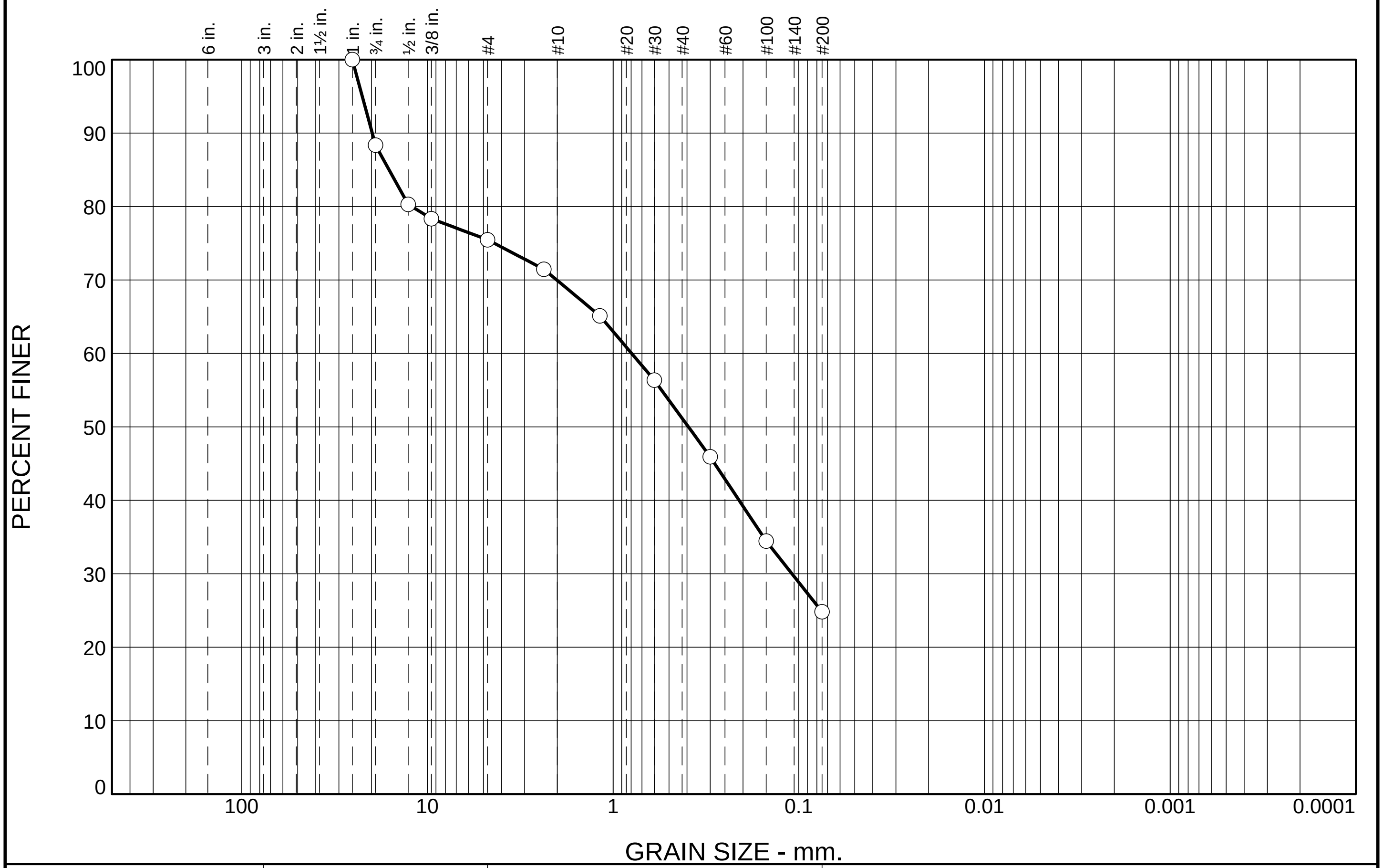
**Date:** 6/21/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel |  | % Sand |  |  | % Fines |  |
|---|---|---|---|---|---|---|---|
|  | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 11.6 | 12.9 | 5.5 | 18.8 | 26.4 | 24.8 |  |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1 | 100.0 |  |  |
| .75 | 88.4 |  |  |
| .5 | 80.3 |  |  |
| .375 | 78.3 |  |  |
| #4 | 75.5 |  |  |
| #8 | 71.5 |  |  |
| #16 | 65.1 |  |  |
| #30 | 56.4 |  |  |
| #50 | 45.9 |  |  |
| #100 | 34.5 |  |  |
| #200 | 24.8 |  |  |

* (no specification provided)

### Material Description

Silty sand with gravel

### Atterberg Limits

PL= LL= PI=

### Coefficients

$D_{90}$= 19.8323 $D_{85}$= 16.0790 $D_{60}$= 0.7947
$D_{50}$= 0.3933 $D_{30}$= 0.1089 $D_{15}$=
$D_{10}$= $C_u$= $C_c$=

### Classification

USCS= SM AASHTO=

### Remarks

M%= 12.4

**Source of Sample:** B-4 **Depth:** 8'-10'
**Sample Number:** S3

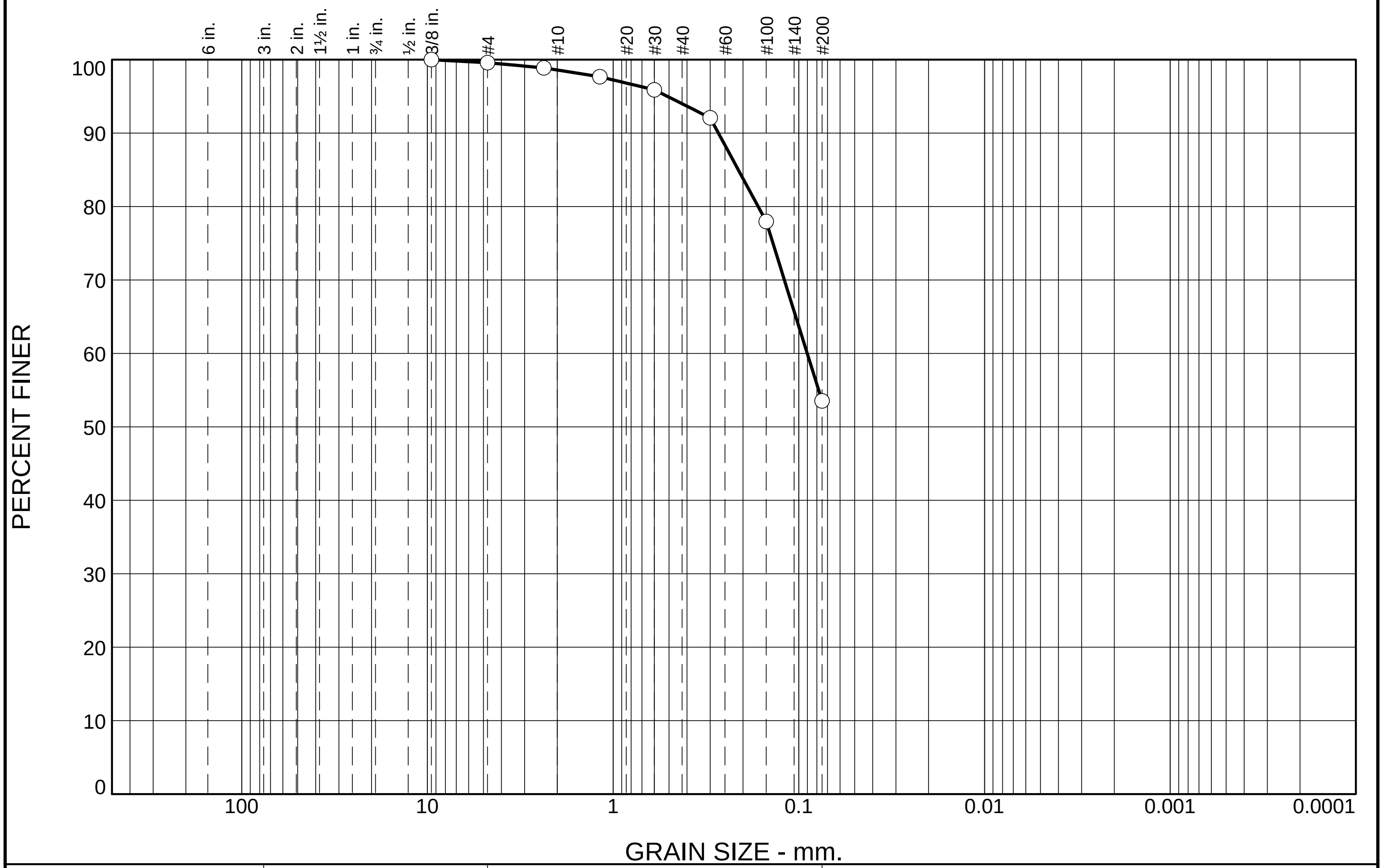
**Date:** 6/21/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel |  | % Sand |  |  | % Fines |  |
|---|---|---|---|---|---|---|---|
|  | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 0.0 | 0.4 | 1.0 | 4.6 | 40.5 | 53.5 |  |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| .375 | 100.0 |  |  |
| #4 | 99.6 |  |  |
| #8 | 98.9 |  |  |
| #16 | 97.7 |  |  |
| #30 | 95.9 |  |  |
| #50 | 92.1 |  |  |
| #100 | 78.0 |  |  |
| #200 | 53.5 |  |  |

* (no specification provided)

### Material Description

Sandy clay

### Atterberg Limits

PL= LL= PI=

### Coefficients

$D_{90}$= 0.2708 $D_{85}$= 0.2118 $D_{60}$= 0.0901
$D_{50}$= $D_{30}$= $D_{15}$=
$D_{10}$= $C_u$= $C_c$=

### Classification

USCS= CL AASHTO=

### Remarks

M%= 21.8

**Source of Sample:** B-5 **Depth:** 3'-5'
**Sample Number:** S2

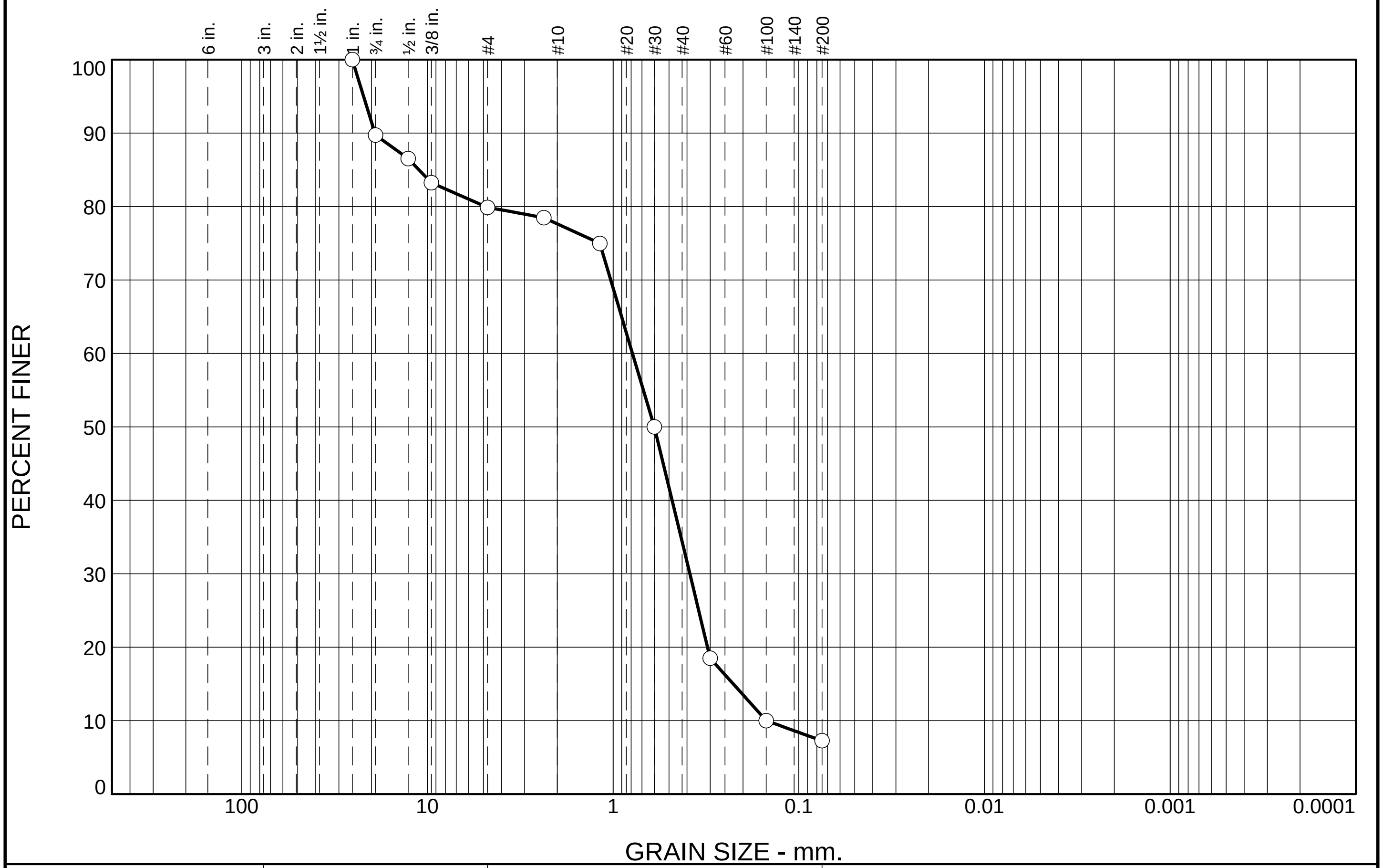
**Date:** 6/21/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 10.3 | 9.8 | 2.2 | 43.4 | 27.0 | 7.3 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1 | 100.0 | | |
| .75 | 89.7 | | |
| .5 | 86.5 | | |
| .375 | 83.2 | | |
| #4 | 79.9 | | |
| #8 | 78.5 | | |
| #16 | 75.0 | | |
| #30 | 50.0 | | |
| #50 | 18.5 | | |
| #100 | 10.0 | | |
| #200 | 7.3 | | |

* (no specification provided)

## Material Description

Poorly graded sand with clay and gravel

## Atterberg Limits

PL= LL= PI=

## Coefficients

$D_{90}$= 19.1893 $D_{85}$= 11.1109 $D_{60}$= 0.7865
$D_{50}$= 0.6000 $D_{30}$= 0.3864 $D_{15}$= 0.2254
$D_{10}$= 0.1498 $C_u$= 5.25 $C_c$= 1.27

## Classification

USCS= SP-SC AASHTO=

## Remarks

M%= 20.1

**Source of Sample:** B-5 **Depth:** 13'-14.42
**Sample Number:** S4

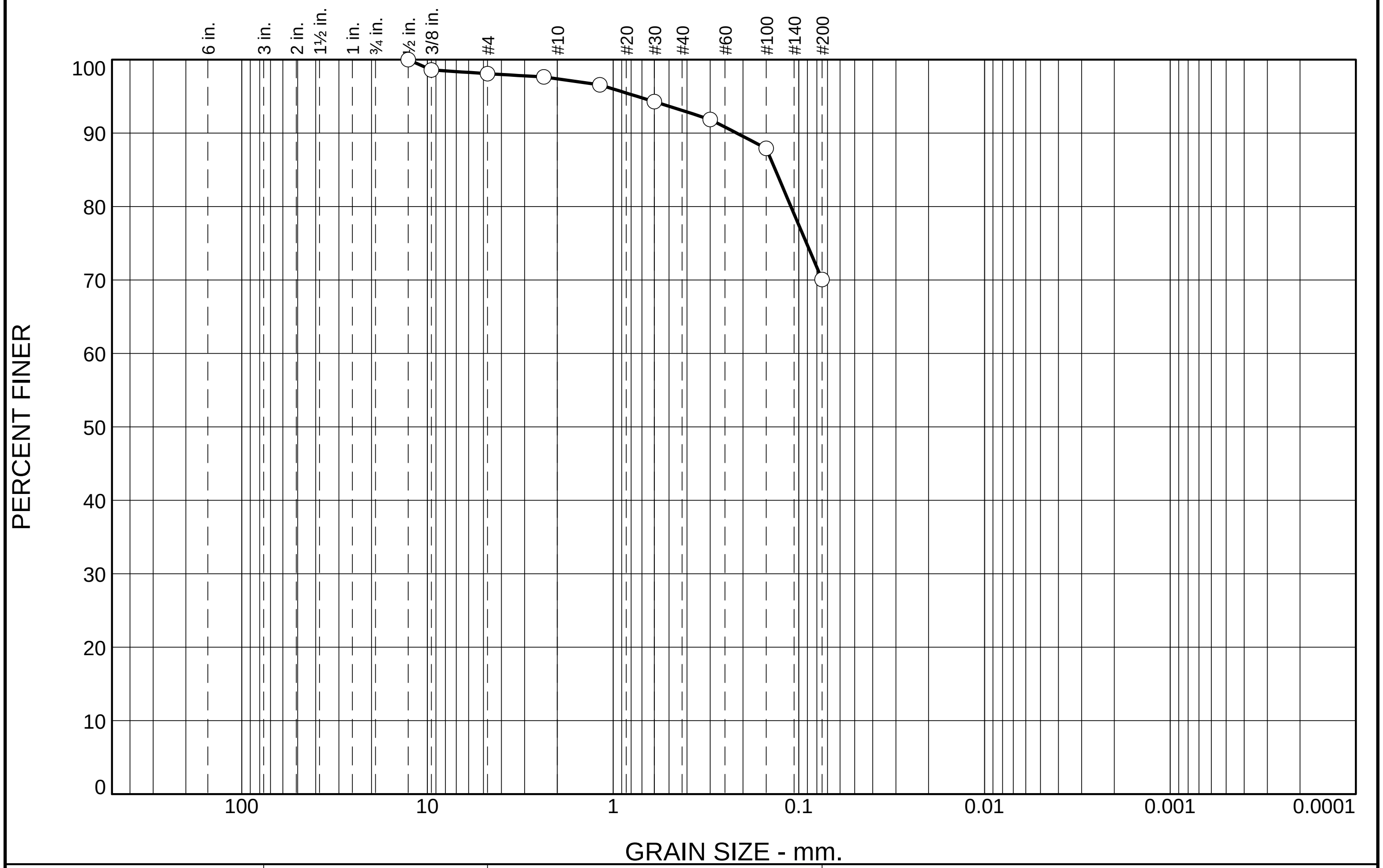
**Date:** 6/21/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 0.0 | 1.9 | 0.7 | 4.3 | 23.0 | 70.1 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| .5 | 100.0 | | |
| .375 | 98.6 | | |
| #4 | 98.1 | | |
| #8 | 97.6 | | |
| #16 | 96.6 | | |
| #30 | 94.3 | | |
| #50 | 91.9 | | |
| #100 | 87.9 | | |
| #200 | 70.1 | | |

* (no specification provided)

## Material Description

Sandy clay

### Atterberg Limits

PL= LL= PI=

### Coefficients

$D_{90}$= 0.2160 $D_{85}$= 0.1339 $D_{60}$=
$D_{50}$= $D_{30}$= $D_{15}$=
$D_{10}$= $C_u$= $C_c$=

### Classification

USCS= CL AASHTO=

### Remarks

M%= 11.8

**Source of Sample:** B-6 **Depth:** 0'-4"
**Sample Number:** S1a

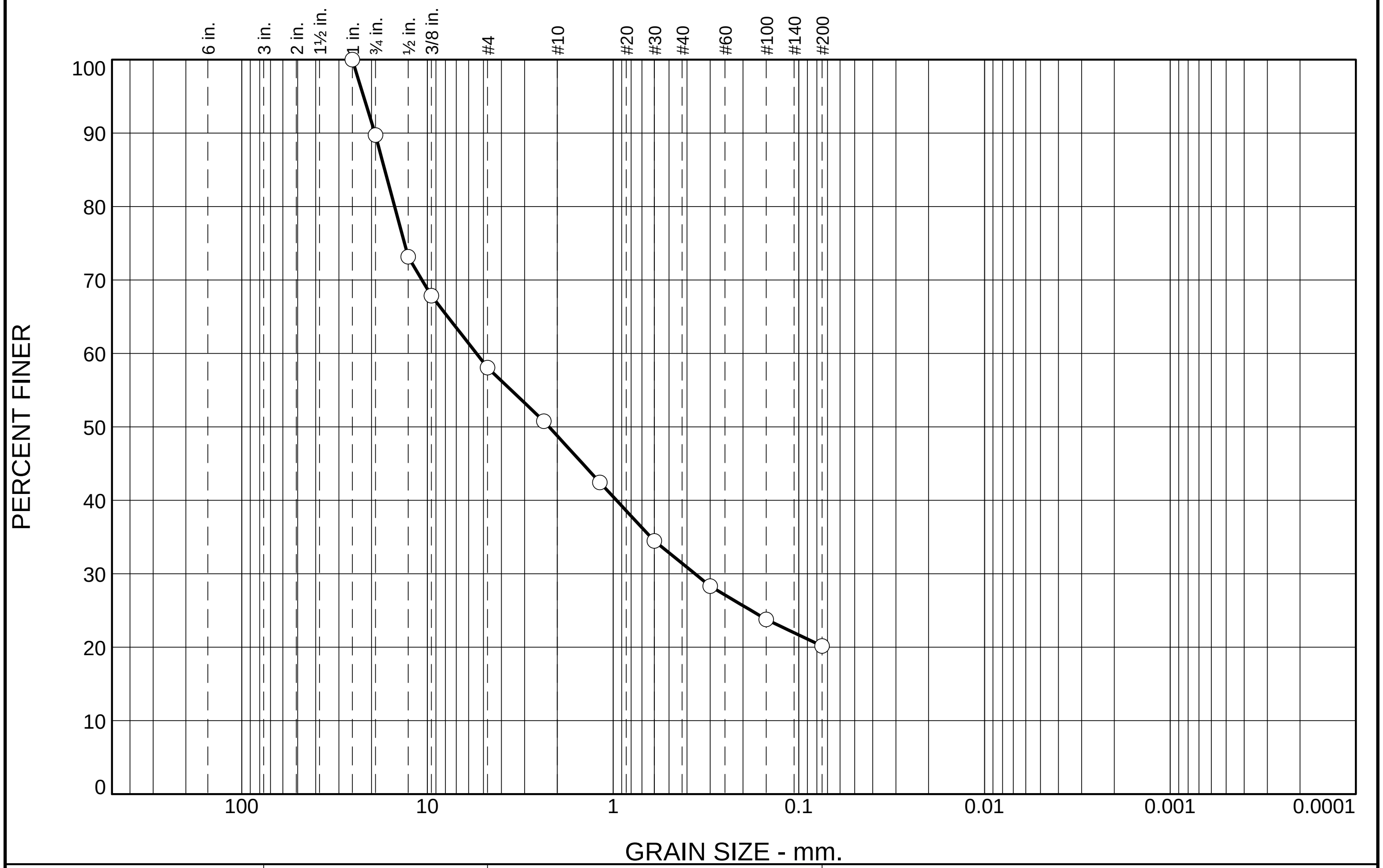
**Date:** 6/21/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 10.3 | 31.6 | 9.3 | 17.4 | 11.2 | 20.2 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1 | 100.0 | | |
| .75 | 89.7 | | |
| .5 | 73.2 | | |
| .375 | 67.9 | | |
| #4 | 58.1 | | |
| #8 | 50.8 | | |
| #16 | 42.4 | | |
| #30 | 34.5 | | |
| #50 | 28.3 | | |
| #100 | 23.8 | | |
| #200 | 20.2 | | |

* (no specification provided)

### Material Description

Clayey gravel with sand

### Atterberg Limits

PL= LL= PI=

### Coefficients

$D_{90}$= 19.1927 $D_{85}$= 16.9667 $D_{60}$= 5.4470
$D_{50}$= 2.2115 $D_{30}$= 0.3626 $D_{15}$=
$D_{10}$= $C_u$= $C_c$=

### Classification

USCS= GC AASHTO=

### Remarks

M%= 13.0

**Source of Sample:** B-6 **Depth:** 18.5'-19.5'
**Sample Number:** S5b

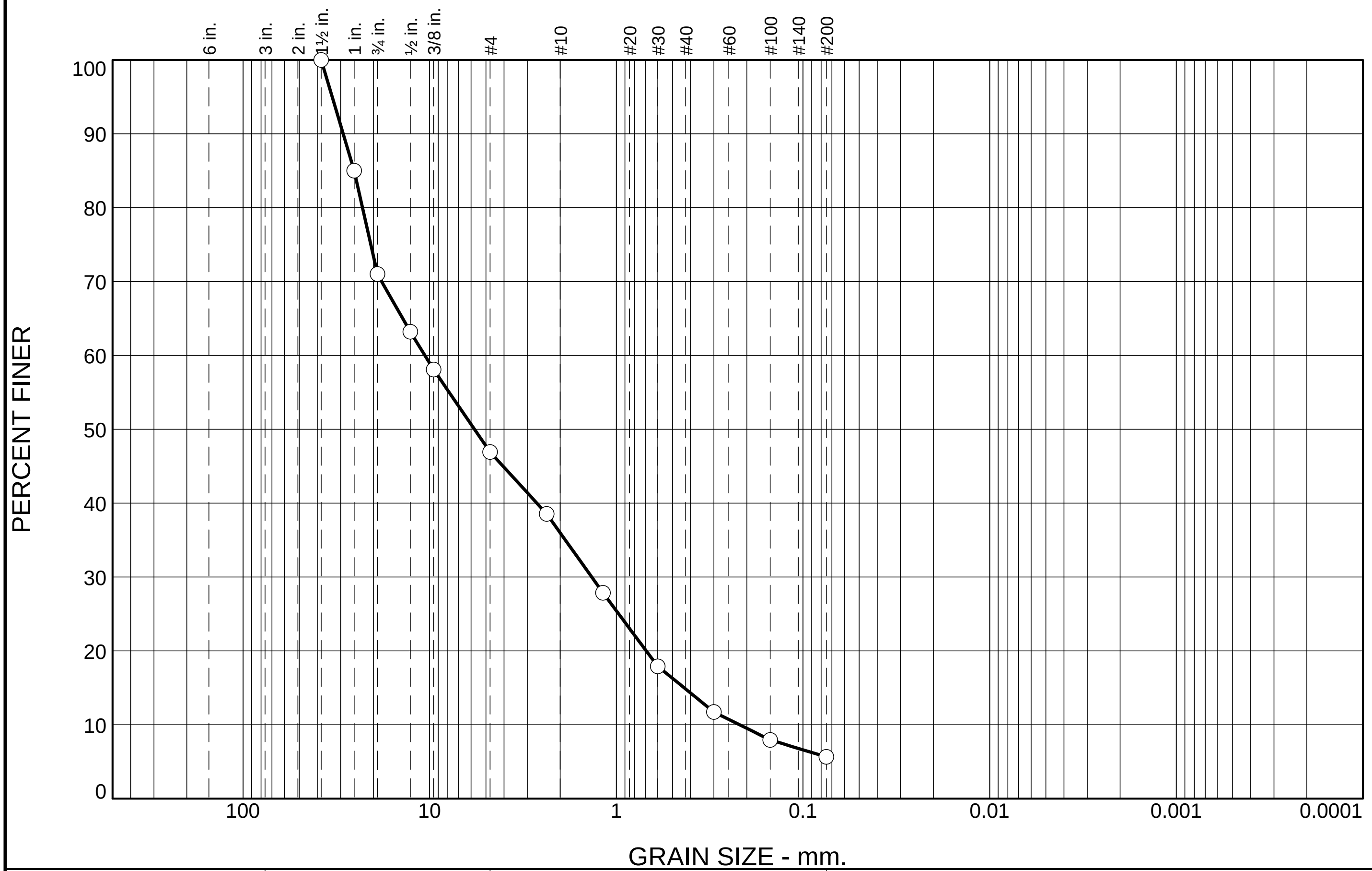
**Date:** 6/21/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel |  | % Sand |  |  | % Fines |  |
|---|---|---|---|---|---|---|---|
|  | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 29.0 | 24.1 | 10.9 | 21.2 | 9.2 | 5.6 |  |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1.5 | 100.0 |  |  |
| 1 | 85.0 |  |  |
| .75 | 71.0 |  |  |
| .5 | 63.2 |  |  |
| .375 | 58.1 |  |  |
| #4 | 46.9 |  |  |
| #8 | 38.5 |  |  |
| #16 | 27.9 |  |  |
| #30 | 17.9 |  |  |
| #50 | 11.7 |  |  |
| #100 | 7.9 |  |  |
| #200 | 5.6 |  |  |

* (no specification provided)

**Material Description**

Poorly graded gravel with sand

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{90}$= 29.0638 $D_{85}$= 25.3881 $D_{60}$= 10.6080
$D_{50}$= 5.7550 $D_{30}$= 1.3552 $D_{15}$= 0.4332
$D_{10}$= 0.2187 $C_u$= 48.51 $C_c$= 0.79

**Classification**

USCS= GP AASHTO=

**Remarks**

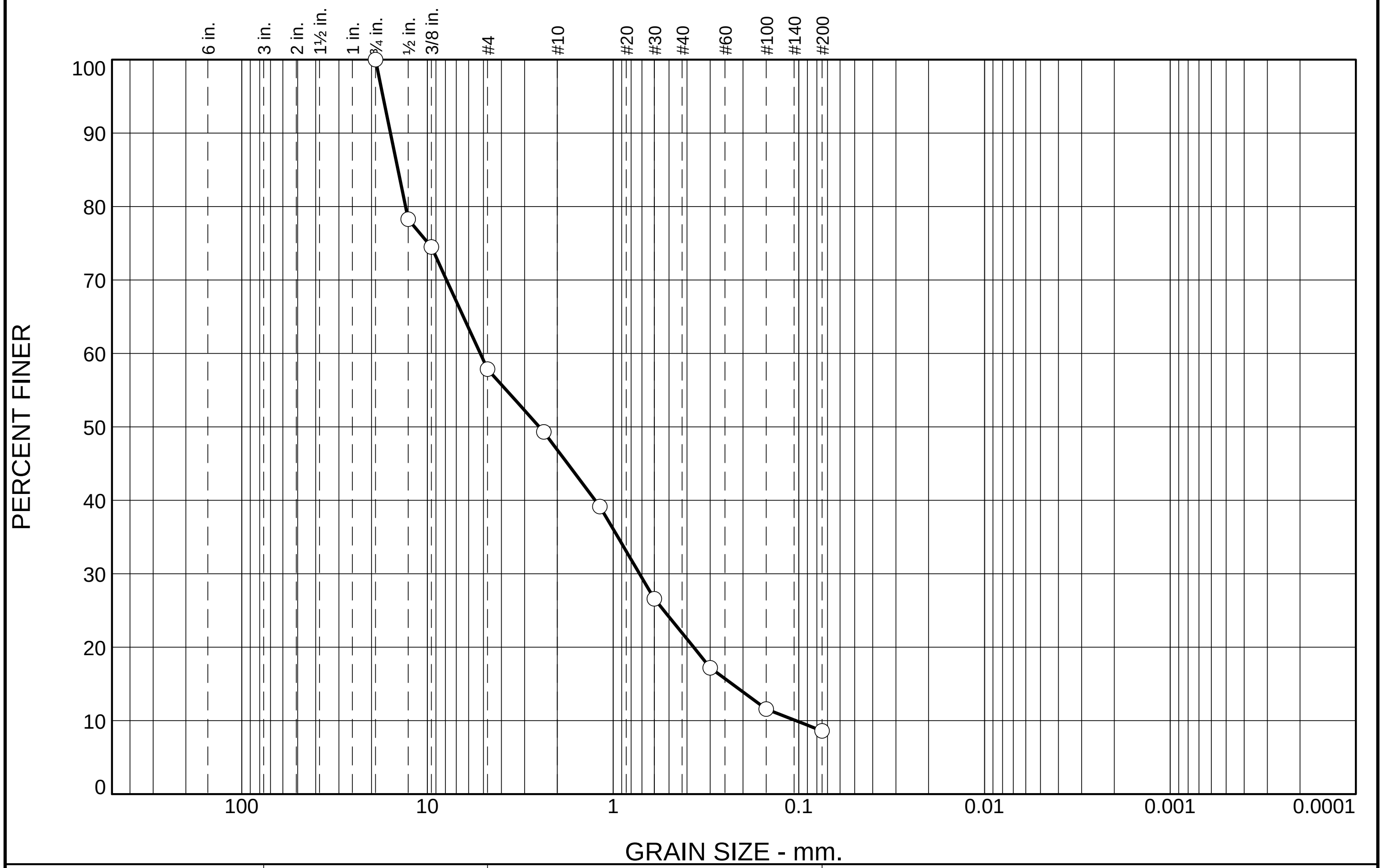
M%= 5.3

**Source of Sample:** B-7 **Depth:** 8'-10'
**Sample Number:** S3 **Date:** 6/21/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches
**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 0.0 | 42.1 | 11.0 | 25.0 | 13.3 | 8.6 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 0.75 | 100.0 | | |
| .5 | 78.3 | | |
| .375 | 74.5 | | |
| #4 | 57.9 | | |
| #8 | 49.3 | | |
| #16 | 39.1 | | |
| #30 | 26.6 | | |
| #50 | 17.2 | | |
| #100 | 11.6 | | |
| #200 | 8.6 | | |

* (no specification provided)

**Material Description**

Poorly graded sand with clay and gravel

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{90}$= 15.8063 $D_{85}$= 14.3979 $D_{60}$= 5.1948
$D_{50}$= 2.4963 $D_{30}$= 0.7206 $D_{15}$= 0.2287
$D_{10}$= 0.1037 $C_u$= 50.10 $C_c$= 0.96

**Classification**

USCS= SP-SC AASHTO=

**Remarks**

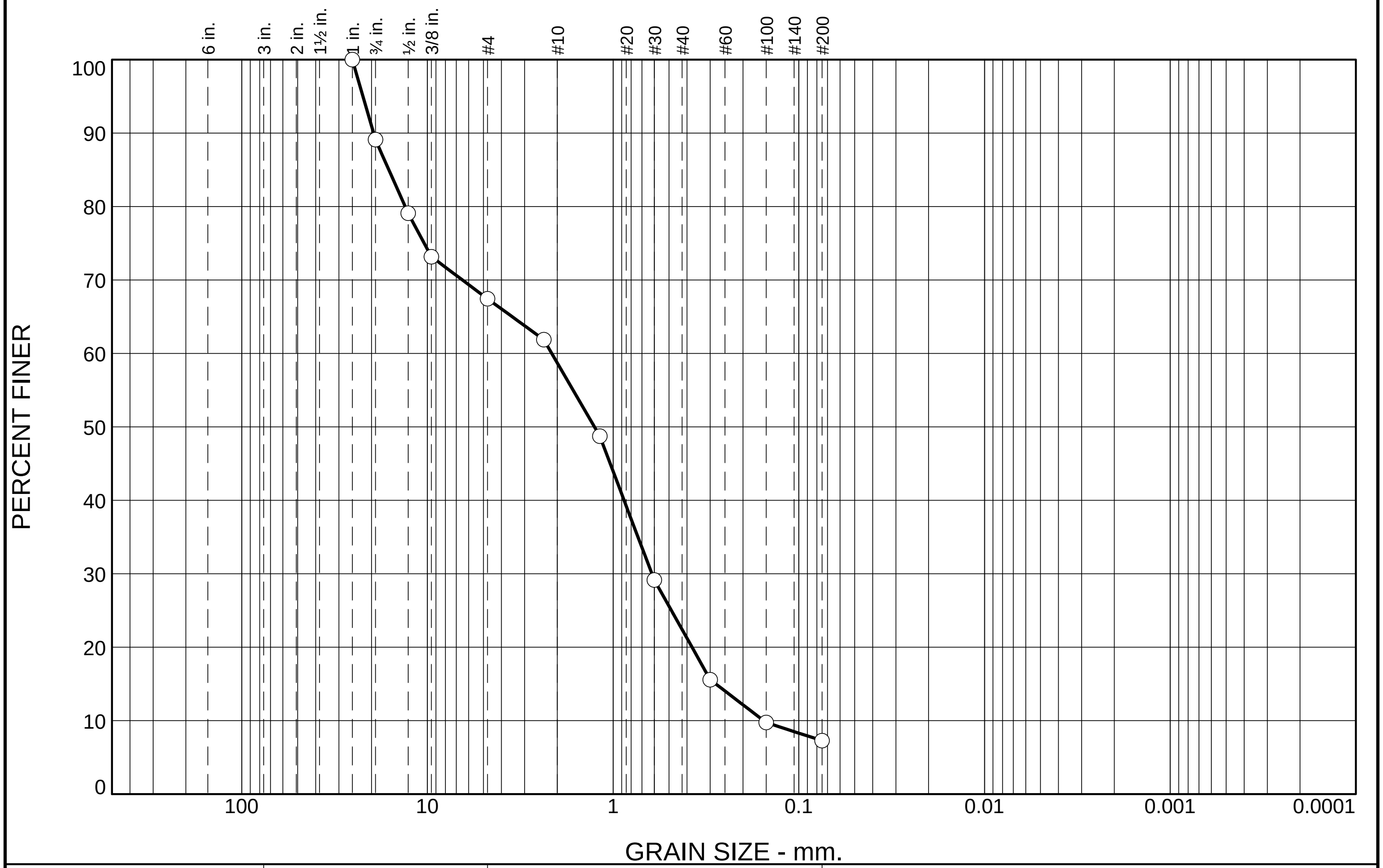
M%= 15.1

**Source of Sample:** B-7 **Depth:** 13'-13.5'
**Sample Number:** S4 **Date:** 6/21/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches
**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 10.9 | 21.7 | 8.7 | 36.3 | 15.1 | 7.3 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1 | 100.0 | | |
| .75 | 89.1 | | |
| .5 | 79.1 | | |
| .375 | 73.2 | | |
| #4 | 67.4 | | |
| #8 | 61.9 | | |
| #16 | 48.7 | | |
| #30 | 29.1 | | |
| #50 | 15.6 | | |
| #100 | 9.7 | | |
| #200 | 7.3 | | |

* (no specification provided)

## Material Description

Well graded sand with clay and gravel

## Atterberg Limits

PL= LL= PI=

## Coefficients

$D_{90}$= 19.5055 $D_{85}$= 16.1328 $D_{60}$= 2.1385

$D_{50}$= 1.2617 $D_{30}$= 0.6180 $D_{15}$= 0.2801

$D_{10}$= 0.1546 $C_u$= 13.83 $C_c$= 1.16

## Classification

USCS= SW-SC AASHTO=

## Remarks

M%= 13.5

**Source of Sample:** B-8 **Depth:** 18'-19.333

**Sample Number:** S5

**Date:** 6/21/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.

**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# APPENDIX II

# LIDSTONE GEOMORPHIC ASSESSMENT

WENCK File #COEA104
July 2016
Revised: September 2016

# Geomorphic Assessment St. Vrain Breaches Restoration Project

*Prepared for:*

**Engineering Analytics, Inc.**

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Suite 209
Fort Collins, CO 80525

Lidstone and Associates - A Wenck Company

*Prepared by:*

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Fort Collins, CO 80525
Phone: 970-223-4705
Fax: 970-223-4706

# Table of Contents

## TABLES

## FIGURES

## APPENDICES

# 1.0 Background

## 1.1 OVERALL ST. VRAIN WATERSHED

The St. Vrain Creek Watershed covers approximately 546 square miles located in Roosevelt National Forest, extending east towards the town of Longmont and eventually to the South Platte River **(Figure 1)**. In total, approximately 54 miles of creek are formed from the confluence of the South St. Vrain Creek, Middle St. Vrain Creek, North St. Vrain Creek, and into the main stem of St. Vrain Creek (Baker, 2014). Historically, the St. Vrain Watershed has been known for its natural and ecological resources, as well as its recreational opportunities throughout the Colorado Front Range.

In September 2013, over 17 inches of rain was recorded in north-central Colorado over a 6-day time period. This precipitation resulted in flash flooding through the canyons west of the Town of Lyons and exited where the tributaries converge at the main stem of the St. Vrain Creek. At its peak, approximately 18,000 cfs rushed through the St. Vrain Creek and made its way to I-25, equivalent to a 130-year storm event. In locations along the North and South St. Vrain Creeks, flood levels reached over the 500-year flow event, forcing the evacuation of hundreds of property owners (Baker, 2014).

The results of the flood were catastrophic, and resulted in damage to large sections of State and Federal Highways, local roads, as well as public and private properties throughout the entire St. Vrain corridor. A large quantity of highly-mobile sediment was deposited in the creek during the recessional limb of the hydrograph. Short-term recovery solutions were implemented, including temporary levee creation with riprap revetment, bank stabilization and excavation of notches or overflow channels to relieve in-channel stress. While these temporary solutions have been adequate immediately after the flood, permanent solutions will be needed to reduce the risk of future flood damage, increase the long-term watershed resilience, and promote geomorphic stability. There have been numerous restoration projects throughout the corridor since 2013, extending from the Town of Lyons to the east side of the Town of Longmont. Various projects, such as the South St. Vrain Creek (SSVC) Hall Meadow Project, is currently underway at the time of publication of this report. The draft report for the Hall Meadow Project was reviewed and analyzed to gather any relevant information for any future permanent repairs.

Boulder County Parks and Open Space (BCPOS), along with stakeholders along the St. Vrain Watershed, are interested in replacing the temporary measures with more permanent solutions in a 3.5 mile reach which includes the main stem of the St. Vrain Creek from US Highway 36 to Hygiene Road. In support of this effort and as part of the St. Vrain Breaches Restoration Project, Lidstone & Associates - a Wenck Company (LA) was contracted by Engineering Analytics, Inc. (EA) to perform a geomorphic assessment of the project area. A draft of this report was completed and delivered on July 1, 2016, prior to any discussions regarding 30% design alternatives. Included in **Appendix A** are the LA responses to BCPOS comments on the draft report. In order to fully analyze the planform characteristics through Hygiene Road, the project reach was extended to 75th Street. For purposes of this report, the Project Reach will refer to the St. Vrain Creek from Highway 36 to 75th Street.

## 1.2 FIELDWORK

On May 9, 2016, the Project Team completed an initial site walkthrough with BCPOS. During this walkthrough, various locations of bank erosion and instability, and aggradational and degradational reaches were noted. After the walkthrough, LA began the fieldwork portion of the geomorphic assessment. This section provides a detailed description of that fieldwork, which includes documentation of the geomorphic conditions observed during the site investigation. **Appendix B** contains field notes, sampling forms and maps from the investigation.

Beginning May 9, 2016, LA conducted an analysis at eight locations throughout the project area. Each site was geomorphically assessed to identify planform, channel and bank stability, vertical change and to characterize bed and bank sediment. Additionally, various restoration constraints including property ownership, bridges, ditches, and the railroad were identified and photographed.

Bed and bank samples were collected on May 16, 2016 at each site, ensuring that at least one sample was taken near each breach location **(Figure 2)**. Bed material samples were collected using an open-ended barrel sampler, which effectively diverts the flow, allowing the sampler to remove the upper surface layer of cobbles and gravels and collect both fine and coarse sediment in a statistically appropriate fashion at a depth below this upper layer. The samples were delivered to Smith Geotechnical to complete a grain-size analysis on each sample. Gradation information for each sample was obtained to correlate hydraulic characteristics and provide an understanding of the geomorphic behavior of the St. Vrain Creek. Select grab bank samples were also obtained and analyzed.

Where appropriate and when the river flows and access allowed, Wolman pebble counts were conducted. The Wolman Count is a field method that provides a textural analysis of the coarse sediment layer on a river bar or bed. In total, Wolman Counts were obtained at five gravel bar and bed locations throughout the Project Reach.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Lidstone and Associates, Inc.

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Lidstone and Associates - A Wenck Company

# ST. VRAIN BREACHES RESTORATION

## Figure 1
Site Vicinity Map

Z:\project\COEA101\GIS\COEA101 SITE BASE MAP.mxd

## Legend

▲ Sediment Samples & Geomorphic Features *(Refer to Site Field Forms)*

● Photo Points

⬢ Site Locations *(Refer to Site Field Forms)*

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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# ST. VRAIN BREACHES RESTORATION

## Figure 2
## Field Sampling Map

N

0 0.25 0.5 1 Miles

Z:\project\COEA101\GIS\COEA101 FIELD SEDIMENT SAMPLING MAP.mxd

# 2.0 Geomorphic Assessment

The St. Vrain Creek in this reach is a fairly straight, slightly meandering gravel-bed pool-riffle channel in a wide valley bottom. A vegetated riparian corridor is interrupted by floodplain ponds (a result of historical gravel mining operations), road crossings, and development (Baker, 2014).

## 2.1 FIELD OBSERVATIONS

EA determined centerline stationing to be utilized during the field investigation to ensure all members of the project team had a consistent means of describing features noted in the field. Field maps showing this stationing, breach and lake locations and relevant notes, are located in **Appendix B**. The project reach was subdivided into four geomorphic sub-reaches in order to characterize the field observations, data, planform and profile evaluations. The project team has prepared challenges and opportunities for each sub-reach. These will be evaluated further as the project progresses to the 30% Design phase. These sub-reaches are shown on **Figure 3**.

### Sub-Reach 1 (Highway 36 to 51st Street)

Sub-Reach 1 is the upstream most portion of the project reach and includes Breach 1. In this sub-reach, emergency repairs were made and there is a leveed section with riprap revetment on the right bank.

**Challenges**: Upstream and downstream of the bank revetment, local bank scour and overall channel degradation has occurred. Bank erosion was observed upstream of Breach 1, on the left bank on the City of Longmont’s property. Mid-channel bars have formed throughout this sub-reach presumably in response to deposition during the recessional limb of the flood. Lateral migration resulted in channel widening and bank erosion. From station 180+00 to 174+00, the channel appears to be in equilibrium with no apparent active erosion or degradation/aggradation. Downstream of this section however, significant bank erosion on the left bank was again observed. The bank in this area is steep and undercut and immediately adjacent to the railroad tracks. Throughout this sub-reach the majority of the channel is exposed with little to no vegetative cover or shading.

**Opportunities**: There are numerous opportunities to utilize on-site large woody debris to assist with bank stabilization and create habitat complexity. Channel narrowing will improve sediment conveyance through this reach and can be accomplished with intermittent construction of stream barbs and vanes. Woody materials can be used to enhance habitat and create slackwater areas on a local basis. Additionally, the large floodplain on the right bank could be utilized to increase the connectivity between the channel and overbanks. To address this, channel narrowing and bank sloping will be required. Lowering, removing, or relocating the temporary berm placed immediately after the 2013 flood should also be considered in an effort to promote connectivity with the floodplain in this sub-reach.

### Sub-Reach 2 (51st Street to 61st Street)

Sub-Reach 2 is downstream of Sub-Reach 1 and includes Breaches 2 and 3 as well as the South Branch Diversion and the Longmont Supply Ditch. During the 2013 flood, flows reportedly followed the South Branch and flowed in a southeasterly direction ultimately into

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Lidstone and Associates, Inc.

WENCK

*Lidstone and Associates - A Wenck Company*

# ST. VRAIN BREACHES RESTORATION

Figure 3
Planform Comparison

N

0 0.275 0.55 1.1
Miles

Z:\project\COEA101\GIS\COEA101 SINUOSITY AND CL ANALYSIS MAP.mxd the aggregate pits in the floodplain. The South Branch currently appears fairly stable and is well vegetated.

It was also reported that the channel plugged with sediment and debris between Breach 2 and the Longmont Supply Diversion structure. This blockage may have caused the formation of Breach 2, allowing flood flows to enter an abandoned aggregate pit known as Lake 2. While the aggradation upstream of the diversion structure is expected, there is no profile data to support a major break in slope. Flows ultimately returned to the main channel through shallow overland flow at Breach 3. Breach 2 was repaired and a temporary riprap inflow structure was built following the flood. The Breach 3 area is well vegetated and in this area, flood waters reportedly flowed overland in a fairly stable manner. No significant erosion was noted.

The field data suggest that Sub-Reach 2 is undergoing degradation, minus the area directly upstream of the Longmont Supply Ditch Diversion Structure. The material that was deposited during the flood suggests that degradation will continue to occur during the near term until large enough flows mobilize the current bed material, allowing an armor layer to form.

**Challenges**: Numerous areas of channel degradation were observed in this sub-reach, especially between Stations 137+00 and 123+00. The bed has noticeably dropped below the shale bedrock layer in this section.

The Longmont Supply Ditch Diversion Structure may have influenced the formation of a sediment plug which likely impacted the formation of Breach 2. In addition, bank erosion was observed on both sides of the channel upstream of the Diversion Structure. The left bank is steep and undercut and very close to the railroad. The sediment data that were collected suggests the material that was left post-flood is highly mobile, which makes sense as the finer material would be deposited during the recessional limb of the hydrograph.

A low water crossing is located in the area of Breach 3 and provides access to Martin Marietta’s property. Boulder County maintains this section and removes debris from this crossing.

**Opportunities**: The spillway structure constructed on the right bank near Breach 2 is located at a reasonably acceptable access point and the riprap contained therein can be used in the construction of a future connection structure. The geometry of this structure, invert elevation and entrance conditions will require additional work. Large woody debris and habitat features can be developed on the river and pit-side of the structure. Lowering of the invert and creating more of a swale feature in this location could serve to allow activation of the right bank floodplain and possibly utilize Lake 2 as a wetland and backwater feature.

Other opportunities in this sub-reach include connecting the channel to Lake 2, possibly in the location of Breach 3 and the low water crossing. Similar connections to Lake 4 downstream could also be considered. Any opportunities for backwater connection to the remnant aggregate pits would create additional wetland habitat while providing storage of flood flows in a large event.

In-stream structures such as cross vanes to provide grade control and j-hooks, barbs or hard revetment to provide bank stabilization should be considered. J-hooks, barbs, and other bank protection structures could also serve to provide locations for excess sediment to settle out. Sediment storage and connectivity are important considerations in this reach.

### Sub-Reach 3 (61st Street to Hygiene Road)

Sub-Reach 3 begins just below the 61st Street Bridge in the vicinity of Breach 4. This area was significantly impacted by the flood and the County has expended considerable efforts on emergency and post-flood permanent repairs. This sub-reach also encompasses Breaches 5 through 9.

**Challenges**: Below the 61st Street Bridge, the channel was completely disrupted by the 2013 flood. Significant debris and sediment were deposited in this reach. The channel has widened considerably and is braided with multiple threads and mid channel bars. A significant portion of the depositional section of this sub-reach is on private property. Upstream of Hygiene Road, the channel can either be left in its current location (through the Hepp #1 Lake on James Hepp's property) or placed back into its original, straighter alignment. Under current conditions the channel currently changes direction very abruptly immediately upstream of the bridge. Evaluation of flood flows and local hydraulics coming out of the Hepp #1 Lake and flood conveyance through Hygiene Road Bridge can serve as decision making tools.

**Opportunities**: On Boulder County's property, additional in channel work could be completed to stabilize the confluence of the 36 inch CMP culvert drainage where it enters the main stem of the channel. In the vicinity of Breach 5, there are opportunities to create backwater habitat areas. The braided system and significant channel meander belt width allow opportunities for sediment storage and additional slackwater development.

### Sub-Reach 4 (Hygiene Road to 75th)

This sub-reach was added to evaluate sinuosity changes downstream of Hygiene Road. As Hygiene Road is the downstream limit of the St. Vrain Breaches Restoration Project, the area between Hygiene Road and 75th Street was not evaluated in the field in detail. This sub-reach is included in the planform and profile analyses to determine if there were any abrupt planform or profile changes downstream of Hygiene Road that could impact Sub-Reach 3.

## 2.2 PLANFORM COMPARISONS

This section presents an analysis of channel planform changes over time between the Highway 36 and 75th Street bridges. Sinuosity changes between 1976 and 2015 are presented on **Figure 3** and discussed in detail in the following paragraphs and figures. Sinuosity is the ratio of channel length to straight line valley length between crossings (Thorne, 1998). A completely straight channel will have a sinuosity of 1.0. Typically, sinuosity is an important factor in defining how a channel evolves over time. In some cases the past can serve as a footprint for the future. Meander Belt Width is the average width of the channel changes over time or is effectively the area of the valley characterized by recent channel changes. Such a concept is important in geomorphic thought since it allows one to address predictions of near term stability. Actions and development that takes place within the Meander Belt Width are clearly subject to modifications by the channel through either accretionary or avulsive processes.

In the case of St. Vrain Creek, final restoration design must balance environmental considerations with hydrology, channel hydraulics and sediment transport to support a stable geomorphic planform. Although the historic development and changes in planform are important, final design to ensure a geomorphically stable channel must address current and future variables.

As part of the St. Vrain Creek Watershed Master Plan, the sinuosities of the South St. Vrain, Middle St. Vrain, North St. Vrain, and St. Vrain Creeks were analyzed by Anderson Consulting Engineers, Inc. (Anderson). While the Master Plan addressed the entire watershed, Anderson did provide Reach-based Plan Form characteristics for the St. Vrain Creek in the vicinity of the project area. As part of their analysis, they determined the average sinuosity between Highway 36 and the 75th Street bridges to be approximately 1.08 - 1.10. To further investigate the planform trends for our project area, LA's analysis subdivided the project reach (Hwy 36 to 75th Street) further into the four sub-reaches shown on **Figure 3**. LA obtained and georeferenced historic and post flood aerial imagery to determine changes in sinuosity over the past 40 years. The results of this analysis can be found in **Table 2.2a**.

**Table 2.2a: Summary of Planform Characteristics from Highway 36 to 75th Street**

| Sub-Reach | Sinuosity | | | | | | | | Trends | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1976 | 1983 | 2000 | 2006 | 2011 | 2013 | 2014 | 2015 | Pre-Flood | Post-Flood |
| 1 | 1.038 | 1.043 | 1.048 | 1.051 | 1.049 | 1.052 | 1.070 | 1.088 | Increasing | Increasing |
| 2 | 1.108 | 1.123 | 1.137 | 1.136 | 1.128 | 1.150 | 1.143 | 1.165 | Fairly Static | Increasing |
| 3 | 1.030 | 1.074 | 1.101 | 1.050 | 1.066 | 1.108 | 1.135 | 1.215 | Generally Increasing (Decrease Between 2000 - 2013) | Increasing |
| 4 | 1.057 | 1.069 | 1.099 | 1.060 | 1.086 | 1.075 | 1.091 | 1.086 | Fairly Static | Fairly Static |

Between 1976 and 2013, the average sinuosity of the St. Vrain Creek increased from approximately 1.06 to 1.10. During this time, St. Vrain Creek flowed freely through the Project Area in a semi-regular, fairly straight meander pattern. As noted in the St. Vrain Master Plan, St. Vrain Creek maintained a prominently stable planform from 1949 through the 2013 flood (Baker, 2014). After the flood in September 2013, the average channel sinuosity increased to 1.14 in 2015. The sub-reach with the highest post-flood sinuosity is Sub-Reach 3 which is between 61st Street and Hygiene Road. While the channel escaped its banks in numerous places during the 2013 flood, the only sub-reach where it remains in a different alignment is Sub-Reach 3. In this sub-reach, the creek captured an old aggregate pit (Hepp #1) and remains in this alignment currently. The old channel alignment was straighter, while the new alignment through the pit creates additional channel length and sinuosity. Significantly, Sub-reaches 1-3 are all exhibiting a post-flood increase in sinuosity trend. This is a reflection of a channel seeking to achieve a new geomorphic condition in a dynamic environment.

A Channel Migration Zone is the average width of the meandering channel as it changes over time. LA analyzed the meandering patterns of the St. Vrain Creek using the planform comparison presented in **Figure 3**. The average channel migration zone of the project area from 1976 to 2015 was able to be determined by calculating channel migration over the record of available historic aerial imagery (**Table 2.2b)**. This nearly 40-year analysis provides insight into predicting future channel characteristics, allowing channel stability issues to be addressed in a long-term manner.

**Table 2.2b: Channel Migration Zone**

| Sub-Reach | Channel Migration Zone (ft) |
|---|---|
| 1 | 261 |
| 2 | 344 |
| 3 | 702 |
| 4 | 313 |

## 2.3 PROFILE/SLOPE ANALYSIS

According to the 2014 Geomorphic Study completed by Anderson as part of the St. Vrain Master Plan (Baker, 2014), Anderson estimated the average bed slope of the project area to be approximately 0.70% prior to the September 2013 flood. Immediately post-flood, bed slope for the project area remained nearly the same: 0.69%

LA utilized pre and post-flood LiDAR imagery to verify the post-flood changes in bed slope within the project reach. **Figures 4 and 5** present the pre and post-flood streambed profiles for St. Vrain Creek. Within the overall project reach the average pre-flood bed slope was approximately 0.70%. Post-flood bed slope was 0.72%. **Table 2.3** shows the pre-flood and post-flood bed slopes of each sub-reach.

**Table 2.3 Channel Profile**

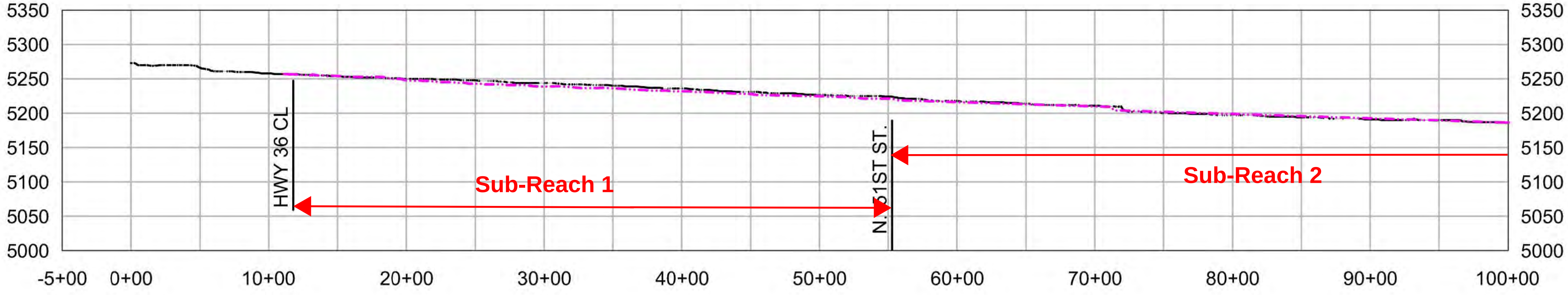
| Sub-Reach | Channel Bed Slope | |
|---|---|---|
| | Pre-Flood | Post-Flood (LiDAR) |
| 1 | 0.83% | 0.79% |
| 2 | 0.79% | 0.84% |
| 3 | 0.65% | 0.56% |
| 4 | 0.52% | 0.69% |
| Average | 0.70% | 0.72% |

## 2.4 BRIDGE INSPECTION REPORTS

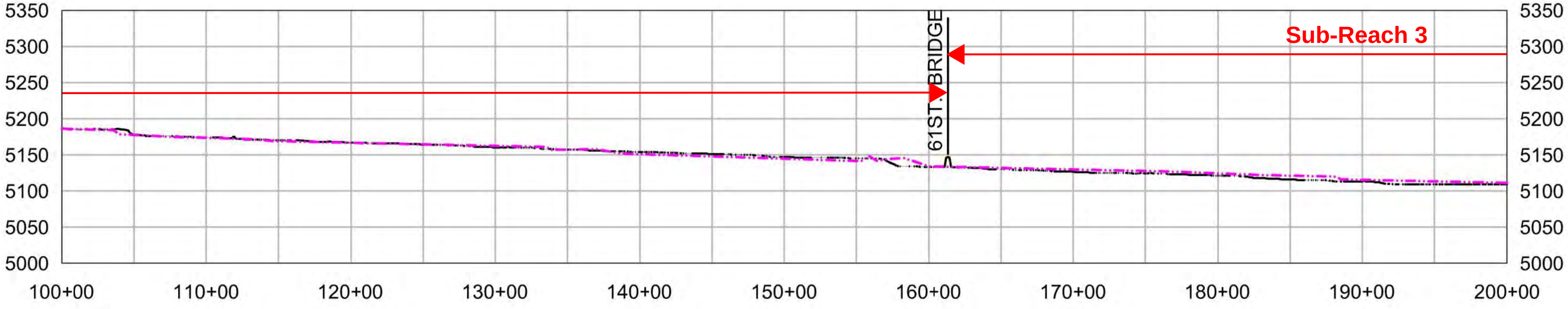
In an effort to evaluate historic bed changes throughout the project reach, inspection reports for the three main bridge crossings were obtained and analyzed: 61st Street, Hygiene Road, and 75th Street. Historical bridge inspection reports dating from 1988 to 2015 were obtained from Boulder County to observe vertical changes at specific locations measured from the low chord elevation of the bridge to the invert of the channel. Bridge inspection reports are included as **Appendix C**. LA also requested bridge inspection reports for the Highway 36 Bridge from CDOT; however, we were unable to acquire useful data on that structure. Based on the information obtained from Boulder County, the aggradational and degradational erosional processes at the three remaining bridges varied annually until the September 2013 flood. During this flood, the channel invert dropped 1.6 feet at the 61st

Street Bridge, just downstream of the Oligarchy Ditch diversion structure. This change was also observed at the 75th Street Bridge, which showed a similar channel invert lowering of approximately 1.5 feet. The Hygiene Road Bridge crossing was not affected as significantly, with only 0.5 feet of lowering of the channel at this location. However, there was lateral migration of the channel in this location. **Tables 2.4a, b and c** and **Figures 5, 6 and 7** present a summary of the bridge inspection data analysis.

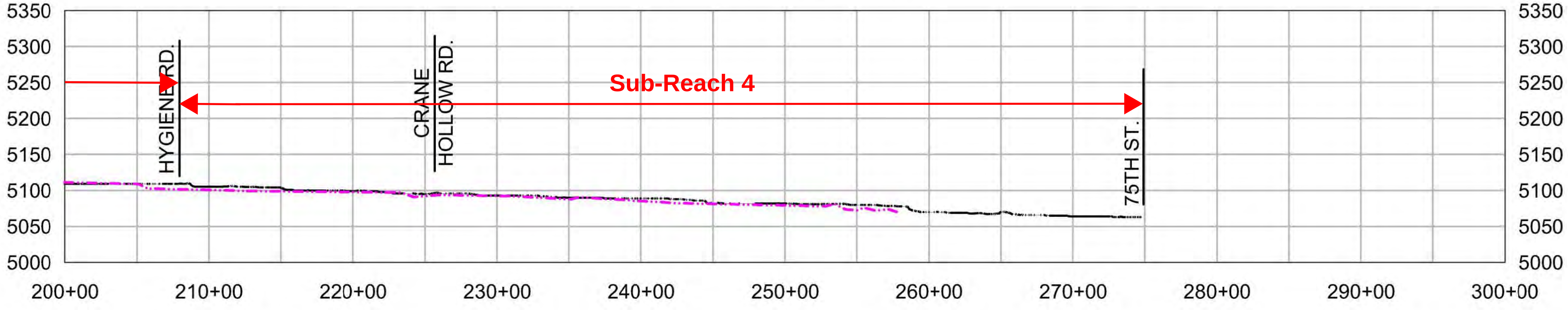
## ST VRAIN CREEK PROFILE
HORIZ. SCALE: 1" = 250'
VERT. SCALE: 1" = 50'



## ST VRAIN CREEK PROFILE
HORIZ. SCALE: 1" = 250'
VERT. SCALE: 1" = 50'



## ST VRAIN CREEK PROFILE
HORIZ. SCALE: 1" = 250'
VERT. SCALE: 1" = 50'



LEGEND

— · · — · · —
ST. VRAIN CREEK
PRE FLOOD

———
ST. VRAIN CREEK
POST FLOOD

GENERAL NOTES

PRE-FLOOD PROFILE BASED ON 2011 LIDAR INFORMATION FROM ENGINEERING ANALYTICS

POST FLOOD PROFILE BASED ON 2013 LIDAR INFORMATION FROM ENGINEERING ANALYTICS

WENCK
Lidstone and Associates, Inc.
Lidstone and Associates - A Wenck Company

St. Vrain Breaches Restoration

PROJECT NUMBER: COEA101
ENGINEER:
CHECKED:
DATE: 6/30/16
APPROVED:
ACAD FILE: COEA101-SAINT VRAIN CREEK W LIDAR.DWG

PROJECT AREA
PRE AND POST FLOOD PROFILES

REVISIONS:
FIGURE
4

Z:\project\COEA101\ACAD\COEA101-Saint Vrain Creek w LiDAR.dwg, POST FLOOD PROFILES, 6/30/2016 2:31:42 PM, frojh0737, ANSI B (11.00 x 17.00 Inches)

### Table 2.4a: Analysis of Bridge Inspection Reports - 61st Street Bridge

| Year | Distance to Top of Left Bank (ft) | Distance to Left Bank Toe (ft) | Depth to Thalweg (ft) | Distance to Right Bank Toe (ft) | Distance to Top of Right Bank (ft) | Change in Channel Invert Elevation (at Thalweg) (ft) | Erosional Description |
|---|---|---|---|---|---|---|---|
| 1991 | 3.0 | 7.3 | 8.5 | 7.3 | 3.0 | -- | -- |
| 1992 | 3.8 | 8.4 | 9.1 | 7.5 | 3.3 | -0.6 | Degradation |
| 1994 | 4.5 | 8.5 | 9.1 | 7.9 | 3.9 | 0.0 | -- |
| 1996 | 3.8 | 8.4 | 9.1 | 7.5 | 3.3 | 0.0 | -- |
| 1998 | 3.8 | 7.9 | 8.2 | 9.2 | 4.5 | 0.9 | Aggradation* |
| 2002 | 5.1 | 9.3 | 9.6 | 7.9 | 6.0 | -1.4 | Degradation |
| 2011 | 5.6 | 9.5 | 9.6 | 9.5 | 3.6 | 0.0 | -- |
| 2013 (Pre-Flood) | 4.0 | 9.1 | 10.0 | 8.7 | 3.0 | -0.4 | Degradation |
| 2015 | 4.0 | 11.2 | 11.6 | 11.1 | 3.8 | -1.6 | Degradation |

**Note: Approximately 2 feet of degradation on the right bank indicating some channel migration*

### Figure 5. 61st Street Bridge

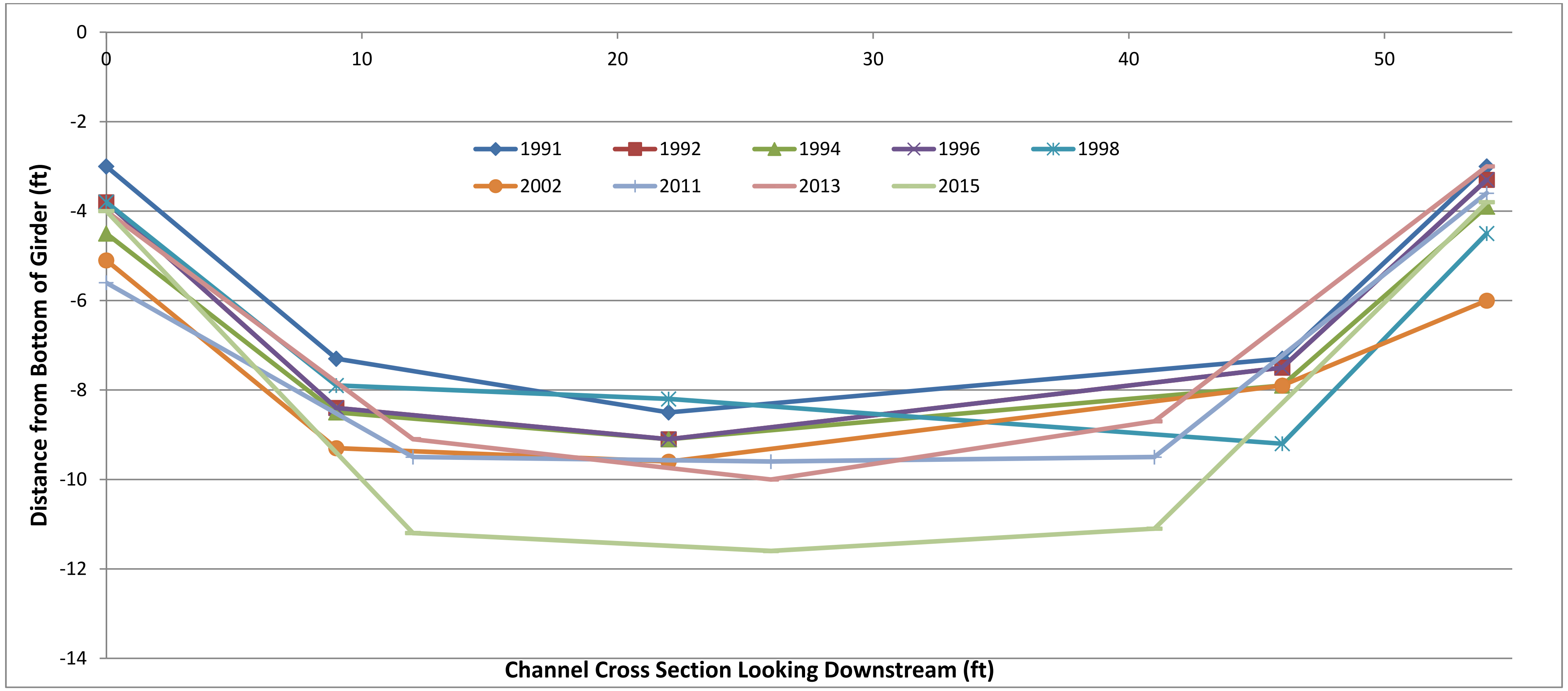
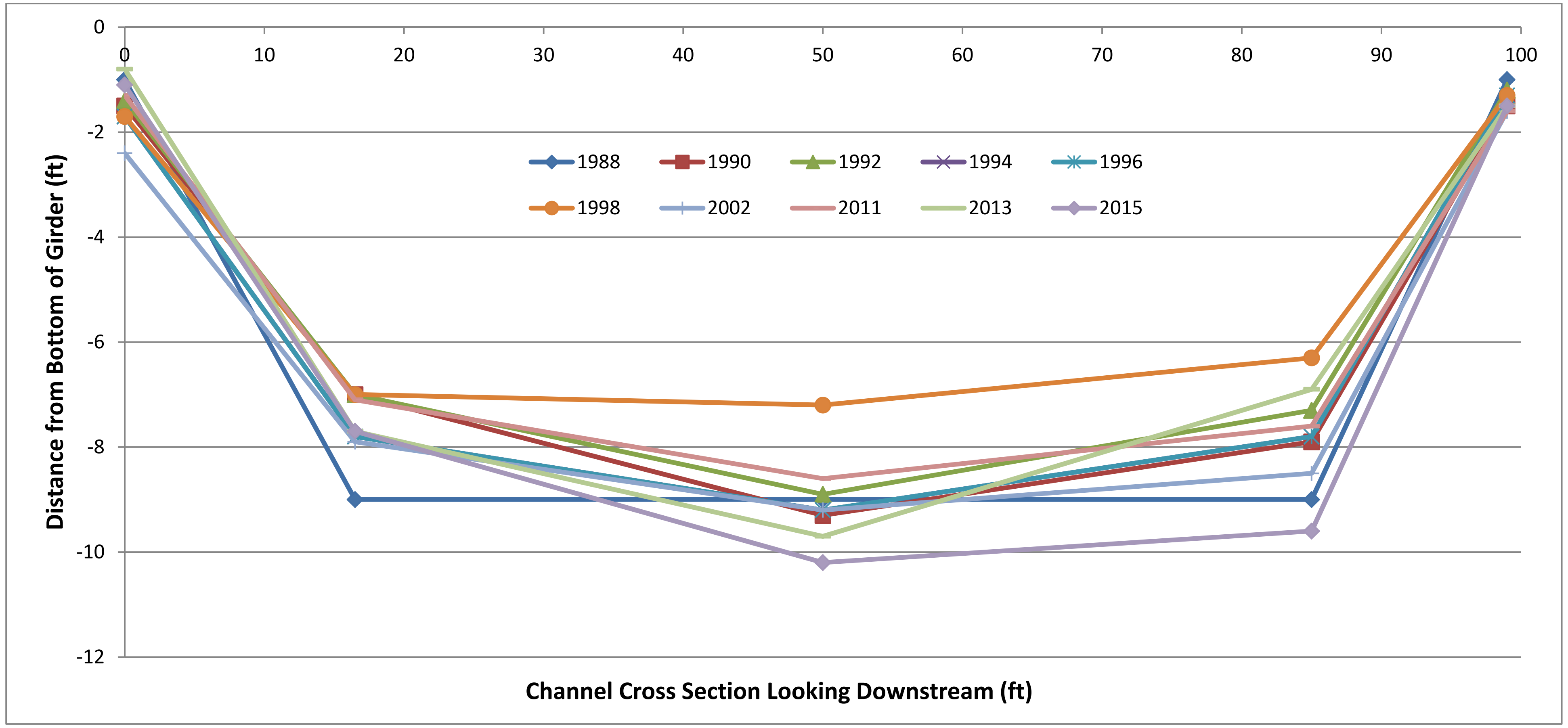


**Table 2.4b: Analysis of Bridge Inspection Reports - Hygiene Road Bridge**

| Year | Distance to Top of Left Bank (ft) | Distance to Left Bank Toe (ft) | Depth to Thalweg (ft) | Distance to Right Bank Toe (ft) | Distance to Top of Right Bank (ft) | Change in Channel Invert Elevation (at Thalweg) (ft) | Erosional Description |
|---|---|---|---|---|---|---|---|
| 1988 | 1.0 | 9.0 | 9.0 | 9.0 | 1.0 | -- | -- |
| 1990 | 1.5 | 7.0 | 9.3 | 7.9 | 1.5 | -0.3 | Degradation |
| 1992 | 1.4 | 7.0 | 8.9 | 7.3 | 1.2 | 0.4 | Aggradation |
| 1994 | 1.7 | 7.8 | 9.2 | 7.8 | 1.3 | -0.3 | Degradation |
| 1996 | 1.7 | 7.8 | 9.2 | 7.8 | 1.3 | 0.0 | -- |
| 1998 | 1.7 | 7.0 | 7.2 | 6.3 | 1.3 | 2.0 | Aggradation |
| 2002 | 2.4 | 7.9 | 9.2 | 8.5 | 1.6 | -2.0 | Degradation |
| 2011 | 1.3 | 7.1 | 8.6 | 7.6 | 1.6 | 0.6 | Aggradation |
| 2013 (Pre-Flood) | 0.8 | 7.7 | 9.7 | 6.9 | 1.5 | -1.1 | Degradation |
| 2015 | 1.1 | 7.7 | 10.2 | 9.6 | 1.5 | -0.5 | Degradation |

**Figure 6. Hygiene Road Bridge**

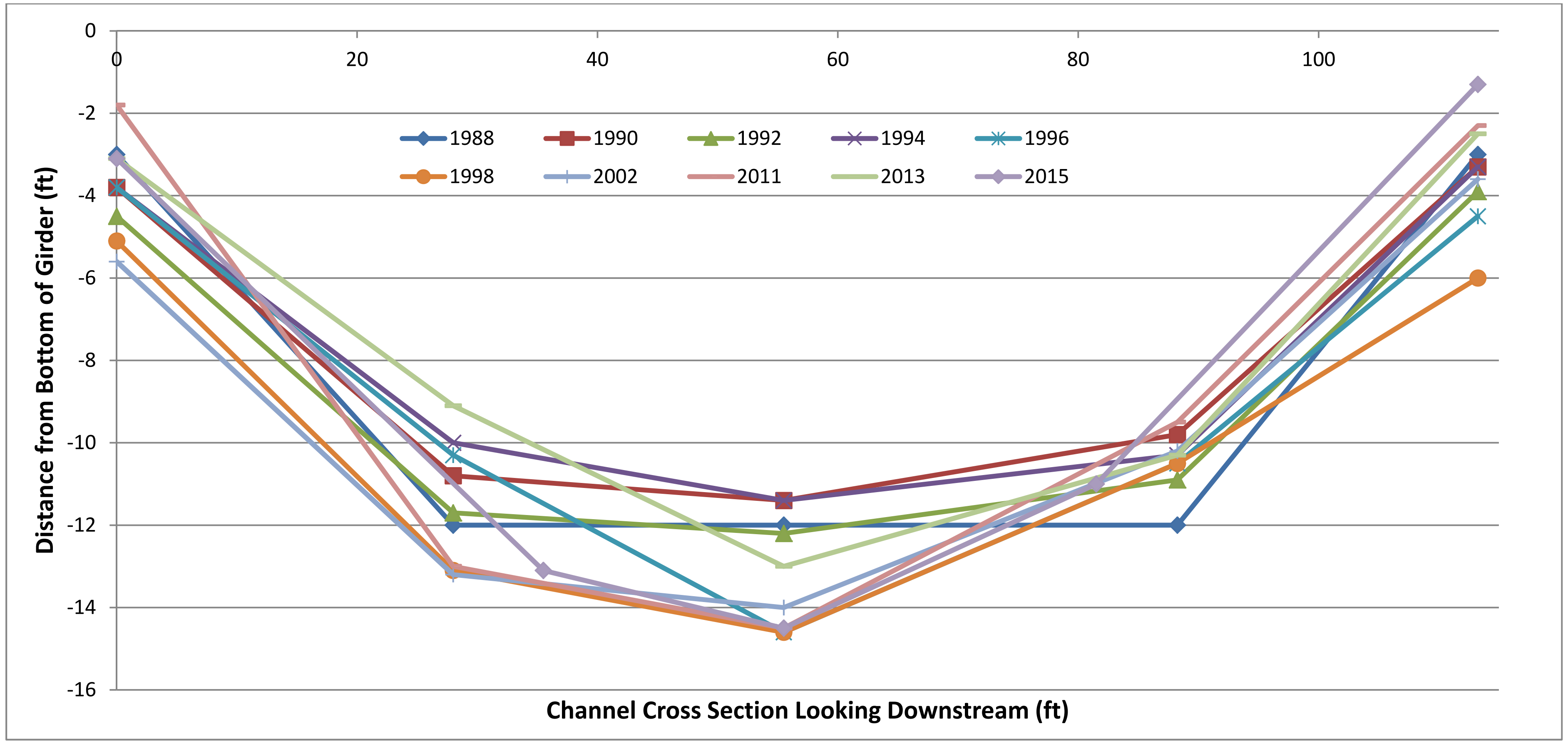


## Table 2.4c: Analysis of Bridge Inspection Reports - 75th Street Bridge

| Year | Distance to Top of Left Bank (ft) | Distance to Left Bank Toe (ft) | Depth to Thalweg (ft) | Distance to Right Bank Toe (ft) | Distance to Top of Right Bank (ft) | Change in Channel Invert Elevation (at Thalweg) (ft) | Erosional Description |
|---|---|---|---|---|---|---|---|
| 1988 | 3.0 | 12.0 | 12.0 | 12.0 | 3.0 | -- | -- |
| 1990 | 3.8 | 10.8 | 11.4 | 9.8 | 3.3 | 0.6 | Aggradation |
| 1992 | 4.5 | 11.7 | 12.2 | 10.9 | 3.9 | -0.8 | Degradation |
| 1994 | 3.8 | 10.0 | 11.4 | 10.3 | 3.3 | 0.8 | Aggradation |
| 1996 | 3.8 | 10.3 | 14.6 | 10.5 | 4.5 | -3.2 | Degradation |
| 1998 | 5.1 | 13.1 | 14.6 | 10.5 | 6.0 | 0.0 | Channel Migration to Left Bank |
| 2002 | 5.6 | 13.2 | 14.0 | 10.2 | 3.6 | 0.6 | Aggradation |
| 2011 | 1.8 | N/A | > 14.0 | 9.5 | 2.3 | 0.0 | -- |
| 2013 (Pre-Flood) | 3.1 | 9.1 | ~ 13.0 | 10.3 | 2.5 | 1.0 | Aggradation |
| 2015 | 3.1 | 13.1 | 14.5 | 11.0 | 1.3 | -1.5 | Degradation |

*Note: Proper measurement collected in 2011 and 2013 was affected by presence of ice in the channel*

Figure 7. 75th Street Bridge



## 2.5 PLANFORM AND PROFILE SUMMARY

While local changes in bed slope have occurred throughout the project reach and can be observed on specific sub-reaches, the overall profile through the project area has remained fairly consistent. Although significant planform changes were observed following the September 2013 flood, the St. Vrain Creek has returned to its original alignment through emergency flood restoration efforts by the County, adjacent landowners and agencies. The exception to this is Sub-Reach 3, which remains in its new alignment through the Hepp #1 Lake aggregate pit above Hygiene Road. Both aggradation and degradation have been observed at the bridges over the last 30 years suggesting relatively steady state changes within the bridge sections. However, the 2013 flood resulted in consistent degradation of a relatively large magnitude through each County bridge, suggesting a consistent post flood re-entrenchment of the system.

There was a slight decrease (flattening) of bed-slope at Sub-Reach 1. This combined with the field observations indicate that this sub-reach has not significantly degraded but has areas of local scour and degradation. Overall, Sub-Reach 1 has minimal bed profile change. As shown on **Table 2.3**, Sub-Reach 2 exhibited a significant increase (steepening) in bed slope following the flood. During our field investigation in May 2016, LA noted a section of obvious degradation in Sub-Reach 2 where the channel bed has eroded through a layer of shale. The steepening in bed slope post-flood aligns with this observation and supports the conclusion that Sub-Reach 2 is degradational.

Based on the profile comparison shown on **Table 2.3**, the bed slope of Sub-Reach 3 flattened out post flood. This coincides with the field investigation and current alignment of the channel in this sub-reach. Since the channel now flows through Hepp #1, increasing overall channel length, the slope is accordingly reduced through this section. Finally, while Sub-Reach 4 is downstream of the original project reach and therefore was not investigated in the field, the profile and bridge analysis indicate that this sub-reach is also degradational based on the increase in bed slope post flood and the degradation observed at the 75th Street bridge.

## 2.6 WIDTH TO DEPTH RATIOS

LA utilized the hydraulic output from EA's HEC-RAS model to evaluate post flood width to depth ratios throughout the project area. The cross sections used for the width to depth analysis are shown on **Figure 3** and are located on the field investigation maps in **Appendix B**. In general, a stable channel connected to its floodplain would show an increase in width to depth ratio coinciding with increasing flood frequency (return period event). Generally, the 1.5 to 2 year flood event reflects a bank full condition. As river stage height increases, the floodwaters pass over the floodplain and width to depth ratios increase. The data for the post flood St. Vrain Creek channel through the project reach are presented (in **Table 2.6**). The data suggest that within the project reach, there are locations where the channel has excessive bank full capacity and even the 10 year event is confined in the main channel. This results in significant disconnection from the floodplain.

Conversely, there are locations where the width to depth ratio remains fairly stable or is decreasing, indicating the channel geometry has been disrupted to such a degree that the channel is now a multi-thread braided channel with even low flows unconfined. This is especially occurring in Sub-Reach 3, where the original channel geometry was disrupted, both banks were eroded and a significant amount of debris and sediment were deposited. In these locations there is no longer a single thread channel with typical overbanks.

**Table 2.6: Width to Depth Ratios**

| Sub-Reach | River Station | W/D Ratios | | |
|---|---|---|---|---|
| | | 2 year | 5 year | 10 year |
| 1 | 18695 | 18.0 | 15.0 | 13.6 |
| | 16494 | **39.9** | **37.8** | **35.0** |
| 2 | 12801 | 11.0 | **16.7** | **15.7** |
| | 9197 | 28.0 | 22.7 | 20.4 |
| 3 | 5098 | 32.3 | 28.4 | 55.5 |
| | 4547 | 9.1 | 7.8 | 7.3 |
| | 2700 | **78.9** | **71.7** | **64.9** |
| | 2401 | **57.1** | **53.8** | **48.4** |
| | 1800 | **79.4** | **66.4** | **58.5** |
| | 1349 | 31.4 | 25.5 | 22.9 |

Notes:

- Sub-Reach 4 extends beyond project area and was not included in hydraulic modeling.
- Bold values indicate return interval event flows out of banks of main channel.

# 3.0 Sediment Analysis

## 3.1 FIELD SAMPLE RESULTS

In a natural, stable channel, a well-developed coarse armor will develop, which will protect the underlying and significantly finer sub-armor material. This coarse armor develops on the surface of a bar and on the bed of the channel after numerous smaller events have winnowed away all of the fine materials. In a stable system, this armor is disrupted periodically causing the sub-armor layer to become mobile. The average grain size of the armor is typically significantly larger than that of the sub-armor. Due to its larger particle size and resistance to entrainment under lower flow conditions, the armor layer (which on a spatial basis reflects less than 1% of the channel bed alluvial materials) will often dictate the conformation of the channel (Schumm 1977).

The sub-armor is indicative of the bed material which is transported during more typical flows. Its median size (D50) or more representatively, its graphical mean, allows one to estimate the average annual peak flows or the dominant discharge of the channel. The statistical characteristics of the grain size distribution curve, standard deviation and skewness, allow one to evaluate the river's ability to sort the sample. A geomorphically stable river with a relatively constant supply of sediment and an adequate amount of time for the river forces to act on the bed will be represented by a moderately well sorted sub-armor bed material. Typically the bank material of a stable river system will reflect a smaller grain size, may be less well sorted and be significantly finer skewed.

Bed and bank samples were collected throughout the project reach, ensuring that at least one sample was taken in the proximity of each breach location **(Figure 2)**. Bed samples were carefully collected using a bed material sampling barrel, which effectively diverts the flow around the barrel, allowing the sampler to remove the armor layer (if present) and collect both fine and coarse sediment in a statistically appropriate fashion at a depth below this upper layer. The samples obtained were delivered to Smith Geotechnical on May 16, 2016 for gradational analysis. Select grab bank samples were also obtained and analyzed. Detailed information on bed and bank material samples is located in **Appendix D**.

Where appropriate and when the river flows and access allowed, Wolman pebble counts were conducted. The Wolman Count is a field method that provides a textural analysis of the coarse sediment layer on a river bar or bed. In total, Wolman Counts were obtained at five gravel bar and bed locations throughout the project reach.

**Table 3.1** presents a summary of the bed material present in the project reach. It should be noted that the results of the field investigation indicate that the 2013 flood disrupted the pre-flood bed armor and a new armor layer has not yet developed. During the flood, the high flows associated with this extreme event disrupted both the armor and sub-armor layers and mobilized them to a location where they were eventually deposited. In the last three years since the flood, there has not been large or long duration high flow events of sufficient magnitude to reform an armor layer and/or establish the typical sorting and skewness of a stable bed load stream.

**Table 3.1: Bed Material Size Classification**

| | Site 1 | | | | Site 2[4] | Site 3 | | Site 4 | | | | Site 5 | | Site 6 | Site 7 | Site 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Sample #1* | | *Sample #2* | | *Sample #1* | *Sample #1* | | *Sample #1* | | *Sample #2* | | *Sample #1* | | *Sample #1* | *Sample #1* | *Sample #1* | |
| | Wolman | Sieve | Wolman | Sieve | Sieve | Wolman | Sieve | Wolman | Sieve | Wolman | Sieve | Wolman | Sieve | Sieve | Sieve | Wolman | Sieve |
| **D50 (in.)** | 0.47 | 0.70 | 1.26 | 0.48 | 0.04 | 0.63 | 0.41 | 0.51 | 3.02 | 0.51 | 1.21 | 0.87 | 3.04 | 1.02 | 3.16 | 2.20 | 2.28 |
| **Graphical Mean[1] (in.)** | N/A | 0.47 | N/A | 0.32 | 0.16 | N/A | 0.27 | N/A | 1.74 | N/A | 0.46 | N/A | 1.37 | 0.39 | 2.59 | N/A | 1.69 |
| **Sorting[2]** | N/A | 2.75 | N/A | 3.17 | 2.98 | N/A | 2.7 | N/A | 1.64 | N/A | 3.43 | N/A | 2.19 | 3.84 | 0.78 | N/A | 1.45 |
| **Skewness[3]** | N/A | -0.34 | N/A | -0.26 | 0.96 | N/A | -0.38 | N/A | -0.9 | N/A | -0.65 | N/A | -0.93 | -0.56 | -0.85 | N/A | -0.63 |

Notes

[1] Graphical Mean is the mean of three data points on the percent retained graph - D16, D50, and D84

[2] Sorting (Folk, 1974) or inclusive graphic standard deviation is a numerical evaluation of the uniformity of the sediments. Values greater than 2.0 are very poorly sorted.

[3] Skewness (Folk, 1974) or inclusive graphic skewness, is a measure of the degree of asymmetry of the grain size curve. Symmetrical curves have a skewness of 0.00. Those with a negative skewness exhibit excess coarse material.

[4] Bed sample location at Site 2 was in a backwater area. Due to high flows, this was the only accessible location, however the bed material sample at this location is not indicative of the channel bed at this Site due to the slack water and organics present. The positive skewness value of the bed sample at Site 2 is anomalous and reflects excess fine material at this location.

### Bank Material Analysis

During the field investigation, a total of eight bank samples were obtained. All organic material was removed from the bank and a vertical composite of the underlying alluvial material was collected. The channel banks of each site evaluated in the field are qualitatively characterized on the field data sheets, located in **Appendix B**. These banks range from well-vegetated stable banks to eroded, barren banks. Within the Project Area, the channel bank material consisted primarily of medium to coarse clayey sands with some gravel and cobbles in the majority of the sampling locations. Where river alluvium was present and a representative sample could be collected, bank samples were obtained and submitted to the laboratory for particle size analysis. These data are also presented in **Appendix D**.

## 3.2 SHIELD'S ANALYSIS/INCIPIENT MOTION

To understand the St. Vrain Creek channel behavior, LA completed a basic incipient motion analysis to characterize the sediment transport regime of this section of the channel. Incipient motion is a measure of the hydraulic condition upon which particle motion begins along an alluvial channel bed. In layman's terms, it is a reflection of the depth of flow or the velocities necessary to initiate erosion despite the presence of channel armor.

Armoring occurs when the bed surface material is coarsened as the sub-surface material is entrained. An armor layer develops as shear stresses increase enough to mobilize the fine materials but not the large material on the surface layer. The fine particles are winnowed from the bed surface, thus forming a coarser layer to shelter the remaining finer particles in the subsurface layer. In the St. Vrain Creek, there would have been an armor layer before the September 2013 flood, however when large enough flow events occur to mobilize even the largest bed material, the armor layer is disrupted. The process of armoring the creek bed surface then restarts.

Incipient motion can be computed from the Shields relation, which can be used to determine shear stress for certain hydraulic conditions (SLA, 1982). This shear stress can then be equated to a critical particle size, which can then be compared to existing bed material to determine the relative stability of the channel. The bed shear that results from a given event can be determined using the equation for incipient motion:

$\tau = \gamma RS$

$\tau$ = bed shear
$y$ = specific weight of the water
$R$ = hydraulic radius
$S$ = bed slope

If the known bed shear for a given event is calculated, the critical particle size that will move during that event can also be determined by the Shields equation (1936) where:

$\tau = 0.06(\gamma s - \gamma)Ds$

$\tau$ = bed shear
$\gamma s$ = specific weight of the sediment
$\gamma$ = specific weight of the water (62.4 lb/ft3)
$Ds$ = particle diameter
0.06 = Shield's parameter (usually between 0.04 and 0.07)

**Tables 3.2a, b and c** show the bed shear and corresponding particle size for the 2, 5, and 10-year flow events. Hydraulic information utilized for each flow event was based on the hydraulic modeling completed by EA. As the tables show, the existing bed material does not consistently exceed the critical particle size (Ds) for any given flow event. In other words, the threshold for incipient motion varies from site to site. This is to be expected after a large event which resulted in the complete disruption of the armor layer. **Table 3.2a: Bed Shear and Corresponding Particle Size – 2-Year Flow Event**

| | | | 2 - Year Flow Event (850 cfs) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | **Sub-Reach** | **Bed Slope (ft/ft)** | **Flow Area ($ft^2$)** | **Wetted Perimeter (ft)** | **Hydraulic Radius (ft)** | **Bed Shear ($lb/ft^2$)** | **Particle Size, $D_s$ (in.)** | **Graphic Mean (in.)** | **Sample $D_{50}$ (in.)** | **Wolman $D_{50}$ (in.)** |
| 1-1 | 1 | 0.008242 | 125.35 | 53.72 | 2.33 | 1.20 | 2.33 | 0.47 | 0.70 | 0.47 |
| 1-2 | 1 | 0.008242 | 125.35 | 53.72 | 2.33 | 1.20 | 2.33 | 0.32 | 0.48 | 1.26 |
| 2 | 3 | 0.002268 | 239.03 | 102.49 | 2.33 | 0.33 | 0.64 | 0.16 | 0.04 | -- |
| 3 | 3 | 0.001132 | 439.45 | 278.92 | 1.58 | 0.11 | 0.22 | 0.27 | 0.41 | 0.63 |
| 4-1 | 3 | 0.010559 | 183.46 | 167.61 | 1.09 | 0.72 | 1.40 | 0.46 | 1.21 | 0.51 |
| 4-2 | 3 | 0.005568 | 238.25 | 199.36 | 1.20 | 0.42 | 0.81 | 1.74 | 3.02 | 0.51 |
| 5 | 1 | 0.007518 | 187.05 | 136.37 | 1.37 | 0.64 | 1.25 | 1.37 | 3.04 | 0.87 |
| 6 | 2 | 0.008126 | 111.78 | 39.91 | 2.80 | 1.42 | 2.76 | 0.39 | 1.02 | -- |
| 7 | 2 | 0.004517 | 176.14 | 80.08 | 2.20 | 0.62 | 1.21 | 2.59 | 3.16 | -- |
| 8 | 3 | 0.004429 | 136.41 | 41.65 | 3.28 | 0.91 | 1.76 | 1.69 | 2.28 | 2.20 |

**Table 3.2b: Bed Shear and Corresponding Particle Size – 5-Year Flow Event**

| | | | 5 - Year Flow Event (1550 cfs) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | **Sub-Reach** | **Bed Slope (ft/ft)** | **Flow Area ($ft^2$)** | **Wetted Perimeter (ft)** | **Hydraulic Radius (ft)** | **Bed Shear ($lb/ft^2$)** | **Particle Size, $D_s$ (in.)** | **Graphic Mean (in.)** | **Sample $D_{50}$ (in.)** | **Wolman $D_{50}$ (in.)** |
| 1-1 | 1 | 0.010154 | 174.69 | 58.48 | 2.99 | 1.90 | 3.68 | 0.47 | 0.70 | 0.47 |
| 1-2 | 1 | 0.010154 | 174.69 | 58.48 | 2.99 | 1.90 | 3.68 | 0.32 | 0.48 | 1.26 |
| 2 | 3 | 0.002485 | 341.05 | 108.39 | 3.15 | 0.49 | 0.95 | 0.16 | 0.04 | -- |
| 3 | 3 | 0.001071 | 644.62 | 283.06 | 2.28 | 0.15 | 0.30 | 0.27 | 0.41 | 0.63 |
| 4-1 | 3 | 0.004851 | 371.45 | 221.57 | 1.68 | 0.51 | 0.99 | 0.46 | 1.21 | 0.51 |
| 4-2 | 3 | 0.011896 | 264.42 | 185.65 | 1.42 | 1.06 | 2.05 | 1.74 | 3.02 | 0.51 |
| 5 | 1 | 0.008839 | 265.51 | 150.11 | 1.77 | 0.98 | 1.90 | 1.37 | 3.04 | 0.87 |
| 6 | 2 | 0.007741 | 233.40 | 98.46 | 2.37 | 1.15 | 2.23 | 0.39 | 1.02 | -- |
| 7 | 2 | 0.004872 | 255.46 | 87.19 | 2.93 | 0.89 | 1.73 | 2.59 | 3.16 | -- |
| 8 | 3 | 0.005480 | 193.02 | 47.26 | 4.08 | 1.40 | 2.71 | 1.69 | 2.28 | 2.20 |

### Table 3.2c: Bed Shear and Corresponding Particle Size – 10-Year Flow Event

| | | | 10 - Year Flow Event (2212 cfs) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Site | Sub-Reach | Bed Slope (ft/ft) | Flow Area (ft$^2$) | Wetted Perimeter (ft) | Hydraulic Radius (ft) | Bed Shear (lb/ft$^2$) | Particle Size, $D_s$ (in.) | Graphic Mean (in.) | Sample $D_{50}$ (in.) | Wolman $D_{50}$ (in.) |
| 1-1 | 1 | 0.012125 | 209.23 | 61.52 | 3.40 | 2.58 | 5.00 | 0.47 | 0.70 | 0.47 |
| 1-2 | 1 | 0.012125 | 209.23 | 61.52 | 3.40 | 2.58 | 5.00 | 0.32 | 0.48 | 1.26 |
| 2 | 3 | 0.002806 | 413.65 | 112.80 | 3.67 | 0.64 | 1.25 | 0.16 | 0.04 | -- |
| 3 | 3 | 0.000966 | 828.68 | 287.92 | 2.88 | 0.17 | 0.34 | 0.27 | 0.41 | 0.63 |
| 4-1 | 3 | 0.004247 | 479.92 | 223.22 | 2.15 | 0.57 | 1.11 | 0.46 | 1.21 | 0.51 |
| 4-2 | 3 | 0.013343 | 316.90 | 186.62 | 1.70 | 1.42 | 2.75 | 1.74 | 3.02 | 0.51 |
| 5 | 1 | 0.009733 | 320.87 | 151.96 | 2.11 | 1.28 | 2.49 | 1.37 | 3.04 | 0.87 |
| 6 | 2 | 0.005422 | 334.34 | 108.60 | 3.08 | 1.04 | 2.03 | 0.39 | 1.02 | -- |
| 7 | 2 | 0.004897 | 326.16 | 94.57 | 3.45 | 1.06 | 2.05 | 2.59 | 3.16 | -- |
| 8 | 3 | 0.006432 | 235.85 | 51.59 | 4.57 | 1.84 | 3.57 | 1.69 | 2.28 | 2.20 |

In summary, within the project reach, there is no armor layer present. The current bed material is poorly sorted and until a new armor layer develops, the bed will be in motion at much lower flows. In general, this evaluation shows that the bed material is fairly stable for a 2-year flood event; however, as the flow increase between a 5 and 10-year event, the bed material will begin to become disrupted. Since the flood, shear stresses in the channel have not been high enough to disrupt the finer particles in the subsurface layer thus not allowing coarsening of the surface layer to occur. If consistent lower flows continue to occur for a sufficient time prior to a large event, the fines in the bed will be winnowed out and an armor layer will likely develop. This armor layer would serve to further prevent bed movement in larger events.

# 4.0 GENERAL RESTORATION GUIDANCE

The general restoration methods presented in this section identify possible solutions for streambank stabilization and floodplain connectivity. This section does not propose any specific structure, but rather presents the structures that may provide the best stabilization for the channel. The opportunities presented below include j-hooks, stream barbs, and grade control structures; however, there are many other structures that the project team has analyzed. These include: w-weir, riprap, grouted rock, berms, log erosion barriers, and log jetties. Based on the project team's understanding of BCPOS' project goals and in an effort to facilitate the geomorphic transition of the St. Vrain River, we conclude that riverine structures will provide the best river restoration tools for the St. Vrain. In addition, we recognize the benefits of using natural plantings and large woody debris in any streambank stabilized reach and will utilize bioengineering methods in the channel restoration. As this project proceeds to final design and the alternative analysis is completed, the proper stabilization methods will be selected and further evaluated. In any case, bioengineering methods will be incorporated into the final design, as discussed below.

Local bank erosion can be addressed with a variety of stabilization measures. Due to the sensitive aquatic and terrestrial species in this area, bioengineering methods should be utilized whenever feasible. Even in areas where harder stabilization materials such as rock are warranted large woody debris can and should be incorporated into the structure to provide habitat complexity. Rock structures on the banks can be overdressed with soil to allow riparian species to be planted directly on the structure.

From a restoration standpoint, it is also imperative that sediment be able to move throughout the system. A significant amount of material was carried from the upstream reaches of the St. Vrain watershed and deposited in the project reaches. Unfortunately, due to the lack of sediment gages in the St. Vrain Corridor, it is extremely difficult to quantify the exact amount of sediment, which will enter the restoration reaches. Different hydraulic conditions will result in deposition, aggradation or pass through of sediment in a given reach. During the field investigation, geomorphic observations allow the project team to identify areas of aggradation and degradation. These sub-reaches will be addressed in the design phase, as a sediment balance throughout the project reach must occur. For example, Sub-Reach 2 in general, was degradational; however there was an area directly upstream of the Longmont Supply Diversion Structure which had aggraded. While this aggradation was expected because of the presence of this structure, the 30% design will incorporate methods to maintain a sediment balance throughout this reach.

Riverine structures such as j-hooks and barbs can serve multiple purposes. Such rock structures extend into the stream flow and locally influence hydraulics by providing bank protection and sediment storage on the lee side of the barb, while locally influencing the bed topography by increasing flow depth through the processes of local scour. Stream barbs transfer erosive velocities away from the channel bank through the interruption of helicoidal currents and cross stream flow that will erode a channel bank. Most importantly on a system like post flood St. Vrain, they will allow fish passage and provide locations for sediment to settle, increasing the overall storage capacity of the system. In general, a well-designed restoration plan using such structures will allow the development of an alternating bar system and locally improve stream hydraulics. New habitat features will include deeper cooler water, backwater or slackwater conditions, stable banks and the opportunity for vegetation plantings and shading within the riparian system.

In degradational areas such as Sub-Reach 2, grade control structures and cross vanes may be required to prevent headcutting upstream. Degradation occurs when the stream flow energy is high relative to the sediment input. Such degrational reaches require stabilization methods to prevent continual scour of the channel bed during larger return period flood events. It is critical that such grade control structures and cross vanes be limited in scope such that they result in minimal interference of fish passage while reconnecting the river to its floodplain. Generally, they are constructed of large natural boulders that are adequately spaced to hold channel grade while providing a riffle pool environment. These boulders are sized to withstand flows in excess of the 100-year event. While there may be some “tweaking” to the boulders and other dynamic structures after large events, the goal is for them to withstand large flows and provide benefit during all flow events. Where keyed into the bank, natural wood features will be used to provide additional protection and habitat improvements. Collaboration with Boulder County and ECOS will be completed in the preliminary design phase for these structures to ensure that they are designed to accommodate fish passage wherever possible.

Further evaluation of the location near Breach 2 where the channel plug occurred is warranted during the design phase. The detailed hydraulic analysis should address further routing of flood flows through this area during large events. While there are no feasible ways to prevent the large slug of sediment that accompanies a 100-year or greater event, this particular location is a likely bottleneck due to the confined nature of the channel with the proximity to the railroad tracks. There are opportunities to connect the channel with the right floodplain and a more permanent improvement of the Breach 2 repairs is warranted. Additional storage or flood attenuation may also be possible through Lakes 2 and 4 with the creation of spill structures. Along with flood attenuation and reconnection of the floodplain to the river, these Lakes could provide backwater and slackwater habitat- where properly designed.

# 5.0 REFERENCES

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# Appendices

# Appendix A

## Response to Comment

## Appendix A
## Response to Comments
## Boulder County Parks and Open Space Department's August 12, 2016 Response to the Basis of Design Report

**Comment**: I noticed no samples were collected downstream of Breach 2 in the reach that aggradated.

> **Response:** Two samples were collected immediately downstream of the Breach 2 (one bed and one bank). The bed sample reflects the material that was deposited and is now currently being reworked by St. Vrain. As you can see from Table 3.1, this sample is very poorly sorted and reflects the chaotic state of the flood and is negatively skewed. Based on the Shields analysis, this material will remain in motion during even lower flows and will continue to do so until an adequate armor develops. This location will likely reflect the influence of the Longmont Supply Ditch.

**Comment**: Is the Creek channel also over-flattened as it approaches the Longmont Supply Ditch diversion structure downstream of Breach 2?

> **Response**: During the field investigation, it was noted that there was an increase in sediment and debris between the Longmont Supply Ditch and Breach 2.The project team did investigate pre-flood and post flood LIDAR at this area in response to BCPOS questions and found little indication of a change (pre- to post) break in slope profile. With that said, the effects of the Longmont Supply Ditch and local hydraulics may clearly have influenced the sediment plug that reportedly influenced Breach 2. Unfortunately we cannot confirm any forensic data to support this conclusion.

**Comment**: (Page 154) Riprap at erosion scar downstream of Breach 2. Disagree. We have kept this area free of riprap (with Longmont's cooperation) for future placement of rootwads and bioengineering. Unless critical and proven otherwise, this should be i.e. rootwads.

> **Response**: We assume you are referring to Figure 6 of 13, Appendix B of the LA report. This figure has been superseded by the alternatives analysis and will continue to be superseded as the 30% Design progresses to final design. The project team does not intend to propose riprap at any location. Our overall approach will be to continue to work with biotechnical slope protection, native plantings and toe slope protection where appropriate.

**Comment**: Bridges. Much analysis was presented about bridges. I do not recall reading about "needs" of engineering for bridges. Are there any upshots or interpretations or suggestions that will come out of this report that state specific needs for each bridge in the project area? I may have missed something.

> **Response**: The project team has made no specific recommendation regarding the county or state bridges and bridge protection other than the project design intent to balance water and sediment yield upstream and through the bridges. The reason for the bridge analysis included in our report was to utilize historic data collected as part of bridge inspections. Such data provide an excellent history of channel bed changes-albeit at a set (and man-influenced) location. Historic bridge inspection reports were utilized to verify whether the channel bed at that location was aggrading or degrading (Section 2.4, pg. 2-6 through 2-10).

**Comment**: Native fish passage, upstream extent, CPW input. I am currently advocating for the lowest-grade, least fragmenting in-stream designs possible for the entire project area. The stream type(s) in our project area do not naturally contain large drops and boulders or other high-jump features – and that includes the upstream, colder-water Breach 1 area. Regardless of the presence or absence of state listed small transitional warm water fishes, I am convinced all of this work needs to be built using the same low-grade, little or no drop conditions – matching the stream type and natural materials in these reaches to which these native species evolved and are critical for their survival. Existing drops in the stream are a known challenge, POS is working on this, but these existing features are not a deterrent to our stream restoration design targets.

> **Response**: The project team agrees with your concern. With that said, maintaining adequate conveyance to ensure sediment transport and sediment storage are critical components of successful habitat restoration and geomorphic stability. The effects of the large flood, physically blew out the banks, widened the channel and created a multiple thread low water condition. In response to our 30% design concerns, we have proposed natural boulders used for "low head (low elevation) grade control structures (cross vanes). These structures will be necessary in select reaches to hold grade, prevent head cutting, and direct flows away from banks during the rising limb of the hydrograph. These structures will be constructed in a manner that accommodates cold-water fish passage. Additionally, where keyed into the bank, they provide additional habitat improvement opportunities through the installation of natural wood features and plantings.

**Comment**: The restoration guidance is excessively vague and not actionable at this level of detail. Likewise, the individual reach descriptions lack enough description for a reader to translate this to 30% design work that needs to be done.

> **Response**: As part of the initial scope, LA was responsible for drafting a geomorphic assessment identifying sediment sources, aggradational and degradational subreaches, and to divide the overall project area into geomorphically similar Sub-Reaches. The general restoration guidance section of LA's geomorphic assessment was completed prior to 30% design alternatives being analyzed. It was not intended to outline 30% design concepts but to outline possible stabilization measures.

**Comment**: The last two sentences of the last paragraph of page 4-1 are vague and possibly inconsistent with other work currently underway. This should be deleted unless this can be made more specific and has been evaluated to at least a conceptual level and is known to fit with this other work.

> **Response**: Similar to the above comment, LA's geomorphic assessment was completed and delivered on July 1, prior to any discussions regarding design alternatives and deciding not to implement any spill structures. The sentences in question identify opportunities (and constraints in earlier sections of Section 4.0) and do not present the evolution of selected alternatives. These sentences have been removed.

**Comment**: In addition to above – much attention was paid to South Branch during H&H investigation. Was the finding that the South Branch is actually the “preferred natural alignment” of the creek? Is there a tendency for the creek to move out of the main-stem at the South Branch “diversion”, but actually this is a natural point of flow for the creek? Should we expect future avulsion in this area?

> **Response**: There are multiple historic alignments of the St. Vrain River-all of which have been influenced by gravel mining within this reach. There was no conclusion relative to the preferred alignment but rather the South Branch provides an opportunity for off channel flow to enhance habitat features. Portions of the main channel reach has seen degradation and as such near term indicators are that there will not be near term avulsion. Limited data base (air photo analysis) suggests a relatively stable pattern.

**Comment**: (Page 110) Bed Shear, and “natural” re-armoring and stabilizing of the channel over time only by consistent high flows winnowing away the fines and leaving behind an armor layer in the channel. There are too many diversions. Given the stream is dewatered most years and months, is it possible for the stream to re-armor its bed and banks? How long will it take to “re-armor” and stabilize sediment given current hydro regime? Does the regime need to change for some amount of time (if it were possible?).

> **Response**: Yes. Even streams with multiple diversions re-armor themselves. The time for re-armoring is dependent on stream flow, flood duration and material character and type. One can anticipate that the St. Vrain will eventually develop an armor and the proposed restoration project is intended to help that process along. Since 2013, a flow event of this magnitude (> 10-yr event) has not occurred.

**Comment**: (Page 109) Shear and sediment movement tables – Site 2 seems to have very low power to move particles compared to all other sites 2,5,10yr : 0.64”,0.95”,1.25”), if I am interpreting, so it would seem it is aggradational? But, it is described as degradational?

> **Response**: As noted in Note 4 in Table 3.1, the sampling location of Site 2 was in a backwater area. Due to the high flows, this was the only accessible location near Breaches 8 and 9. This sample is not indicative of the channel bed and was not used during the classification of the Sub-Reach.

**Comment**: (Page 112) Please clarify: “Finally the South Branch Diversion in Sub-Reach 2 provides an example of off channel flow and the concomitant benefits of off channel habitat improvement. There are select locations in Sub-Reach 3 where similar off channel diversions can be constructed with minimal water rights impact. The existing channel between Breaches 4 and 8 as well as the abandoned channel on the Hepp property (Breaches 6, 7 and 8) provide multiple opportunities for multiple channel thread design.”

- Where do we construct new off-channel diversions for habitat?
- Also, are you advocating for "multi-thread" channels for high habitat value, or are we working towards a low-flow single channel design - most of the in-stream grade control discussion in the BoD is about thalweg formation and low-flow single channel engineering, even in the high-flow channel through Hepp #1.

> **Response**: Again this statement predated many of the meetings and subsequent alternative evaluations conducted by BCPOS and the project team. The design intent is to maintain channel forming flows within a single thread channel (1- 2 year bank full conditions) and where possible to allow flood relief into the floodplain and adjacent lakes. There are opportunities to connect the Hepp Lakes and provide frequent water and inundation in an "off channel" environment.

**Comment**: (151). “Downed Trees to be removed”. Why? In fact, unless absolutely critical to the physical integrity of the breaches projects, no downed trees should be removed.

> **Response**: We fully agree with the concept of leaving large woody debris in channel. These particular downed trees were at a location, where they were creating adverse geomorphic response. Due to the railroad being in close proximity to this river at this location, we want to prevent any future erosion along this bend. The downed trees will be incorporated into the proposed rock vanes during the 30% to final design process. In every case, final design considerations will balance rock with LWD.

**Comment**: Little discussion of how existing channel profile and slope contributes to sediment movement or storage other than on a broad sub-reach scale. Identify localized areas of aggradation and degradation, particularly the aggradation problem just downstream of Breach 2, and design solutions beyond rock vane structures. The latter is called out on page 4-1, but has yet to be addressed in the design phase.

> **Response**: Please refer to pages 4-1 and 4-2 for revised comments. Aggradation and degradation has been addressed in the design phase and sediment balance is a critical element in the selection of cross vanes versus straight vanes. Degradation occurs when the stream flow energy is high relative to the sediment input. Conversely, aggradation occurs when the sediment input is much larger relative to the stream flow energy. In areas where the stream flow energy is high, such as in most areas of Sub-Reach 2, stabilization measures are needed to prevent the scour of the bed material. Final design of Sub-Reach 1 must be balanced with Sub Reach 2. As additional sediment enters Sub-Reach 2, adequate conveyance (cross vanes) must be addressed and storage sites must be developed (hence the design of vanes within the Breach 2 Reach). This has been initially developed during the 30% Design.

**Comment**: Differentiation between permanent structures (like grouted rock) and temporary "dynamic" structures (like LWD, boulders, boulder clusters that deteriorate or can move to another location and still provide value) should be made so that their durability and maintenance requirements are known.

> **Response**: Please refer to pages 4-1 and 4-2 for revised comments. LA has not proposed any grouted riprap, however the large rock structures are fairly permanent as the boulders are sized to withstand flows in excess of the 100-year event. While there may be some "tweaking" to the boulders and other dynamic structures after large events, the goal is for them to withstand large flows and provide benefit during all flow events.

**Comment**: There needs to be a description of what stream armoring is and its importance in terms of stream flowline grade. The associated write-up on page 3-5 should also address the likely pre-flood armoring status, what it will take to armor the stream under current conditions (e.g. how much "winnowing" will be required to create the armor, whether enough armor size material exists in the bed, whether supplemental rock should be added as bed material to assist this armoring to occur, etc.).

> **Response**: Please refer to page 3-3 for an additional description of armoring.

**Comment**: Prefer to see specific examples of in-stream structure alternatives to J-hooks, cross veins, bendway weirs – what alternatives may exist and the pros and cons?

> **Response**: Please refer to pages 4-1 and 4-2 for revised comments. The project team is happy to discuss such alternatives such as j-hooks, w-weirs, riprap, grouted rock, berms, log erosion barriers, log jetties, etc. Based on our understanding of the BCPOS goals and an effort to facilitate the geomorphic transition of the St. Vrain River, we feel that cross vanes (grade controls) and vanes will provide the best restoration tools for the St. Vrain. In addition, natural plantings, bank slope reduction, and selective use of rootwads and large woody debris will be utilized in the channel restoration.

**Comment**: There is no description of sediment (wash load and bed load) carried by the stream as it enters the subject reach. To describe this as a "significant amount of material" is inadequate. This is information that should be available from the SSVC Hall Meadow Project (currently underway) and similar work completed for the Town of Lyons. This should include the current (post flood) nature of the sediment, how it differs from normal, how long this is likely to last and the impact that this has on the creek geomorphologic conditions. In particular, it seems that there is a higher than normal amount of sand being carried by the Creek and being deposited as a temporary, yet significant bed form as it travels through the reach as a post flood impact. If this is true, how do the proposed improvements deal with this phenomenon and still work for longer term conditions?

> **Response**: Please refer to page 1-1 for revised comments. LA recognizes that there is considerably more sediment in the stream post-flood than there was during pre-flood conditions. A lot of this material has deposited in the channel and the surrounding floodplains. Unfortunately, we have no way to quantify this amount as there are no sediment gages upstream of the project reach. The project team has been unsuccessful is obtaining sediment data from any similar projects that have occurred in the St. Vrain corridor. The purpose of in-stream structures is to address the bed load and wash load sediment. The bed load will be mobilized during a large enough storm event that has not occurred since the 2013 flood. Once this material is mobilized, there will be a large demand for sediment storage, thus rock vanes.

**Comment:** (Page 94) Sub-reach 1. Railroad Erosion – Does CEMEX own this R&R track? Do they have comments about railroad impacts by stream? Have they done armoring work in the past? Do they have any requirements for protecting the R&R (in the floodplain)? The railroad is completely eliminating the north bank floodplain in many areas. Do we need to compensate in any way by grading and benching some south bank areas?

> **Response**: CEMEX does not own the railroad and there is not enough room to grade the banks back. To address the severe bank erosion issue, the preferred alternative proposes to place a series of vanes along the bend that is most threatening the railroad. These vanes will prevent future bank erosion and will protect the railroad. Grading issues will be addressed as the project progresses from 30% towards final design.

**Comment:** (Page 94) Sub-reach 2. Degradation – while it did erode below shale layer, in downstream sections it aggraded and formed a plug – are there different things going on in this reach? Is this being addressed at the proper scale? Why did shear and sediment analysis show low (small-size) sediment moving capability over all modeled flows?

> **Response:** Naturally there is some aggradation that has occurred as a result of the Longmont Supply Ditch Diversion structure. As a whole, Sub-Reach 2 was degradational as the slope increased from 0.79% to 0.84%. The sediment analysis at Site 6 (Breach 2) and Site 7 (Breach 3) varied because of how the water breached those areas. (For particle size distributions the median is called the d50.) The d50 at Site 7 was much larger than at Site 6 as a result of the overland flow that occurred near Site 7. Site 6 (Breach 2) overtopped and flooded the adjacent pond, thus depositing smaller material into the channel when flows subsided. The larger material traveled downstream and overland to Site 7 where a lot of the flooding re-entered the main channel.

**Comment:** Subreach 2: The overall summary was that this reach is degradational. However, we had significant aggradation just downstream of Breach 2. This has not been addressed in the Draft Geomorphic Report. The scale of Sub-Reach 2 may be too long to be useful. May need to break this sub-reach up into more sub-reaches.

> **Response:** Please refer to page 2-2 for revised comments. We understand that BCPOS has concluded that this reach is aggradational just downstream of Breach 2 and that the sediment plug likely impacted the formation of the breach. As previously mentioned, the aggradation just downstream of Breach 2 is expected because of the Longmont Supply Diversion Structure. With that said, there is no profile data to support a major break in slope. The sediment data that was collected suggests the material that was left post-flood is highly mobile. This makes sense given that after the breach formed (Breach 2), stream power within the main channel decreased and finer material may have been deposited during the recessional limb of the hydrograph. The field data on an entire Sub-Reach basis suggests Sub-Reach 2 is currently undergoing degradation and will do so during the near term.

**Comment:** (Page 123) Cottonwoods on right bank stressed and dying. What are we going to do with this "island" of dead trees that will become the right bank of the "pre-flood" restored channel?

> **Response:** As water reenters the pre-flood channel, the groundwater table will rise and will hopefully provide an acceptable alluvial condition. This is an excellent comment to consider in the revegetation phase of the later designs.

**Comment:** (Page 160). Stream work at Breach 4. Lots of barbs. Why? The current alignment of the creek has shifted over the years, does not look like current photo. Is it necessary for stabilization in this area?

> **Response:** The red lines on the field investigation maps do not represent vanes (barbs), but rather areas of erosion. This is now clarified on the figures.

**Comment:** Subreach 3: It seems like there is a lot of variation within this sub-reach, and that it too should be split up into smaller sub-reaches. In particular, upstream of the 63rd St bridge is different than downstream of the 63rd St Bridge to the Hepp Property, and the Hepp Property itself should, perhaps, be a stand-alone reach.

> **Response:** When the Sub-Reaches were divided, the project team looked at a variety of characteristics to decide when and where the Sub-Reaches began and ended. These factors included sinuosity, profile, channel geometry, and upstream and downstream boundaries. One can certainly divide the subreaches further based on discussions subsequent to the development of this report. Our intention was to confine the subreaches to the above geomorphic factors as presented on page 2-1. In truth one can subdivide reaches further based on vegetation factors, nature of breaches, localized aggradation and localized degradation.

**Comment:** (Page 99) North Branch diversion – lateral migration occurred around the diversion. In future, if North Branch is highly armored to NOT allow lateral migration around or through it (as suggested), will this increase floodplain inundation height on Hepp compared to pre-flood and in other ways drop out sediment upstream of the Hygiene Road bridge?

> **Response:** Yes, if the diversion structure is armored, the inundation height will increase.

**Comment:** River stations are not marked on any map. Therefore, it is difficult to follow the discussion about W/D ratio on Reach 3 decreasing.

> **Response:** Great comment. We have added stationing to Figure 3 and on the field investigation maps in Appendix B. Our original thought was this report would tie directly into a base report with stationing and local hydraulics. Table 2.6: Width to Depth Ratio's includes the river stationing where the cross sections were taken for the analysis.

We thank you for your time in reviewing the St. Vrain Breaches Restoration Project Basis of Design (B.o.D.) Report and specifically the Geomorphic Assessment located in Appendix B of the B.o.D. Report. We hope that the revisions satisfy your requests and please do not hesitate to contact us with any more questions.

# Appendix B

## Field Notes

# Field Data Sheet

## 1. General Information

Stream: St. Vrain Site I.D. No. 1 (Breach-1) GPS File: 019 – near CP Bull 01

Latitude: _____ Longitude: _____ Photo Log: _____

Date: 5/9/16 Time: _____ Surveyors: ZSB, ELR, CDL

Location Description: _____

## 2. Channel Characteristics

Slightly sinuous, P=1.2

Planform: _____ Straight x Meander _____ Braided

Site Geometry: _____ Bend x Straight Channelized: x Yes _____ No

Bed Form: _____ Uniform Flow x Pool/Riffle
_____ Step/Pool _____ Cascade

Channel Width (ft): 75 Top _____ Bankfull _____ EW

RB Levee Height = 6.0

LB Vegetated = 6.0

GPS 020: Bed Sample #1 (1-Bed 1) – bucket + 7" + 8" cobble (tossed) in live water to right of bar

GPS 021: Bed Sample #2 (1-Bed 2) – at apex of bar (dry)

GPS 020 Bed Sample #1 (1-Bed 1) - bucket + 7" + 8" cobble (tossed) in live water to R of bar

GPS 021 Bed Sample #2 (1-Bed 2) - @ apex of bar (dry)

|  | Bed | Left | Right |
|---|---|---|---|
| **Bank Height (ft.)** |  | 6.0 | 6.0 |
| **Bank Angle (°)** |  | Vertical | 2:1 |
| **Bank Stability** |  | Active tailing eroded | Levee |
| **Seepage Present** |  | none | none |
| **Armoring** |  |  |  |
| **Bed/Bank Material** | Cobble bed | 2.5 feet sdy loam cobble steady | Armored riprap |
| **Bed Form Meas.** |  |  |  |
| **Agg./Deb. Length (ft.)** | degradation |  |  |
| **Sediment Depth (ft.)** |  |  |  |
| **Vegetation** | Willow development | Large older gallery, ? | None |
| **O.B. Vegetation** |  |  | None |
| **Levee Vegetation** |  |  | Grasses |
| **Levee Height (ft.)** |  |  | 6.0 |
| **Levee Width (ft.)** |  |  | Top width 4 feet |
| **Manning's "n"** | .030 | .060 | .035 |

Notes concerning above: No O.B. vegetation at sampling location, downstream has a lot of young cottonwoods and willows getting established

## 3. Structures

Diversion: _____ Yes ___x__ No

________ Conveyance Capacity Est. (______L______W______S)

Describe material, condition, and problems: _____Large Paint bar downstream of bed sample locations (about 100 downstream) (500 long), additional bank erosion on other side of river from large bar___

Channel Improvements (describe type and effectiveness): _Bank reverted as temporary fix of breach – riprap effective so far but it is flat and poorly graded

Other Structures: _____Bridge _____Culvert _____Levee _____Fence _____Other

Description (type, scour/deposition, problems, etc.): ________________________________

## 4. Floodplain

Vegetation: _________ Crops ___________ Range ____x____ Natural

Indicate vegetation type (e.g., cottonwood, shrubs, etc.) and condition (young, old, dying):

- Young cottonwoods and willows growing downstream of sampling location
- Established vegetation on left side of river
- None on right side of sampling location_

Structures immediately adj. to channel: ____Home ____Deck ____Business

____Roads

Describe condition, age, and elevation above channel: ________________________________

Debris in Floodplain: __x____Trees _________Dump Areas

Count and/or areal extent: _____Downstream of sampling location, a lot of downed trees

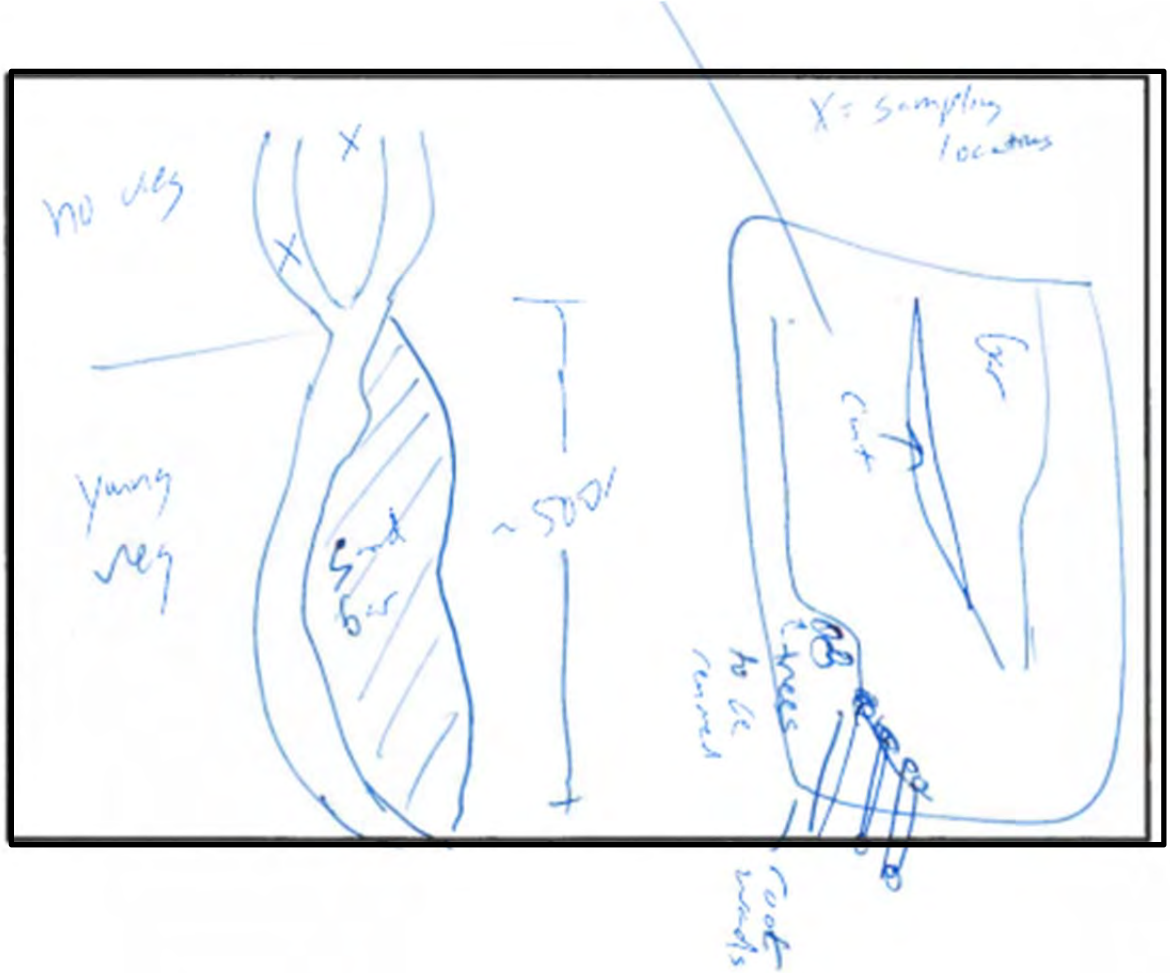
# Cross Section Sketch

Cross Section Sketch

(500')

downstream of bar does not require any work - bar needs to be broken up and lowered (see below)

(3) large trees on right side across from bar needs to be removed and root wads anchored (cut trench) at different location



## NOTES

**Channel Banks** (angle, stability, failure type, cause of instability (e.g., channel migration), color, vegetative condition (good, fair, poor): ______________________________

- vertical/poor shape on left
- riprap on right side (breach)

**Channel Bed** (bed form (e.g., dunes, pool/riffle, etc.), bed material, armoring (also depth to hard material in alluvial channels), aggradation, degradation): riffle, no armoring, semi-degradational reach

**Channel Vegetation** (type (cottonwood, shrubs, etc.), extent (banks only, channel banks, sandbars), density (scattered, average, etc.), condition (healthy, dead, regrowth, etc.):

Cottonwoods and willows- young (right) and old (left)

.

**Structures** None

**Channelization**: "Split" channel at sampling location, only split during high enough flows

**Floodplain**: Full of cobble

# Field Data Sheet

## 1. General Information

Stream: St. Vrain Site I.D. No. 2 (Breaches 8+9) GPS File: 022 Bed-1

Latitude: ______ Longitude: ______ Photo Log: ______

Date: 5/10/16 Time: 8:30 am Surveyors: ELR/ZSB

Location Description: Near Hygline Road Bridge. Downstream at bridge diversion structure/grade control

Active discharge is out of Lake, hard turn but immediately upstream and through bridge channel straight

## 2. Channel Characteristics

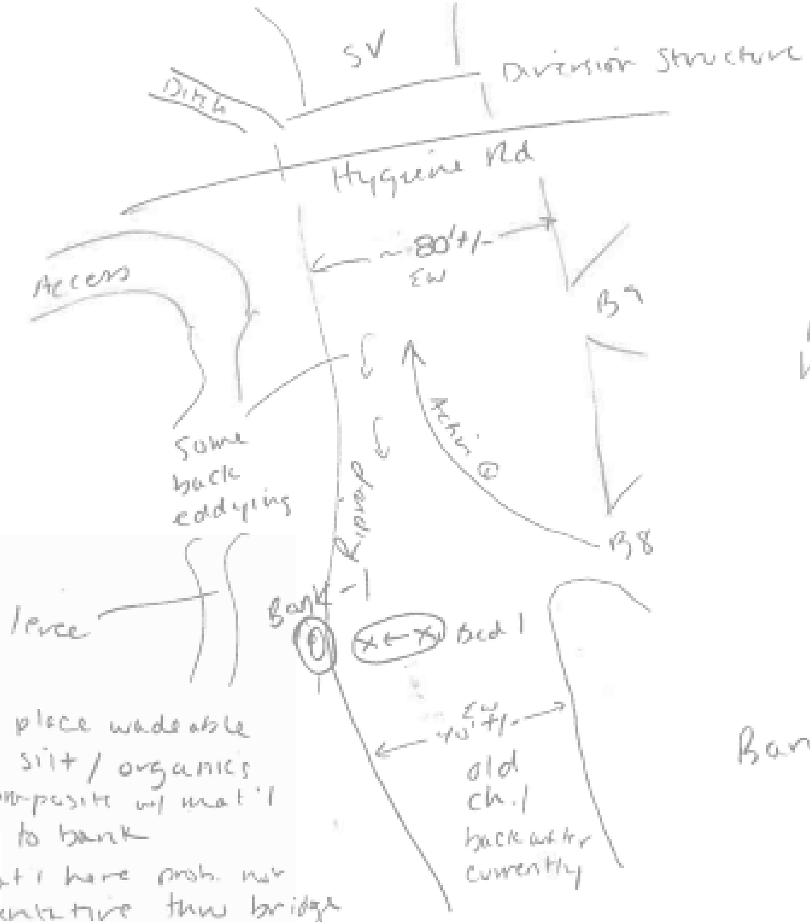
Planform: x Straight ____ Meander ____ Braided

Site Geometry: ____ Bend x Straight Channelized: ____ Yes ____ No

Bed Form: x Uniform Flow ____ Pool/Riffle ____ Step/Pool ____ Cascade

Channel Width (ft): ______ Top ______ Bankfull ______ EW

thru bridge uniform



Riprap on LB has sloughed ↓

Bed #1 - only place wadeable
mucky silt / organics
took composite w/ mat'l
closer to bank
bed mat'l here prob. not
representative thru bridge
b/c of backwater

Bank #1 -
Composite of
LB u/s of
armor

| | Bed | Left | Right |
|---|---|---|---|
| **Bank Height (ft.) (from EW)** | | 10’ | 5’ |
| **Bank Angle (°)** | | Upstream of armor- 48, 1:1<br>Armor- 3:1? | Upstream of armor- 3:1<br>Across from armor (LB)- 4:1 |
| **Bank Stability** | | Left bank has been armored. Toe erosion? Has sloughed down. | Stable/Veg/flatter slope |
| **Seepage Present** | | | |
| **Armoring** | | Poorly graded sandstone, slabby | |
| **Bed/Bank Material** | At sample pt.-mucky backwater with organics and some cobbles | Cobbles in bank with sand and gravels | Cobbles in bank with sand and gravels |
| **Bed Form Meas.** | | | |
| **Agg./Deb. Length (ft.)** | Appears to have degraded some along reveted section, some toe erosion, no apparent degradation on right bank | | |
| **Sediment Depth (ft.)** | | | |
| **Vegetation** | | Grass, sparse willows | Grass, sparse willows |
| **O.B. Vegetation** | | Sparse on levee, healthier willows behind | Some cottonwoods appear stressed |
| **Levee Vegetation** | | Grass, weeds, cobbles | |
| **Levee Height (ft.)** | | 5’ | |
| **Levee Width (ft.)** | | 25’ +/- | |
| **Manning’s “n”** | Can’t see between but bed #1 is very fine (.03) | Above armor-.04<br>Armor-.045 | .04 |

Notes concerning above: _

## 3. Structures

D/S of Hygiene Rd. Bridge

Diversion: __x___ Yes ______ No

________ Conveyance Capacity Est. (______L______W______S)

Describe material, condition, and problems: __Per county – grade structure mainly held during flood, some repairs after event. Larger flows mainly flanked structure through ditch take off. Wingwall replaced after ‘13 flood. ____________________

Channel Improvements (describe type and effectiveness): _County armored left bank across from breach 8, emergency placement (not designed). Toe appears to have eroded and riprap slumped down ____________________

Other Structures: ___x__Bridge _____Culvert ___x__Levee _____Fence _____Other

Description (type, scour/deposition, problems, etc.):

- Hygeine Bridge 9/5 of B.9
- Levee on left bank

## 4. Floodplain

Vegetation: _________ Crops ___________ Range __x__ Natural

Indicate vegetation type (e.g., cottonwood, shrubs, etc.) and condition (young, old, dying):

Cottonwoods on right bank stressed/dying

Left bank is healthier____________________

Structures immediately adj. to channel: ____Home ____Deck ____Business

____Roads

Describe condition, age, and elevation above channel: ____________________

____________________

Debris in Floodplain: ___x____Trees _________Dump Areas

Count and/or areal extent: ____________________

____________________

# Cross Section Sketch

## NOTES

**Channel Banks** (angle, stability, failure type, cause of instability (e.g., channel migration), color, vegetative condition (good, fair, poor): _ Bank sample taken directly next to bed samples, armoring left bank, banks in old channel appear fairly stable, left bank is steep

**Channel Bed** (bed form (e.g., dunes, pool/riffle, etc.), bed material, armoring (also depth to hard material in alluvial channels), aggradation, degradation):

- Only accessible sampling located slightly upstream of B.8 in backwater area of old channel, very mucky with organics
- Section immersed upstream of bridge appears much deeper (bed deg?) but no apparent drop visible on right bank

**Channel Vegetation** (type (cottonwood, shrubs, etc.), extent (banks only, channel banks, sandbars), density (scattered, average, etc.), condition (healthy, dead, regrowth, etc.):

.

**Structures**: _

**Channelization**: __Yes, downstream of Breach 9

**Floodplain**: _

# Field Data Sheet

## 1. General Information

Stream: St. Vrain Site I.D. No. 3-old channel GPS File: 023

Latitude: ______ Longitude: ______ Photo Log: ______

Date: 5/10/16 Time: 9:35 Surveyors: ZSB, ELR

Location Description: Old channel, upstream of breach 8

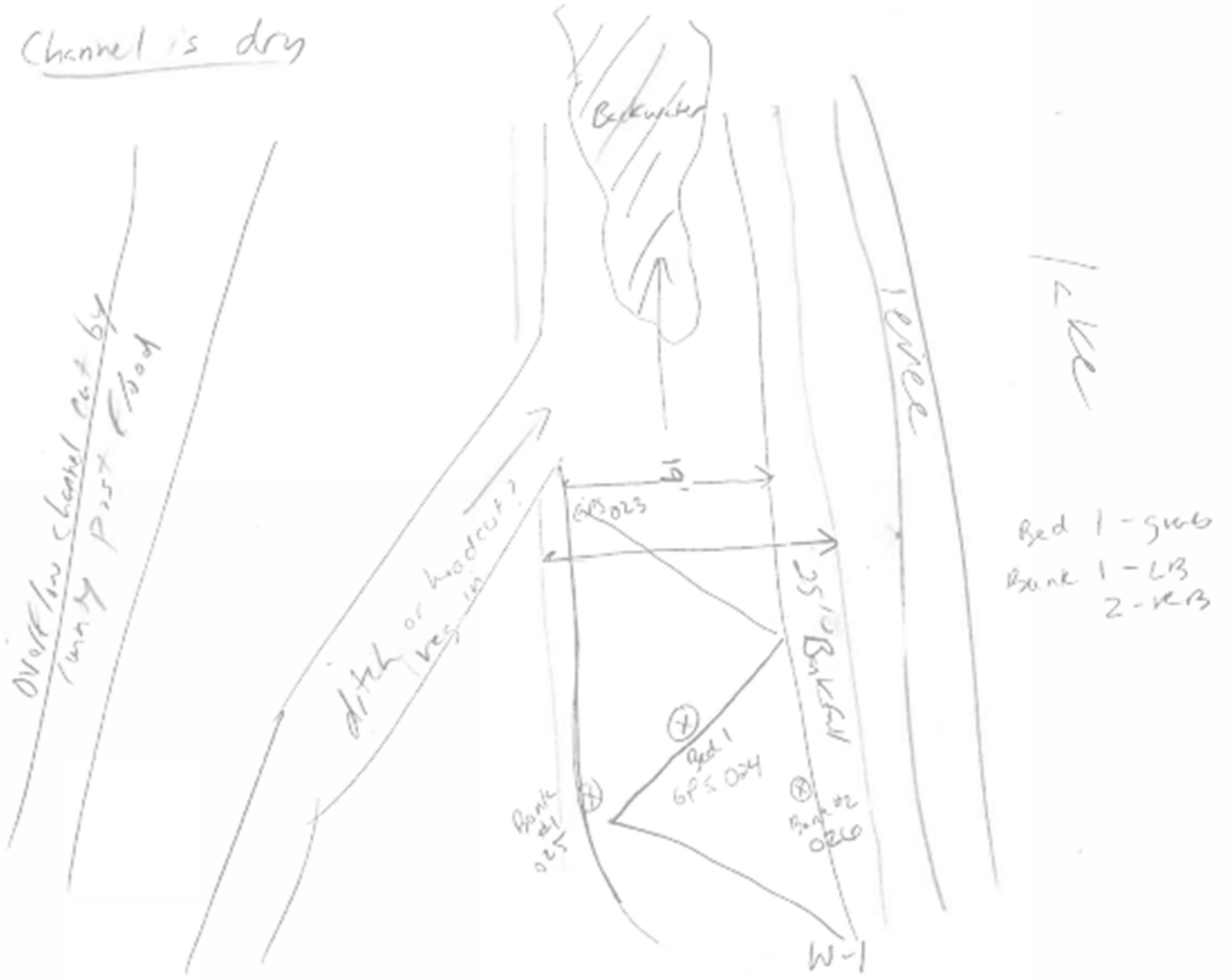
## 2. Channel Characteristics

Planform: x Straight ____ Meander ____ Braided

Site Geometry: ____ Bend x Straight Channelized: ____ Yes ____ No

Bed Form: x Uniform Flow ____ Pool/Riffle ____ Step/Pool ____ Cascade

Channel Width (ft): ______ Top 25’ Bankfull 19’ Bottom



| | Bed | Left | Right |
|---|---|---|---|
| **Bank Height (ft.)** | | | |
| **Bank Angle (°)** | | | |
| **Bank Stability** | | Stable, some erosion downstream of GPS 023 | stable |
| **Seepage Present** | none | none | None |
| **Armoring** | None | | |
| **Bed/Bank Material** | cobble | Grass, dead trees | A lot of debris, more cobbles than left bank |
| **Bed Form Meas.** | | | |
| **Agg./Deb. Length (ft.)** | No apparent degradation/aggregation , lot of fines and silts | | |
| **Sediment Depth (ft.)** | | | |
| **Vegetation** | Some in channel downstream of sample location in backwater | grass | Grass |
| **O.B. Vegetation** | x | Dead trees, willows | Sparse, dead trees |
| **Levee Vegetation** | N/A | None | Grass, willows |
| **Levee Height (ft.)** | N/A | N/A | |
| **Levee Width (ft.)** | N/A | N/A | 18’ |
| **Manning’s “n”** | .034-.04 | .03 | .035 |

Notes concerning above: ______________________________________________

______________________________________________

______________________________________________

______________________________________________

## 3. Structures

Diversion: _____ Yes ___x___ No

________ Conveyance Capacity Est. (______L______W______S)

Describe material, condition, and problems: ________________________________________

- Fairly straight- low sinuosity
- Flood debris on right bank

Channel Improvements (describe type and effectiveness): ______________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

Other Structures: _____Bridge _____Culvert _x____Levee _____Fence _____Other

Description (type, scour/deposition, problems, etc.): __________________________________

- Levee on left on other side of city's overflow channel
- Levee on right between channel and lake

## 4. Floodplain

Vegetation: ________ Crops __________ Range ___x___ Natural

Indicate vegetation type (e.g., cottonwood, shrubs, etc.) and condition (young, old, dying):

Mostly stressed cottonwoods__________________________________________________

______________________

Structures immediately adj. to channel: ____Home ____Deck ____Business

____Roads

Describe condition, age, and elevation above channel: ________________________________

______________________________________________________________________________

Debris in Floodplain: ____x___Trees _________Dump Areas

Count and/or areal extent: ____Some flood debris as well

__________________________________________________

# Cross Section Sketch

## NOTES

**Channel Banks** (angle, stability, failure type, cause of instability (e.g., channel migration), color, vegetative condition (good, fair, poor): ______________________________

**Channel Bed** (bed form (e.g., dunes, pool/riffle, etc.), bed material, armoring (also depth to hard material in alluvial channels), aggradation, degradation): ______________________________

- No armoring in bed
- No apparent degradation/aggregation, some left bank channel erosion downstream

**Channel Vegetation** (type (cottonwood, shrubs, etc.), extent (banks only, channel banks, sandbars), density (scattered, average, etc.), condition (healthy, dead, regrowth, etc.):

Mostly grass (left bank) and cobbles (right bank)

**Structures**:

__Levees______________________________

**Channelization**: _Yes______________________________

**Floodplain**: ______________________________

# Field Data Sheet

## 1. General Information

Stream: St.Vrain Site I.D. No. 4- Breach Area GPS File: 027 (Bed 1)

Latitude: ______ Longitude: ______ Photo Log: ______

Date: 5/10/16 Time: 11 am Surveyors: ______

Location Description: Just upstream of riprap

## 2. Channel Characteristics

Meandering down below

Planform: ___ Straight ___ Meander x Braided

Site Geometry: ___ Bend x Straight Channelized: ___ Yes x No

Bed Form: ___ Uniform Flow x Pool/Riffle ___ Step/Pool ___ Cascade

Channel Width (ft): ______ Top ______ Bankfull ______ EW

|  | Bed | Left | Right |
|---|---|---|---|
| **Bank Height (ft.)** |  | Levee 12’ +/- | 12’ +/- |
| **Bank Angle (°)** |  | < 1:1 | Vertical |
| **Bank Stability** |  | Fairly stable LWD | eroded |
| **Seepage Present** |  | None | None |
| **Armoring** | ? | Downstream of section riprap breach? |  |
| **Bed/Bank Material** | cobbles | Cobbles w/ vegetation | Cobbles with sandy loam |
| **Bed Form Meas.** |  |  |  |
| **Agg./Deb. Length (ft.)** | Appears to have dropped large sediment load here but rechannelized/degraded since |  |  |
| **Sediment Depth (ft.)** |  |  |  |
| **Vegetation** |  | Cottonwoods/grass | Bare |
| **O.B. Vegetation** |  |  | Sparse cottonwoods |
| **Levee Vegetation** |  | Grass |  |
| **Levee Height (ft.)** |  | 12’ +/- |  |
| **Levee Width (ft.)** |  | 30’ +/- |  |
| **Manning’s “n”** |  |  |  |

Notes concerning above: _

### 3. Structures

Diversion: _____ Yes ___x___ No

________ Conveyance Capacity Est. (______L______W______S)

Describe material, condition, and problems: ________________________________________

________________________________________________________________________________

________________________________________________________________________________

________________________________________________________________________________

Channel Improvements (describe type and effectiveness): _Riprap below section on left bank

________________________________________________________________________________

Other Structures: _____Bridge _____Culvert ___x__Levee _____Fence _____Other

Description (type, scour/deposition, problems, etc.): __Left bank levee- riprap, poorly graded, slab sandstone________________________________

### 4. Floodplain

Vegetation: _________ Crops ___________ Range __x_ Natural

Indicate vegetation type (e.g., cottonwood, shrubs, etc.) and condition (young, old, dying):

Stressed cottonwoods_____________________________________________________________

_________________

Structures immediately adj. to channel: ____Home ____Deck ____Business

____Roads

Describe condition, age, and elevation above channel: _________________________________

________________________________________________________________________________

Debris in Floodplain: ___x___Trees _________Dump Areas

Count and/or areal extent: __Significant flood debris and sediment deposition

______________________________________________________

## Cross Section Sketch

## NOTES

**Channel Banks** (angle, stability, failure type, cause of instability (e.g., channel migration), color, vegetative condition (good, fair, poor):

- Right bank vertical/active erosion
- Left bank fairly stable, levee (Breach 7) also steep
- Breach 6? To left of levee on left bank _

**Channel Bed** (bed form (e.g., dunes, pool/riffle, etc.), bed material, armoring (also depth to hard material in alluvial channels), aggradation, degradation): _ significant deposition of sediment, since flood channel appears to have channelized-some braiding/split around bars

**Channel Vegetation** (type (cottonwood, shrubs, etc.), extent (banks only, channel banks, sandbars), density (scattered, average, etc.), condition (healthy, dead, regrowth, etc.):

Sparse vegetation in bed of old channel, grass on let bank levee, armoring (Breach 7 repair), cottonwoods on overbanks

**Structures**: _

**Channelization**:

**Floodplain**: _

Bank heights from EW

# Field Data Sheet

## 1. General Information

Stream: St. Vrain Site I.D. No. 5 – upstream of Cemex Dr) GPS File: 030

Latitude: ______ Longitude: ______ Photo Log: ______

Date: 5/10/16 Time: 2:00 pm Surveyors: ZSB, ELR

Location Description: Parked at tarp removal area along Cemex Drive

Through Cemex Drive, meandering upstream bend downstream of breach

## 2. Channel Characteristics

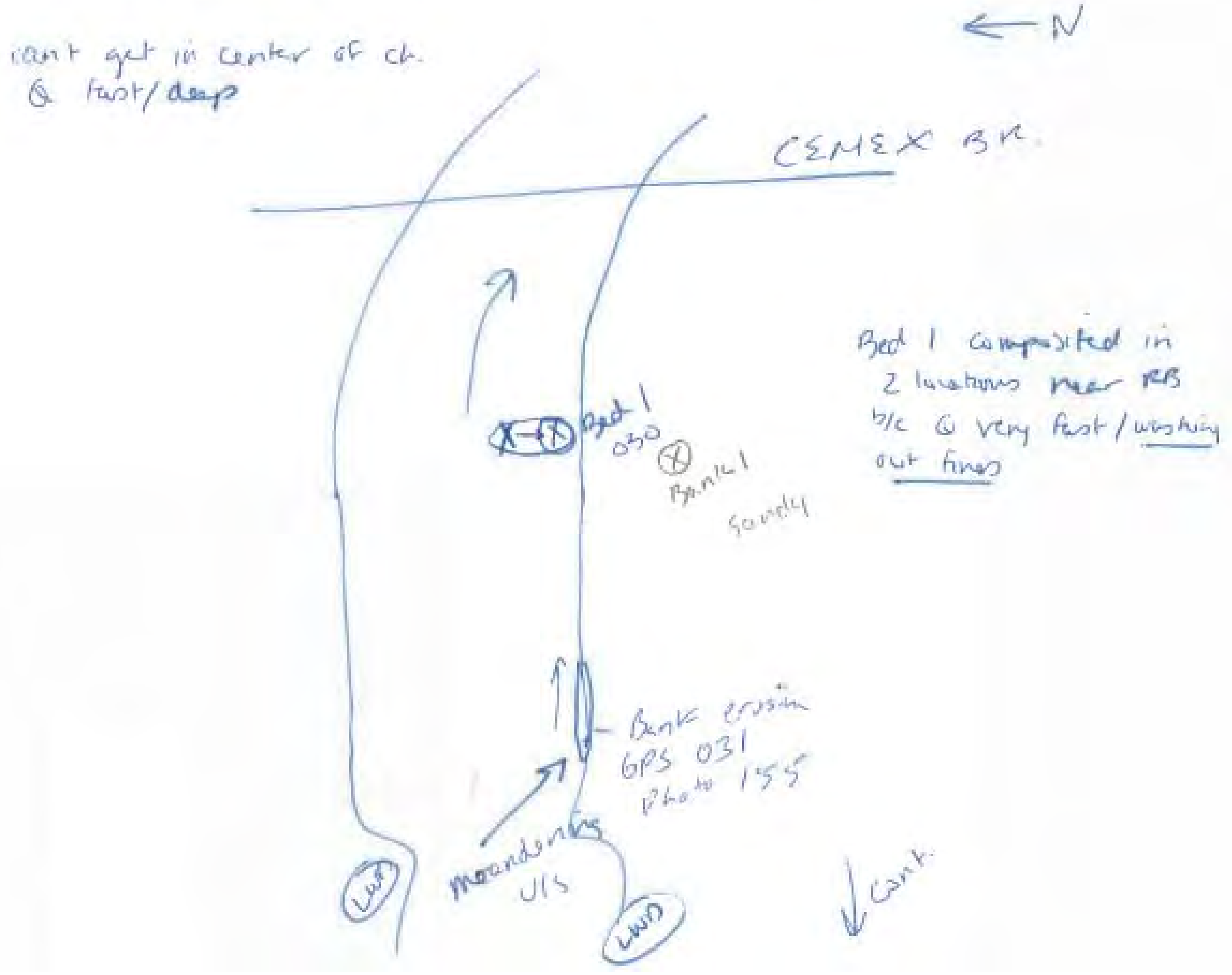
Planform: x Straight ____ Meander ____ Braided

Site Geometry: ____ Bend x Straight Channelized: ____ Yes x No

U/S

Bed Form: x Uniform Flow ____ Pool/Riffle ____ Step/Pool ____ Cascade

Channel Width (ft): ______Top ______ Bankfull 30' +/- EW



can't get in center of ch. @ fast/deep

Bed 1 composited in 2 locations near RB b/c @ very fast/washing out fines

| | Bed | Left | Right |
|---|---|---|---|
| **Bank Height (ft.)** | | 3’ +/- | 3-4’ |
| **Bank Angle (°)** | | 5:1 | Cobble shelf (flat), eroded veg. bank |
| **Bank Stability** | | Fairly stable | Some erosion above cobble |
| **Seepage Present** | | | |
| **Armoring** | None | None | None |
| **Bed/Bank Material** | | Woody debris, grass, cottonwoods | Sand/cobbles vegetation in OB |
| **Bed Form Meas.** | | | |
| **Agg./Deb. Length (ft.)** | No obvious degradation, apparent riffles upstream and below bridge | | |
| **Sediment Depth (ft.)** | | | |
| **Vegetation** | | Grass/cottonwoods/silt | Cobbles/cottonwoods/grass |
| **O.B. Vegetation** | | Tree cover but appears stressed | Nice riprap on OB |
| **Levee Vegetation** | | None | None |
| **Levee Height (ft.)** | | | |
| **Levee Width (ft.)** | | | |
| **Manning’s “n”** | | | |

Notes concerning above: ________________________________________

## 3. Structures

Diversion: _____ Yes ___x___ No

________ Conveyance Capacity Est. (______L______W______S)

Describe material, condition, and problems: ________________________________________

Channel Improvements (describe type and effectiveness): _____________None_____________

Other Structures: __x___Bridge _____Culvert _____Levee _____Fence _____Other

Description (type, scour/deposition, problems, etc.): ________________________________

No obvious scour, deposition behind abetment on left riffle under br.

## 4. Floodplain

Vegetation: _________ Crops ___________ Range _x_ Natural

Indicate vegetation type (e.g., cottonwood, shrubs, etc.) and condition (young, old, dying):

Cottonwoods-old_

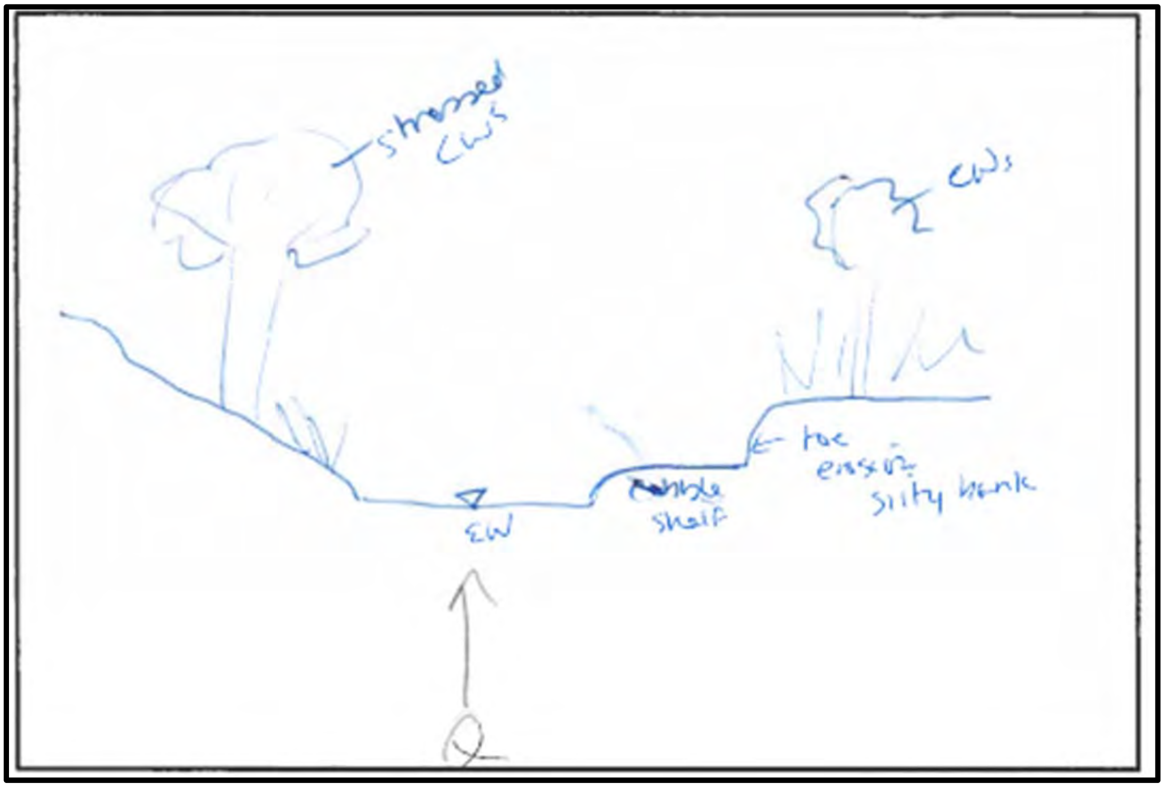
Structures immediately adj. to channel: ____Home ____Deck ____Business ____Roads

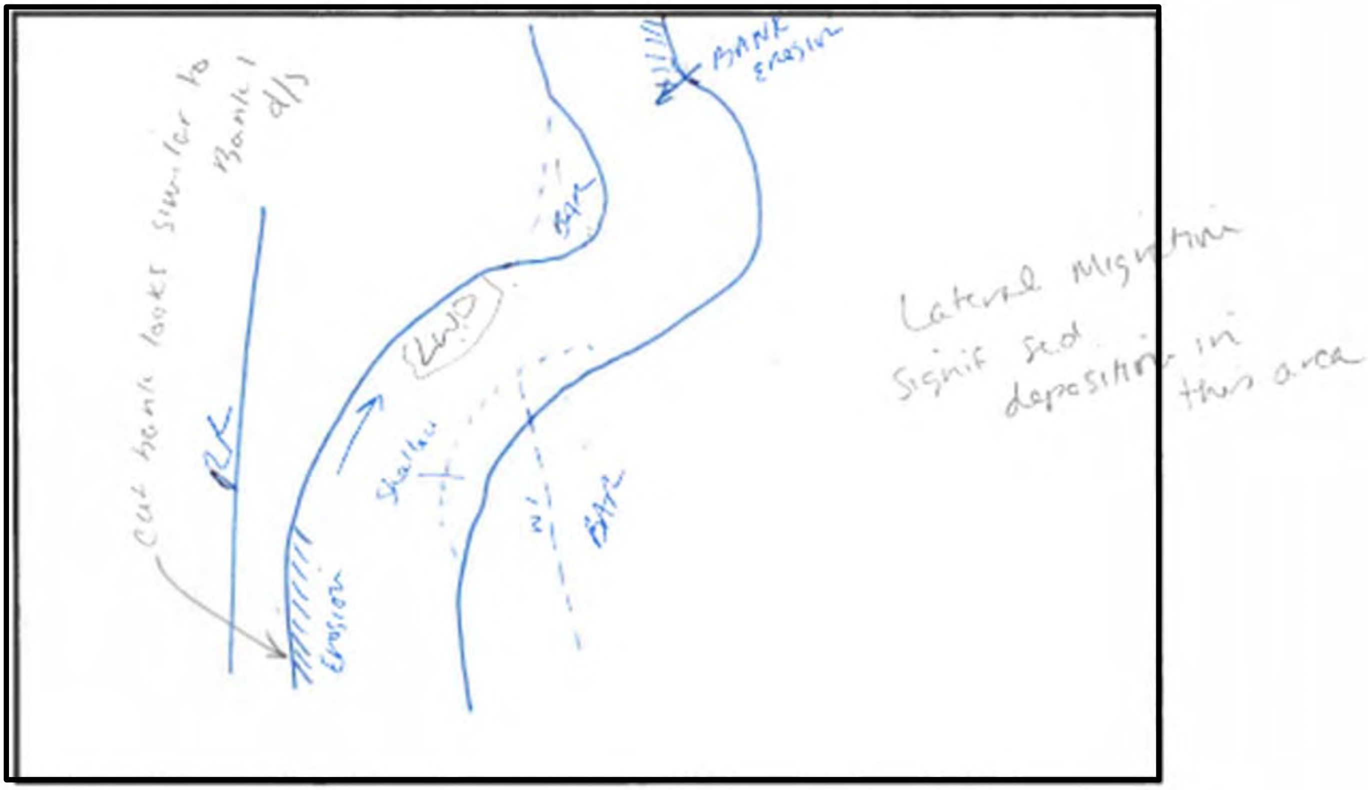
Describe condition, age, and elevation above channel: _________________________________

Debris in Floodplain: ___x____Trees _________Dump Areas

Count and/or areal extent: ______________________________________________________

# Cross Section Sketch





## NOTES

**Channel Banks** (angle, stability, failure type, cause of instability (e.g., channel migration), color, vegetative condition (good, fair, poor): __Fairly stable reach, debris from flood, some scour on right bank

**Channel Bed** (bed form (e.g., dunes, pool/riffle, etc.), bed material, armoring (also depth to hard material in alluvial channels), aggradation, degradation): _Straight section between meanders (upstream) and bend (downstream), obvious riffles upstream and downstream

**Channel Vegetation** (type (cottonwood, shrubs, etc.), extent (banks only, channel banks, sandbars), density (scattered, average, etc.), condition (healthy, dead, regrowth, etc.):

_ No bars, cottonwood, shrubs, grasses on banks and OBs, some cottonwoods stressed

**Structures**: ___Cemex Bridge

**Channelization**: ______No

**Floodplain**:

# Field Data Sheet

## 1. General Information

Stream: St. Vrain Site I.D. No. 6-Breach 2 GPS File: 033

Latitude: ______ Longitude: ______ Photo Log: ______

Date: 5/10/ 16 Time: ______ Surveyors: ELR/ZSB

Location Description: ______

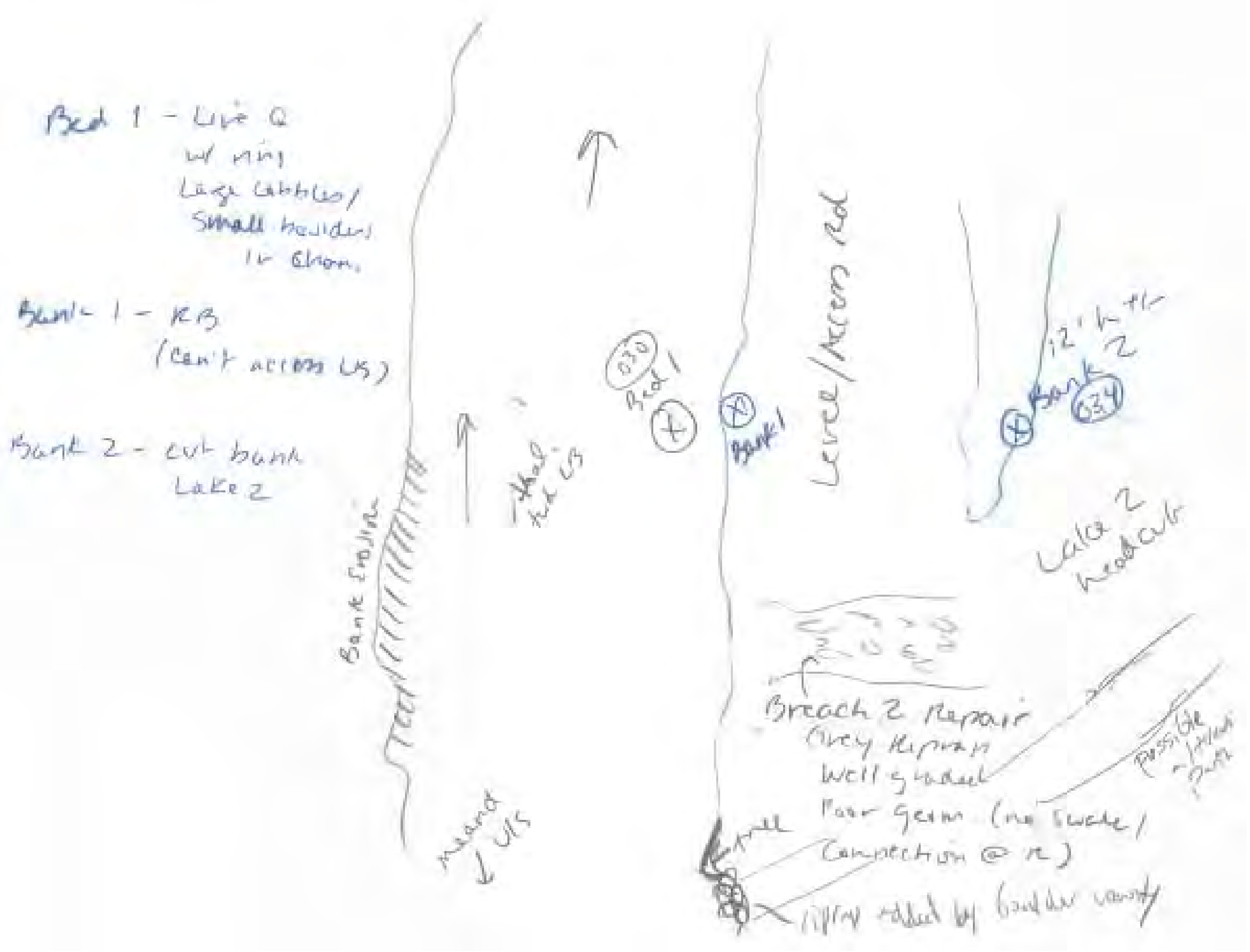
## 2. Channel Characteristics

Planform: x Straight ____ Meander ____ Braided

Site Geometry: ____ Bend x Straight Channelized: ____ Yes ____ No

Bed Form: x Uniform Flow ____ Pool/Riffle ____ Step/Pool ____ Cascade

Channel Width (ft): ______ Top ______ Bankfull ______ EW



| | Bed | Left | Right |
|---|---|---|---|
| **Bank Height (ft.)** | | 3’ | 8’ |
| **Bank Angle (°)** | | Vertical cut | 1.5:1 at B2<br>2:1 downstream |
| **Bank Stability** | | erosion | Some toe erosion |
| **Seepage Present** | | | |
| **Armoring** | no | | On right bank across from Breach 2 |
| **Bed/Bank Material** | | Silty/sand | |
| **Bed Form Meas.** | | | |
| **Agg./Deb. Length (ft.)** | Degradation through reach (through straight section) | | |
| **Sediment Depth (ft.)** | | | |
| **Vegetation** | | Sparse grass/weeds/cottonwoods | Cobbles |
| **O.B. Vegetation** | | “ | Sparse grass and weeds |
| **Levee Vegetation** | | | “ |
| **Levee Height (ft.)** | | | 8’ |
| **Levee Width (ft.)** | | | 45’ +/- |
| **Manning’s “n”** | | | |

Notes concerning above: _ Organics in bed # 1 sample

## 3. Structures

Diversion: _____ Yes ___x___ No

________ Conveyance Capacity Est. (______L______W______S)

Describe material, condition, and problems: ________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

Channel Improvements (describe type and effectiveness):

- Breach 2 repair
- Some riprap on bank side of breach repair____

Other Structures: _____Bridge _____Culvert__x___Levee _____Fence _____Other

Description (type, scour/deposition, problems, etc.): __Right bank between Road and Lake 2

## 4. Floodplain

Vegetation: _________ Crops ___________ Range x___ Natural

Indicate vegetation type (e.g., cottonwood, shrubs, etc.) and condition (young, old, dying):

________________________________________________________________

. ______________________________________________________________

________________________________________________________________

Structures immediately adj. to channel: ____Home ____Deck ____Business

____Roads

Describe condition, age, and elevation above channel: ______________________________

________________________________________________________________

Debris in Floodplain: ___x____Trees _________Dump Areas

Count and/or areal extent: ____________________________________________________

________________________________________________________________

## Cross Section Sketch

## NOTES

**Channel Banks** (angle, stability, failure type, cause of instability (e.g., channel migration), color, vegetative condition (good, fair, poor):

- Undercutting left bank, sparse vegetation
- Straightened section

**Channel Bed** (bed form (e.g., dunes, pool/riffle, etc.), bed material, armoring (also depth to hard material in alluvial channels), aggradation, degradation):

- Uniform through reach, meandering P/R above
- Degradation apparent through section_

**Channel Vegetation** (type (cottonwood, shrubs, etc.), extent (banks only, channel banks, sandbars), density (scattered, average, etc.), condition (healthy, dead, regrowth, etc.):

_Cottonwoods some healthy, some stressed

**Structures**: __Levee on right bank

**Channelization**: _Right bank levee

**Floodplain**: _

# Field Data Sheet

## 1. General Information

Stream: St. Vrain Site I.D. No. 7 GPS File: 036

Latitude: ______________ Longitude: ________________ Photo Log: _______________

Date: 5/11/16 Time: 9:15 Surveyors: ZSB/ELR

Location Description: Downstream of Breach 3- near CDWR gaps

## 2. Channel Characteristics

Planform: _____ Straight x Meander _____ Braided

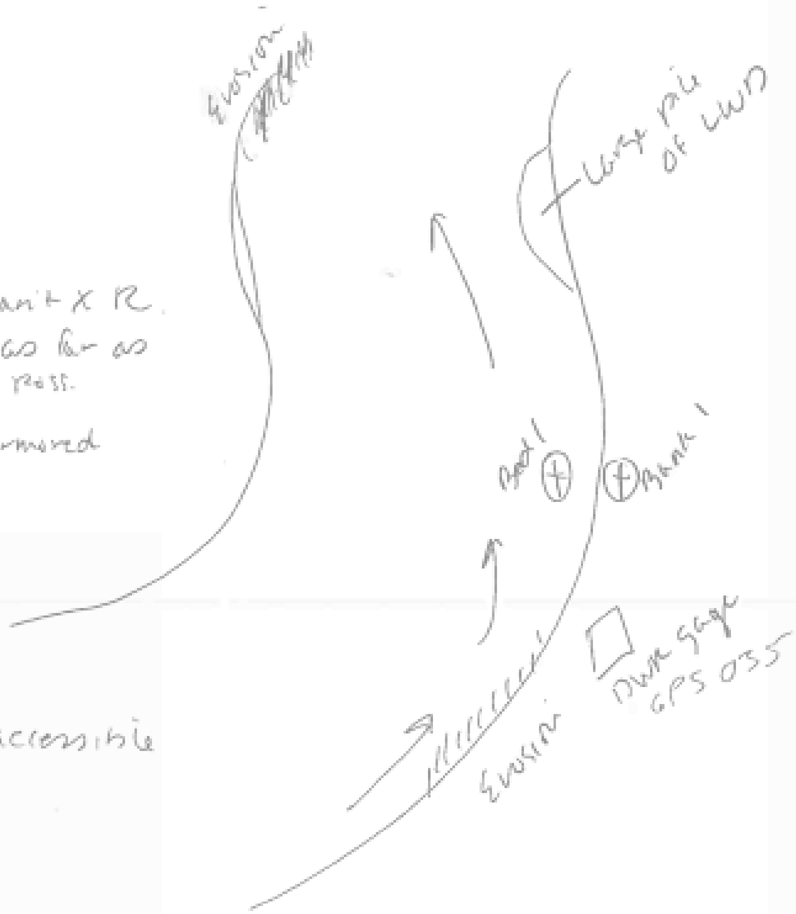
Site Geometry: x Bend _____ Straight Channelized: _____ Yes x No

Bed Form: _____ Uniform Flow x Pool/Riffle _____ Step/Pool _____ Cascade

Channel Width (ft): __________ Top 35' +/- Bankfull 25' +/- EW

Bed 1
grvls in G.
strong current - can't X R.
went into chan. as far as
poss.

bed feels more armored



Bank 1
RB - LB not accessible

|  | Bed | Left | Right |
|---|---|---|---|
| **Bank Height (ft.)** |  | Fairly flat 2’ max | < 2’ |
| **Bank Angle (°)** |  | 8:1? | Near vertical |
| **Bank Stability** |  | Stable here but erosion on outside bends | Some erosion |
| **Seepage Present** |  |  |  |
| **Armoring** | possibly |  |  |
| **Bed/Bank Material** | Large cobbles | Sandy/silt, much fewer cobbles than right bank | Sandy silt with large cobbles |
| **Bed Form Meas.** |  |  |  |
| **Agg./Deb. Length (ft.)** | No apparent degrading of bed visible but clear lateral migration |  |  |
| **Sediment Depth (ft.)** |  |  |  |
| **Vegetation** |  | willows | Grass/cottonwoods |
| **O.B. Vegetation** |  | Willows/cottonwoods | “ |
| **Levee Vegetation** |  |  |  |
| **Levee Height (ft.)** |  |  |  |
| **Levee Width (ft.)** |  |  |  |
| **Manning’s “n”** | .035 | .06 | .05 |

Notes concerning above: _______________________________________________

_______________________________________________________________

_______________________________________________________________

_______________________________________________________________

## 3. Structures

Diversion: _____ Yes ___x___ No

________ Conveyance Capacity Est. (______L______W______S)

Describe material, condition, and problems: ________________________________________

Channel Improvements (describe type and effectiveness): ____________None____________

Other Structures: _____Bridge _____Culvert _____Levee _____Fence _____Other

Description (type, scour/deposition, problems, etc.): ________________________________

## 4. Floodplain

Vegetation: ________ Crops __________ Range x___ Natural

Indicate vegetation type (e.g., cottonwood, shrubs, etc.) and condition (young, old, dying):

.

Structures immediately adj. to channel: ____Home ____Deck ____Business

____Roads

Describe condition, age, and elevation above channel: ______________________________

Debris in Floodplain: ____x__Trees _________Dump Areas

Count and/or areal extent: ____Significant LWD in places

## Cross Section Sketch

## NOTES

**Channel Banks** (angle, stability, failure type, cause of instability (e.g., channel migration), color, vegetative condition (good, fair, poor): _Active lateral migration- thalweg switching around bends outside bend erosion

**Channel Bed** (bed form (e.g., dunes, pool/riffle, etc.), bed material, armoring (also depth to hard material in alluvial channels), aggradation, degradation):

- Pool/Riffle
- Bed appears armored-larger cobbles_

**Channel Vegetation** (type (cottonwood, shrubs, etc.), extent (banks only, channel banks, sandbars), density (scattered, average, etc.), condition (healthy, dead, regrowth, etc.):

healthier riparian areas both sides_

.

**Structures**: _ ____DWR gage – Not active_______

**Channelization**: __________None

**Floodplain**: _

# Field Data Sheet

## 1. General Information

Stream: St. Vrain Site I.D. No. 8 GPS File: 037, 038

Latitude: ________ Longitude: ________ Photo Log: ________

Date: 5/11/16 Time: 10:30 Surveyors: ELR/ZSB

Location Description: Breach 4 area on BCPOS property downstream of 63 bridge

## 2. Channel Characteristics

Planform: ____ Straight ____ Meander x Braided

Site Geometry: x Bend ____ Straight Channelized: ____ Yes x No

Bed Form: ____ Uniform Flow x Pool/Riffle ____ Step/Pool ____ Cascade

Channel Width (ft): ________ Top ________ Bankfull ________ EW

| | Bed | Left | Right |
|---|---|---|---|
| **Bank Height (ft.)** | | Can’t see native bank, all cobble deposition | “ |
| **Bank Angle (°)** | | Cobble deposition | “ |
| **Bank Stability** | | Erosion upstream below br. | Cobble deposition, bank erosion downstream B4 |
| **Seepage Present** | | | |
| **Armoring** | Possibly same in places | | |
| **Bed/Bank Material** | cobble | Banks gore cobble deposition | Bank gore cut into field |
| **Bed Form Meas.** | | | |
| **Agg./Deb. Length (ft.)** | Looks like aggregation originated after flood-now channel trying to braid, rechannelize | | |
| **Sediment Depth (ft.)** | | | |
| **Vegetation** | None | none | None |
| **O.B. Vegetation** | | Sparse cottonwoods | Sparse/stressed cottonwoods |
| **Levee Vegetation** | | | |
| **Levee Height (ft.)** | | | |
| **Levee Width (ft.)** | | | |
| **Manning’s “n”** | Rougher than other locations | | |

Notes concerning above: Talked with Brian (BCPOS) and he said River here used to be single thread-a width of one of the splits (40’+/-), both banks gone, significant widening and flood debris and cobbles

## 3. Structures

Diversion: _____ Yes ___x__ No

________ Conveyance Capacity Est. (______L______W______S)

Describe material, condition, and problems: ______________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

Channel Improvements (describe type and effectiveness): _Can see some attempts of emerging armoring downstream ________

Other Structures: ___x__Bridge _____Culvert _____Levee _____Fence _____Other

Description (type, scour/deposition, problems, etc.): _63rd street bridge upstream about 500 feet _________________

## 4. Floodplain

Vegetation: ________ Crops ________x___ Range __X___ Natural

Indicate vegetation type (e.g., cottonwood, shrubs, etc.) and condition (young, old, dying):

__________________________________________________________________________

. __ __________________________________________________________________ ___

__________________________________________________________________________

Structures immediately adj. to channel: __x__Home ____Deck ____Business

____Roads

Describe condition, age, and elevation above channel: _________________________________

__________________________________________________________________________

Debris in Floodplain: ____x___Trees _________Dump Areas

Count and/or areal extent: ______________________________________________________

__________________________________________________________________________

## Cross Section Sketch

# NOTES

**Channel Banks** (angle, stability, failure type, cause of instability (e.g., channel migration), color, vegetative condition (good, fair, poor): _ Banks were washed out by flood-significant widening

**Channel Bed** (bed form (e.g., dunes, pool/riffle, etc.), bed material, armoring (also depth to hard material in alluvial channels), aggradation, degradation): _Braiding around cobble bars

**Channel Vegetation** (type (cottonwood, shrubs, etc.), extent (banks only, channel banks, sandbars), density (scattered, average, etc.), condition (healthy, dead, regrowth, etc.):

Sparse vegetation on bars

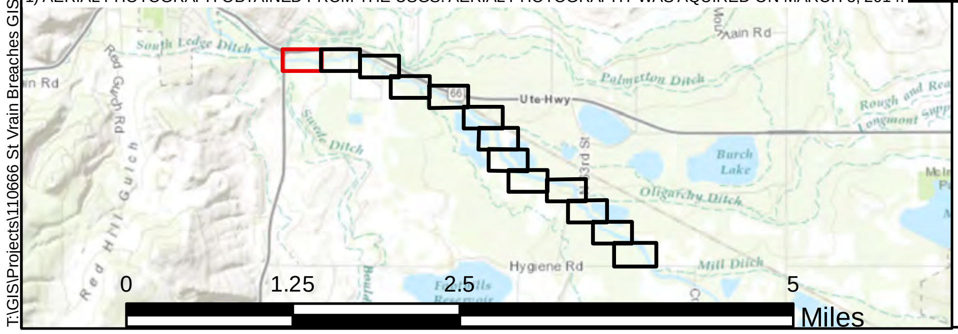
Stressed/dying cottonwoods on banks__

**Structures**: ___63rd bridge upstream

**Channelization**:

**Floodplain**:

NOTES:
1) AERIAL PHOTOGRAPH OBTAINED FROM THE USGS. AERIAL PHOTOGRAPHY WAS AQUIRED ON MARCH 5, 2014.



## EXPLANATION

| | |
|---|---|
| 🟩 | Parcel Owned by BCPOS |
| ☐ | Parcel Owned by Others |
| 🟥 | Observations noted in the field (May 2016) |
| 190+00 | Centerline With Station Number |
| BREACH 1 | Approximate Breach Location |

0 100 200 400
Feet
SCALE: 1" = 100'

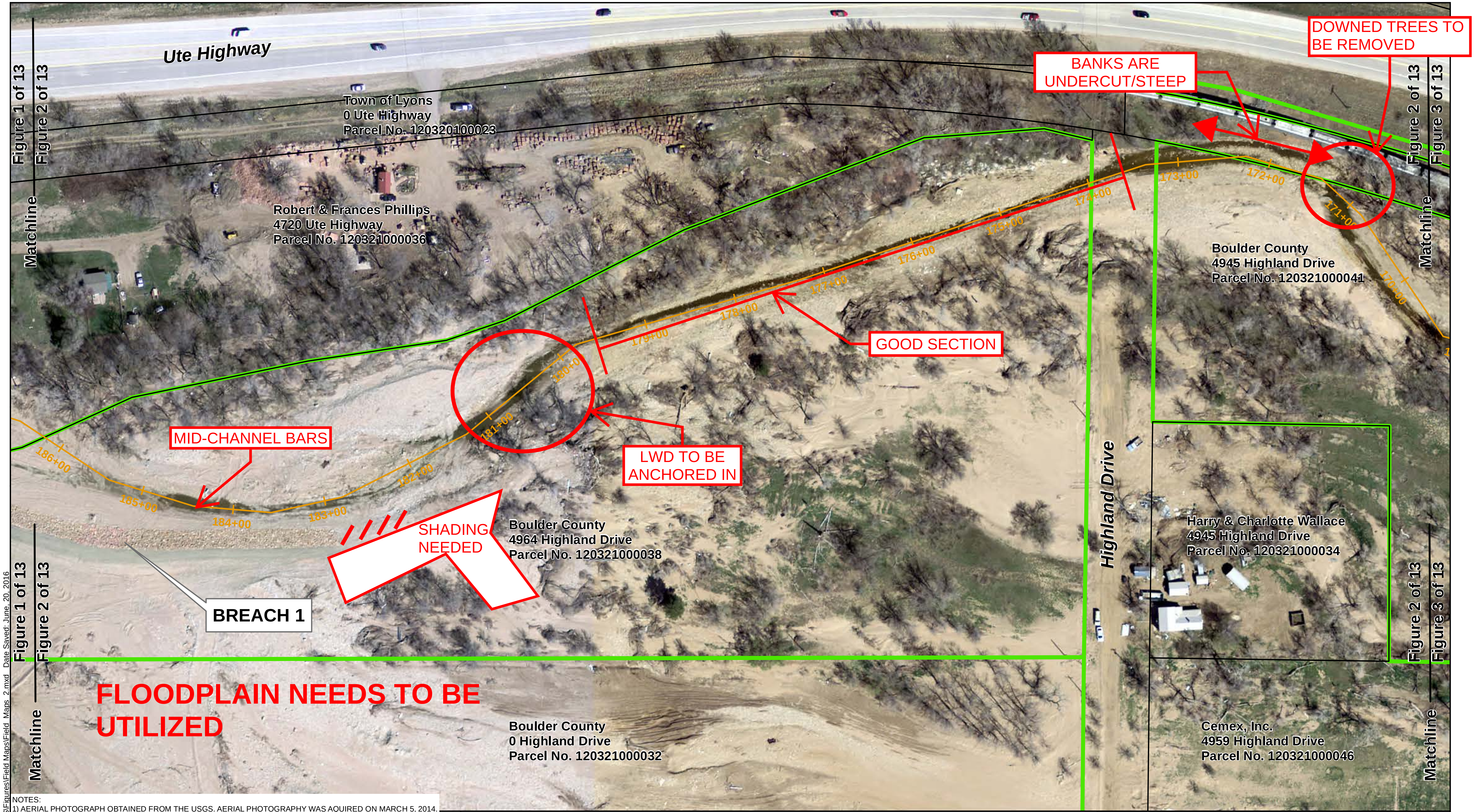
N

Engineering Analytics, Inc.

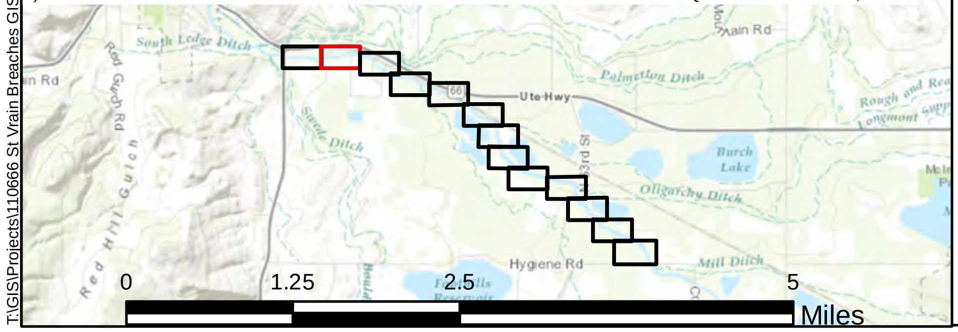
**ST. VRAIN CREEK BREACHES RESTORATION**
**Flood Planning & Preliminary Engineering Services**
**Field Investigation Maps**

Date: June 2016
Project No.: 110666
Figure 1 of 13

T:\GIS\Projects\110666 St Vrain Breaches GIS\Figures\Field Maps\Field Maps 1.mxd Date Saved: June, 20, 2016



NOTES:
1) AERIAL PHOTOGRAPH OBTAINED FROM THE USGS. AERIAL PHOTOGRAPHY WAS AQUIRED ON MARCH 5, 2014.



**EXPLANATION**

| | |
|---|---|
| 🟩 | Parcel Owned by BCPOS |
| ☐ | Parcel Owned by Others |
| 🟥 | Observations noted in the field (May 2016) |
| 190+00 | Centerline With Station Number |
| BREACH 1 | Approximate Breach Location |

0 100 200 400
Feet
SCALE: 1" = 100'

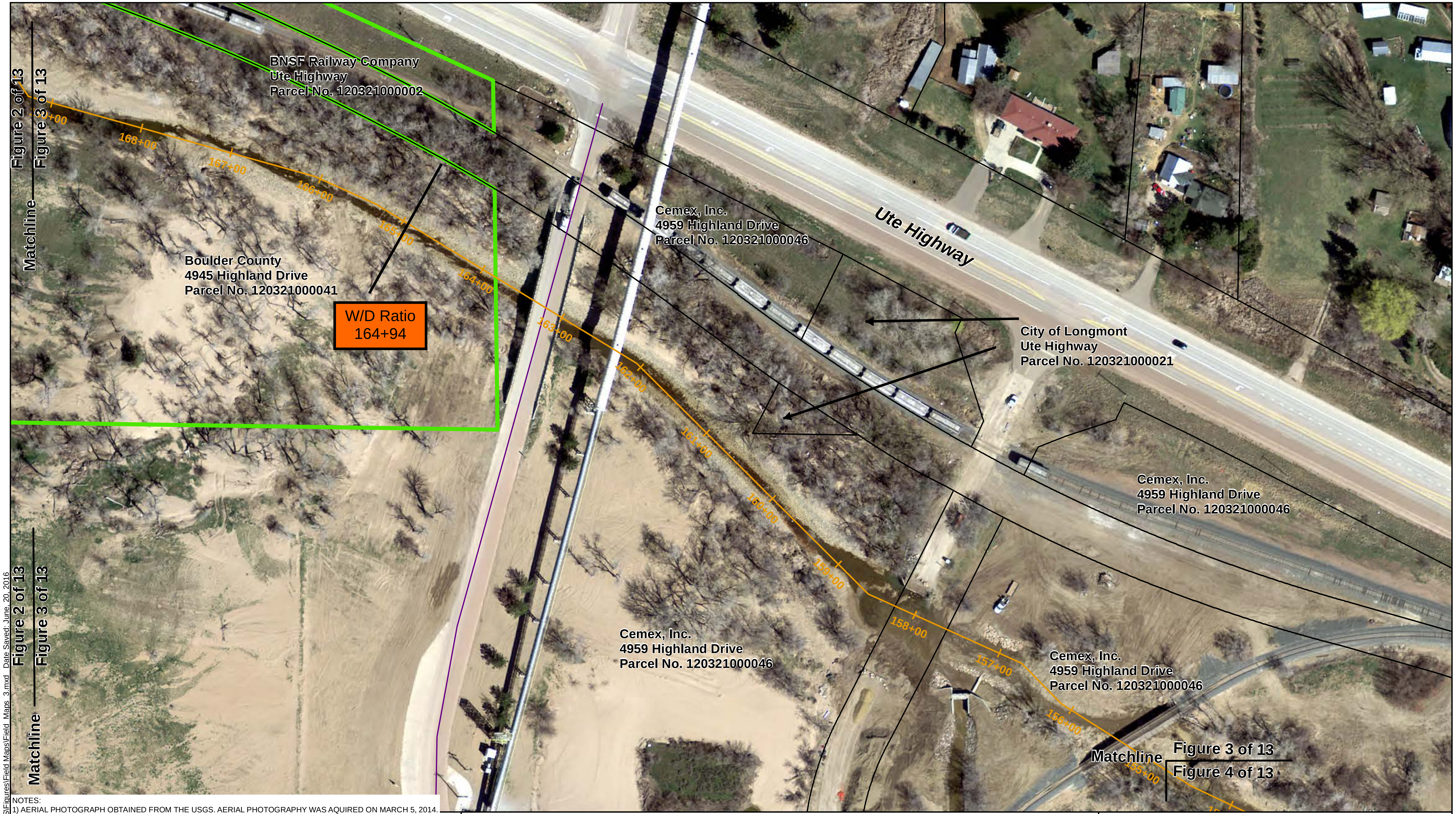
N

Engineering Analytics, Inc.

**ST. VRAIN CREEK BREACHES RESTORATION**
**Flood Planning & Preliminary**
**Engineering Services**
**Field Investigation Maps**

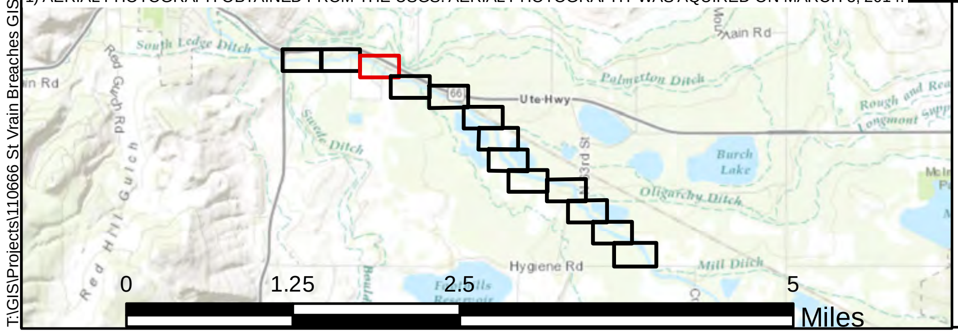
| | | |
|---|---|---|
| Date: June 2016 | Project No.: 110666 | Figure 2 of 13 |

T:\GIS\Projects\110666 St Vrain Breaches GIS\Figures\Field Maps\Field Maps 2.mxd Date Saved: June, 20, 2016



T:\GIS\Projects\110666 St Vrain Breaches GIS\Figures\Field Maps\Field Maps 3.mxd Date Saved: June, 20, 2016

NOTES:
1) AERIAL PHOTOGRAPH OBTAINED FROM THE USGS. AERIAL PHOTOGRAPHY WAS AQUIRED ON MARCH 5, 2014.



## EXPLANATION

| | |
|---|---|
| 🟩 | Parcel Owned by BCPOS |
| ☐ | Parcel Owned by Others |
| 🟥 | Observations noted in the field (May 2016) |
| 190+00 | Centerline With Station Number |
| **BREACH 1** | Approximate Breach Location |

0 100 200 400

Feet

SCALE: 1" = 100'

N

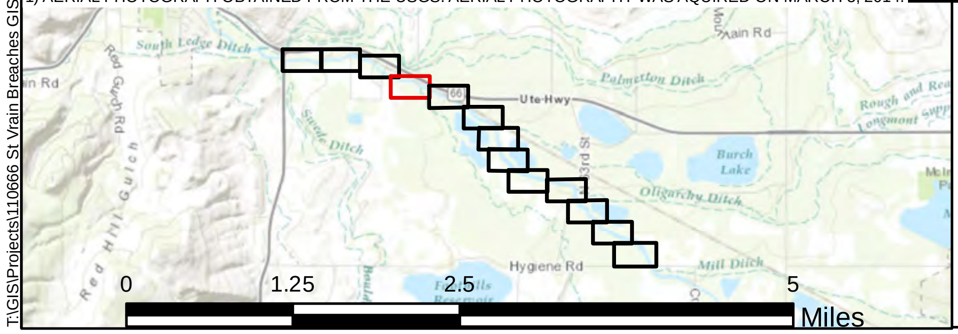
Engineering Analytics, Inc.

**ST. VRAIN CREEK BREACHES RESTORATION**
**Flood Planning & Preliminary**
**Engineering Services**
**Field Investigation Maps**

| | | |
|---|---|---|
| Date: June 2016 | Project No.: 110666 | Figure 3 of 13 |

T:\GIS\Projects\110666 St Vrain Breaches GIS\Figures\Field Maps\Field Maps 4.mxd Date Saved: June, 20, 2016

NOTES:
1) AERIAL PHOTOGRAPH OBTAINED FROM THE USGS. AERIAL PHOTOGRAPHY WAS AQUIRED ON MARCH 5, 2014.



## EXPLANATION

🟩 Parcel Owned by BCPOS

☐ Parcel Owned by Others

🟥 Observations noted in the field (May 2016)

190+00 Centerline With Station Number

**BREACH 1** Approximate Breach Location

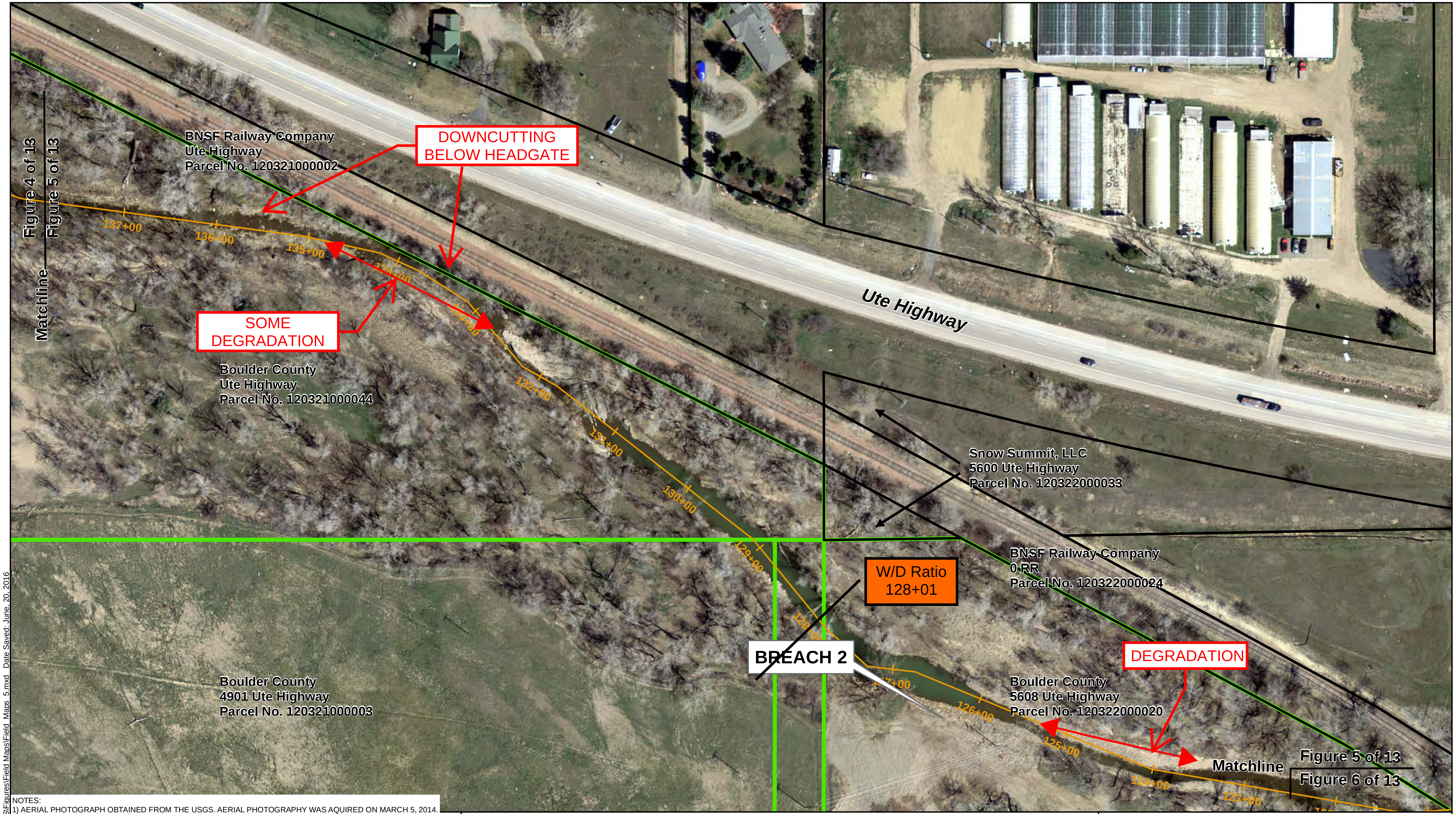
0 100 200 400
Feet
SCALE: 1" = 100'

N

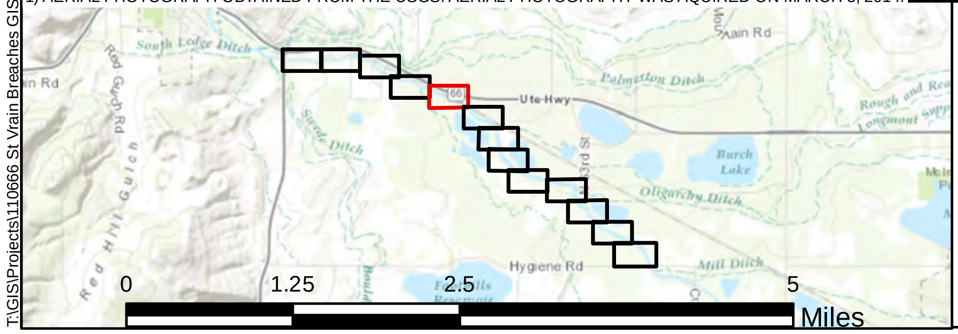
Engineering Analytics, Inc.

**ST. VRAIN CREEK BREACHES RESTORATION**
**Flood Planning & Preliminary**
**Engineering Services**
**Field Investigation Maps**

| | | |
|---|---|---|
| Date: June 2016 | Project No.: 110666 | Figure 4 of 13 |



NOTES:
1) AERIAL PHOTOGRAPH OBTAINED FROM THE USGS. AERIAL PHOTOGRAPHY WAS AQUIRED ON MARCH 5, 2014.



**EXPLANATION**

| | |
|---|---|
| 🟥 | Observations noted in the field (May 2016) |
| 🟩 | Parcel Owned by BCPOS |
| 190+00 | Centerline With Station Number |
| ☐ | Parcel Owned by Others |
| BREACH 1 | Approximate Breach Location |

0 100 200 400
Feet
SCALE: 1" = 100'

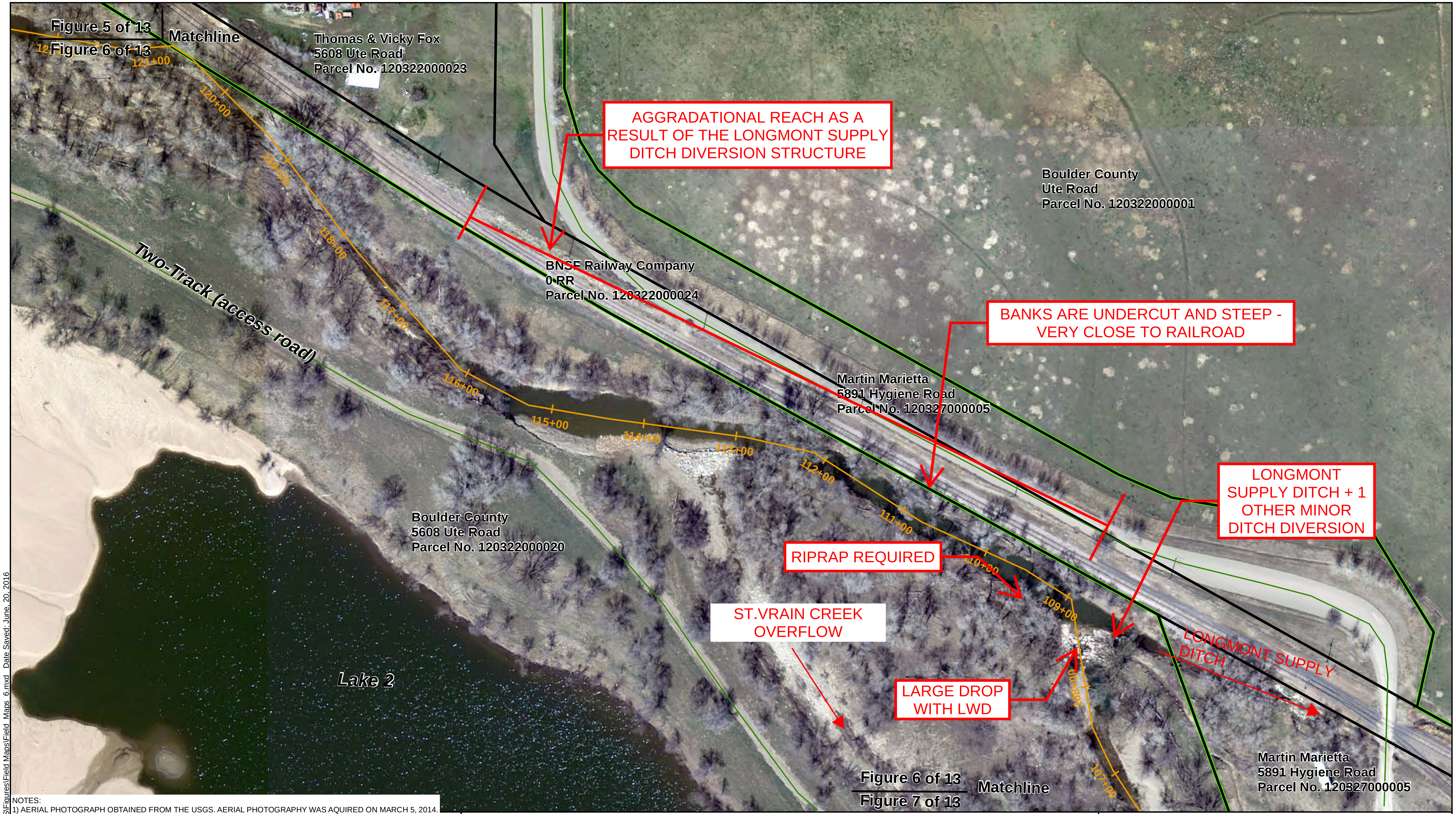
N

Engineering Analytics, Inc.

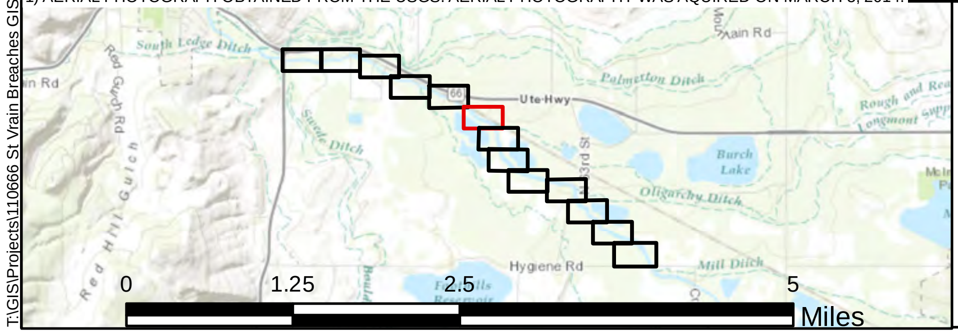
**ST. VRAIN CREEK BREACHES RESTORATION**
**Flood Planning & Preliminary**
**Engineering Services**
**Field Investigation Maps**

| Date: June 2016 | Project No.: 110666 | Figure 5 of 13 |
|---|---|---|

T:\GIS\Projects\110666 St Vrain Breaches GIS\Figures\Field Maps\Field_Maps_5.mxd Date Saved: June, 20, 2016



NOTES:
1) AERIAL PHOTOGRAPH OBTAINED FROM THE USGS. AERIAL PHOTOGRAPHY WAS AQUIRED ON MARCH 5, 2014.



**EXPLANATION**

| | |
|---|---|
| 🟩 | Parcel Owned by BCPOS |
| ☐ | Parcel Owned by Others |
| — | Observations noted in the field (May 2016) |
| 190+00 | Centerline With Station Number |
| BREACH 1 | Approximate Breach Location |

0 100 200 400
Feet
SCALE: 1" = 100'

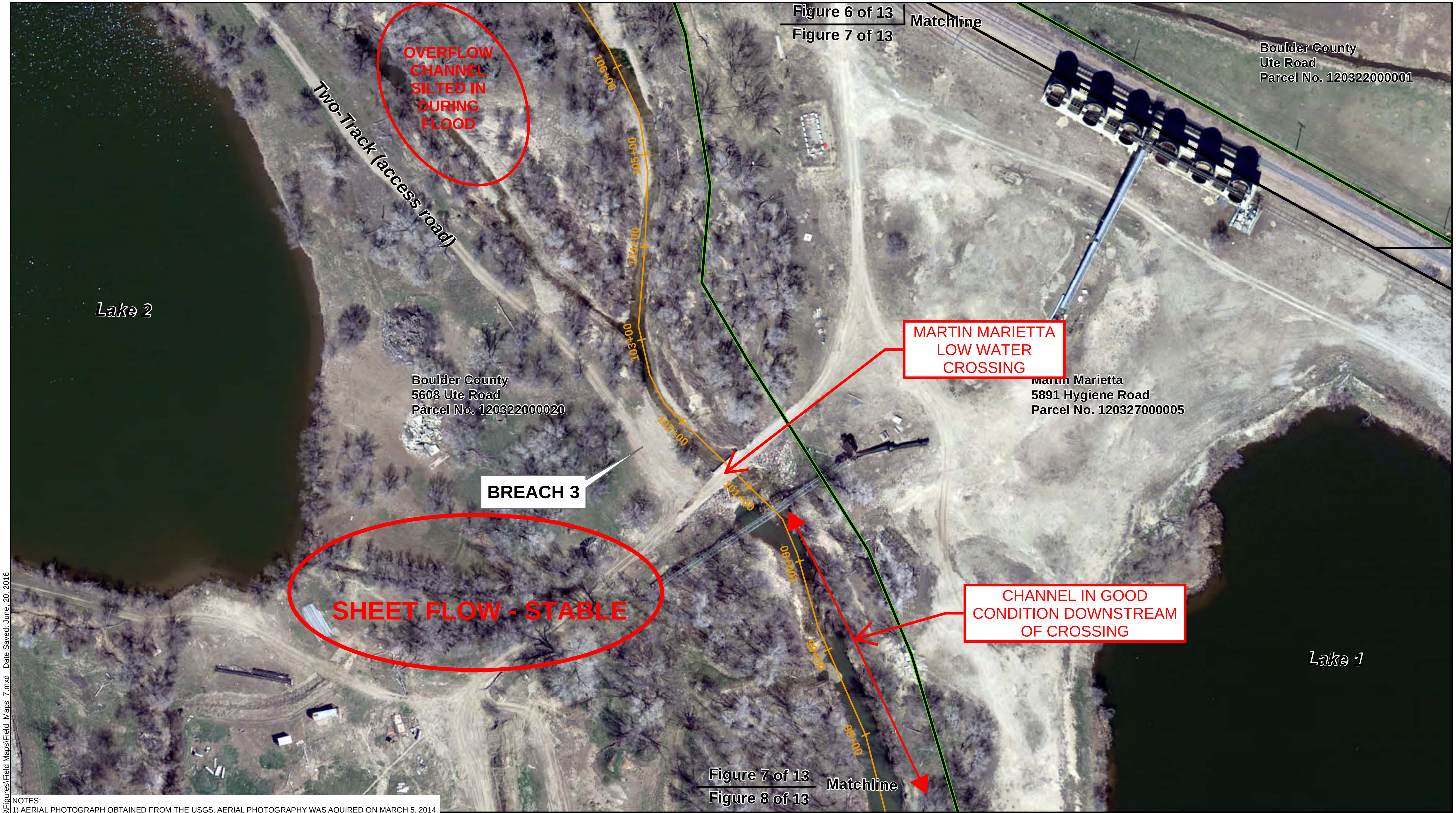
N

Engineering Analytics, Inc.

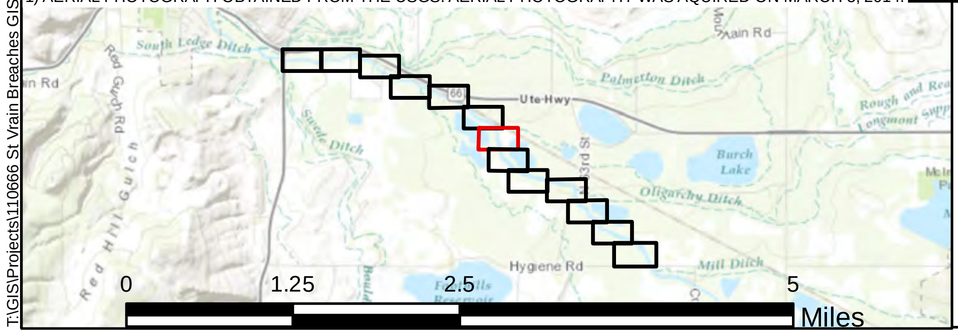
**ST. VRAIN CREEK BREACHES RESTORATION**
**Flood Planning & Preliminary**
**Engineering Services**
**Field Investigation Maps**

| Date: June 2016 | Project No.: 110666 | Figure 6 of 13 |
|---|---|---|

T:\GIS\Projects\110666 St Vrain Breaches GIS\Figures\Field Maps\Field_Maps_6.mxd Date Saved: June, 20, 2016



NOTES:
1) AERIAL PHOTOGRAPH OBTAINED FROM THE USGS. AERIAL PHOTOGRAPHY WAS AQUIRED ON MARCH 5, 2014.



**EXPLANATION**

| | |
|---|---|
| 🟩 | Parcel Owned by BCPOS |
| ☐ | Parcel Owned by Others |
| 🟥 | Observations noted in the field (May 2016) |
| 190+00 | Centerline With Station Number |
| **BREACH 1** | Approximate Breach Location |

0 100 200 400
Feet
SCALE: 1" = 100'

N

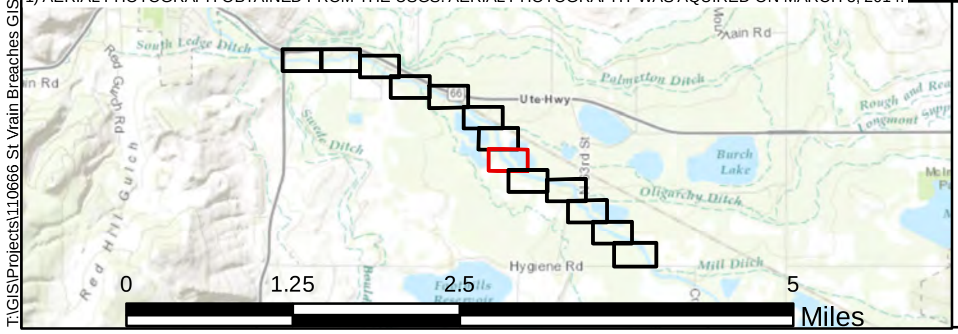
Engineering Analytics, Inc.

**ST. VRAIN CREEK BREACHES RESTORATION**
**Flood Planning & Preliminary**
**Engineering Services**
**Field Investigation Maps**

| | | |
|---|---|---|
| Date: June 2016 | Project No.: 110666 | Figure 7 of 13 |

T:\GIS\Projects\110666 St Vrain Breaches GIS\Figures\Field Maps\Field_Maps_7.mxd   Date Saved: June, 20, 2016

NOTES:
1) AERIAL PHOTOGRAPH OBTAINED FROM THE USGS. AERIAL PHOTOGRAPHY WAS AQUIRED ON MARCH 5, 2014.



T:\GIS\Projects\110666 St Vrain Breaches GIS\Figures\Field Maps\Field_Maps_8.mxd Date Saved: June, 20, 2016

**EXPLANATION**

| | |
|---|---|
| 🟩 | Parcel Owned by BCPOS |
| ☐ | Parcel Owned by Others |
| 🟥 | Observations noted in the field (May 2016) |
| 190+00 | Centerline With Station Number |
| BREACH 1 | Approximate Breach Location |

0 100 200 400
Feet
SCALE: 1" = 100'

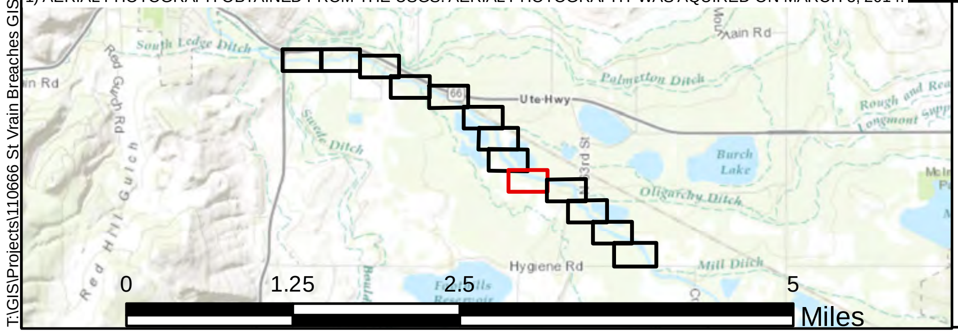
N

Engineering Analytics, Inc.

**ST. VRAIN CREEK BREACHES RESTORATION**
**Flood Planning & Preliminary Engineering Services**
**Field Investigation Maps**

| Date: June 2016 | Project No.: 110666 | Figure 8 of 13 |
|---|---|---|

NOTES:
1) AERIAL PHOTOGRAPH OBTAINED FROM THE USGS. AERIAL PHOTOGRAPHY WAS AQUIRED ON MARCH 5, 2014.



**EXPLANATION**

| | |
|---|---|
| 🟩 | Parcel Owned by BCPOS |
| ☐ | Parcel Owned by Others |
| 🟥 | Observations noted in the field (May 2016) |
| 190+00 | Centerline With Station Number |
| BREACH 1 | Approximate Breach Location |

0 100 200 400
Feet
SCALE: 1" = 100'

N

Engineering Analytics, Inc.

**ST. VRAIN CREEK BREACHES RESTORATION**
**Flood Planning & Preliminary**
**Engineering Services**
**Field Investigation Maps**

| Date: June 2016 | Project No.: 110666 | Figure 9 of 13 |
|---|---|---|

T:\GIS\Projects\110666 St Vrain Breaches GIS\Figures\Field Maps\Field Maps 9.mxd Date Saved: June, 20, 2016

T:\GIS\Projects\110666 St Vrain Breaches GIS\Figures\Field Maps\Field_Maps_10.mxd Date Saved: June 20, 2016

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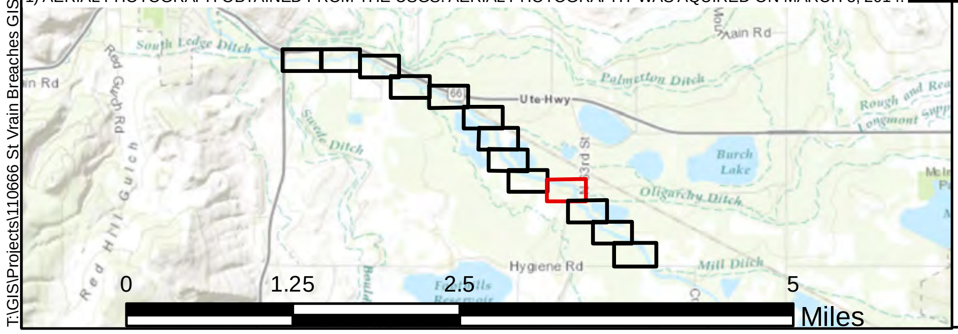
1) AERIAL PHOTOGRAPH OBTAINED FROM THE USGS. AERIAL PHOTOGRAPHY WAS AQUIRED ON MARCH 5, 2014.



**EXPLANATION**

| | | | |
|---|---|---|---|
| 🟩 | Parcel Owned by BCPOS | 🟥 | Observations noted in the field (May 2016) |
| ☐ | Parcel Owned by Others | 190+00 | Centerline With Station Number |
| | | BREACH 1 | Approximate Breach Location |

0 100 200 400

Feet

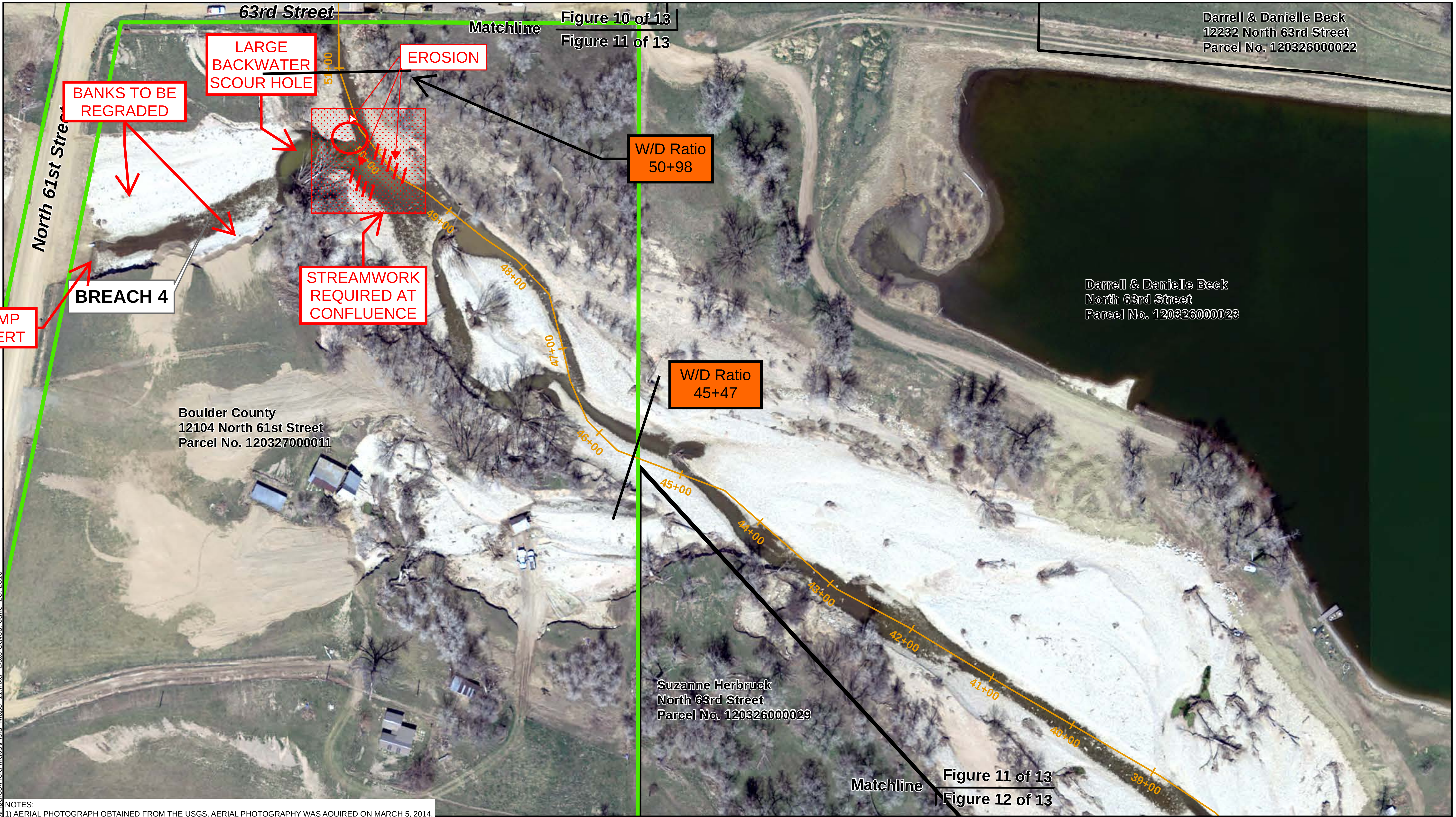
SCALE: 1" = 100'

N

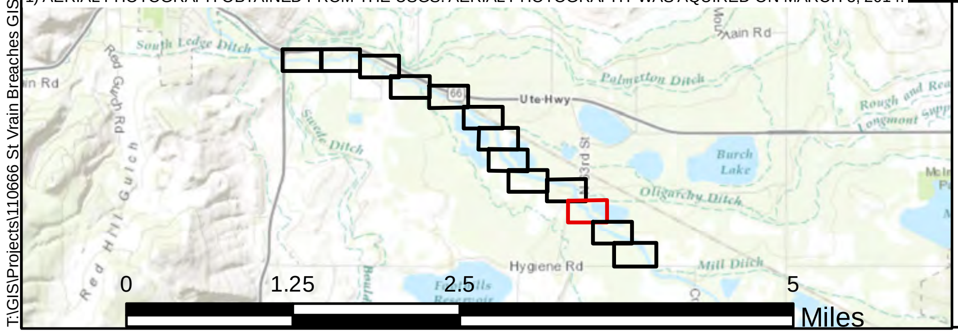
Engineering Analytics, Inc.

**ST. VRAIN CREEK BREACHES RESTORATION**
**Flood Planning & Preliminary**
**Engineering Services**
**Field Investigation Maps**

| Date: June 2016 | Project No.: 110666 | Figure 10 of 13 |
|---|---|---|



NOTES:
1) AERIAL PHOTOGRAPH OBTAINED FROM THE USGS. AERIAL PHOTOGRAPHY WAS AQUIRED ON MARCH 5, 2014.



**EXPLANATION**

🟩 Parcel Owned by BCPOS

☐ Parcel Owned by Others

🟥 Observations noted in the field (May 2016)

190+00 Centerline With Station Number

BREACH 1 Approximate Breach Location

0 100 200 400
Feet
SCALE: 1" = 100'

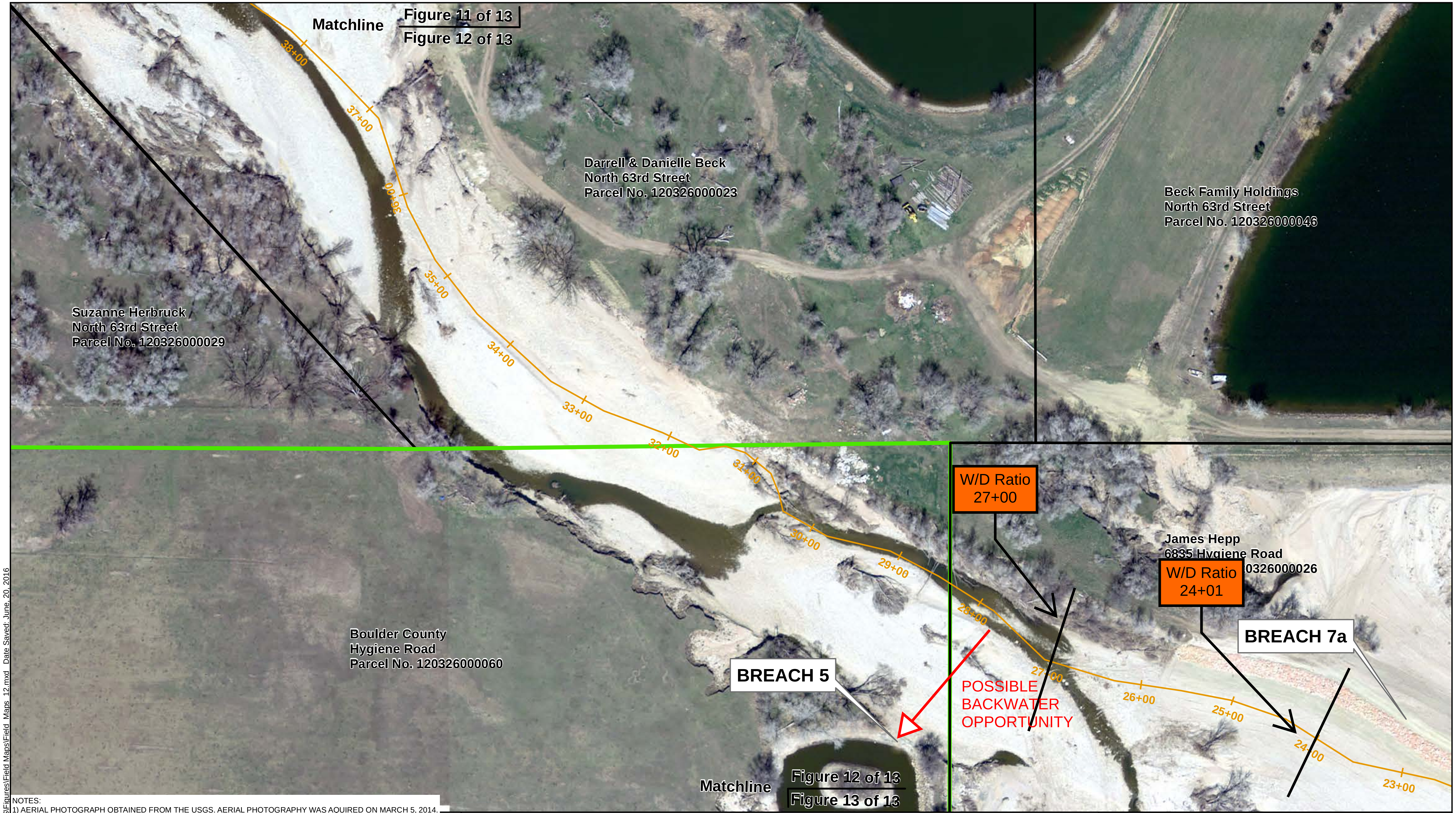
N

Engineering Analytics, Inc.

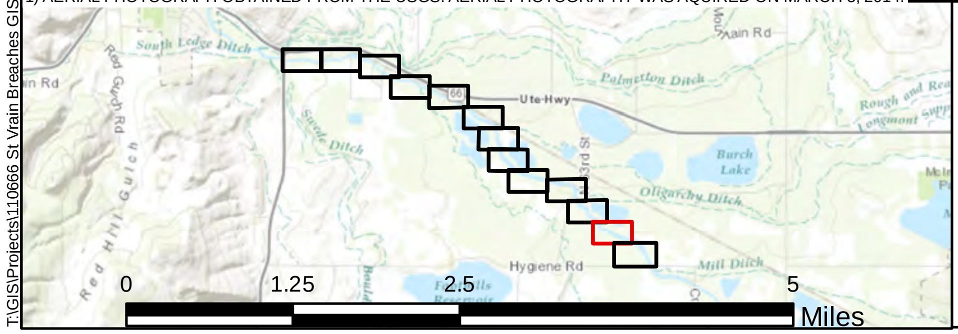
**ST. VRAIN CREEK BREACHES RESTORATION**
**Flood Planning & Preliminary**
**Engineering Services**
**Field Investigation Maps**

| | | |
|---|---|---|
| Date: June 2016 | Project No.: 110666 | Figure 11 of 13 |

T:\GIS\Projects\110666 St Vrain Breaches GIS\Figures\Field Maps\Field_Maps_11.mxd Date Saved: June. 20, 2016



NOTES:
1) AERIAL PHOTOGRAPH OBTAINED FROM THE USGS. AERIAL PHOTOGRAPHY WAS AQUIRED ON MARCH 5, 2014.



**EXPLANATION**

| | |
|---|---|
| 🟩 | Parcel Owned by BCPOS |
| ☐ | Parcel Owned by Others |
| 🟥 | Observations noted in the field (May 2016) |
| 190+00 | Centerline With Station Number |
| **BREACH 1** | Approximate Breach Location |

0 100 200 400
Feet
SCALE: 1" = 100'

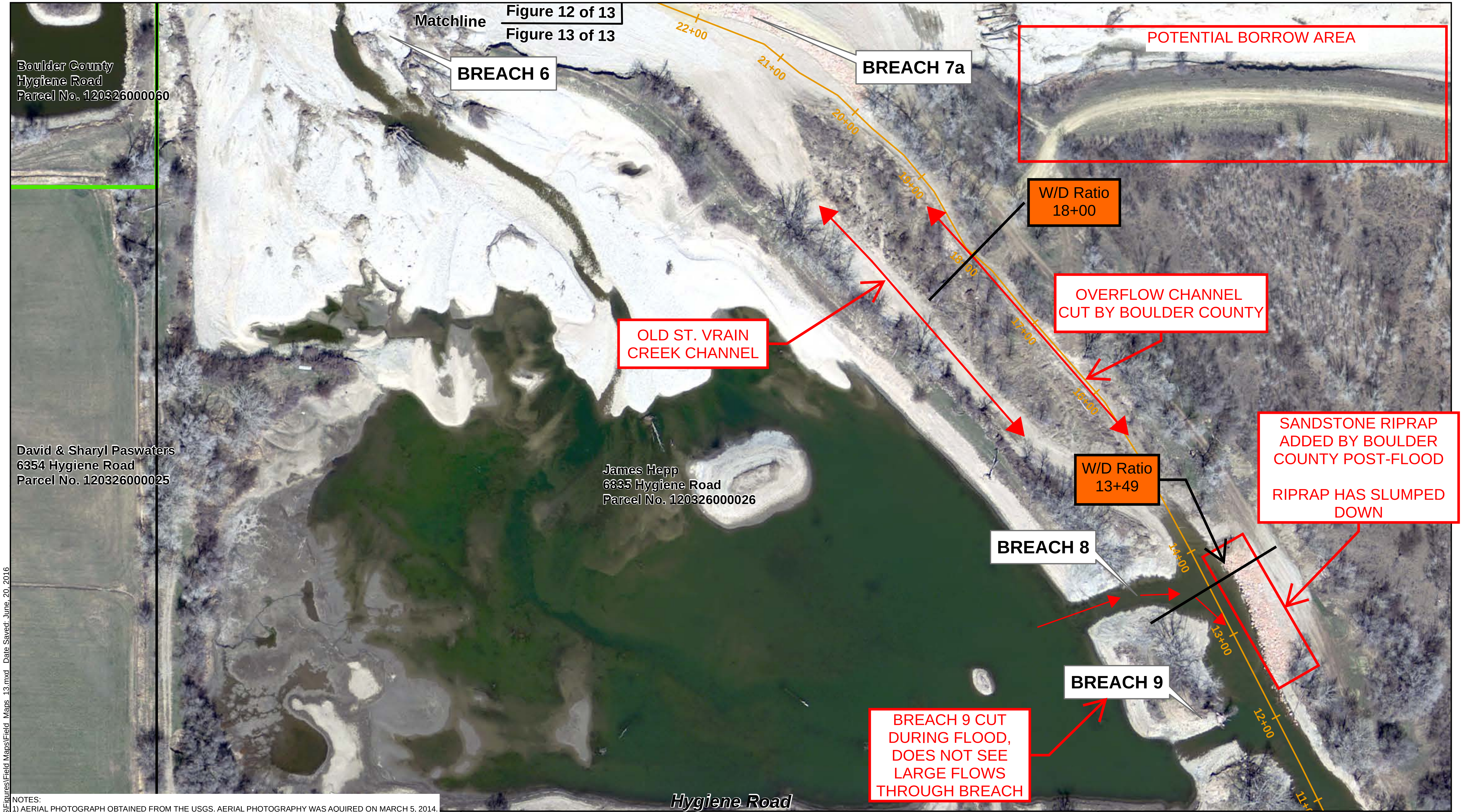
N

Engineering Analytics, Inc.

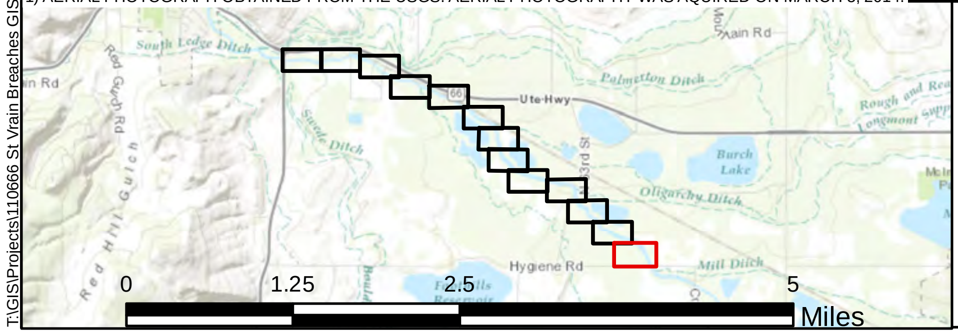
**ST. VRAIN CREEK BREACHES RESTORATION**
**Flood Planning & Preliminary**
**Engineering Services**
**Field Investigation Maps**

| | | |
|---|---|---|
| Date: June 2016 | Project No.: 110666 | Figure 12 of 13 |

T:\GIS\Projects\110666 St Vrain Breaches GIS\Figures\Field Maps\Field_Maps_12.mxd Date Saved: June, 20, 2016



NOTES:
1) AERIAL PHOTOGRAPH OBTAINED FROM THE USGS. AERIAL PHOTOGRAPHY WAS AQUIRED ON MARCH 5, 2014.



**EXPLANATION**

| | |
|---|---|
| 🟩 | Parcel Owned by BCPOS |
| ☐ | Parcel Owned by Others |
| — | Observations noted in the field (May 2016) |
| 190+00 | Centerline With Station Number |
| BREACH 1 | Approximate Breach Location |

0 100 200 400

Feet

SCALE: 1" = 100'

N

Engineering Analytics, Inc.

**ST. VRAIN CREEK BREACHES RESTORATION**
**Flood Planning & Preliminary**
**Engineering Services**
**Field Investigation Maps**

Date: June 2016 | Project No.: 110666 | Figure 13 of 13

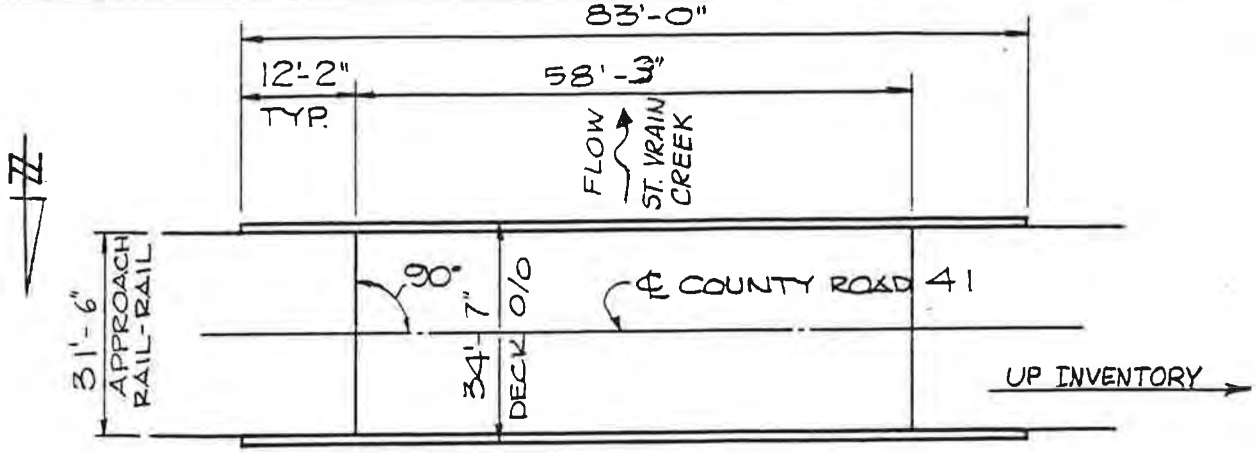
T:\GIS\Projects\110666 St Vrain Breaches GIS\Figures\Field Maps\Field_Maps_13.mxd Date Saved: June, 20, 2016

# Appendix C

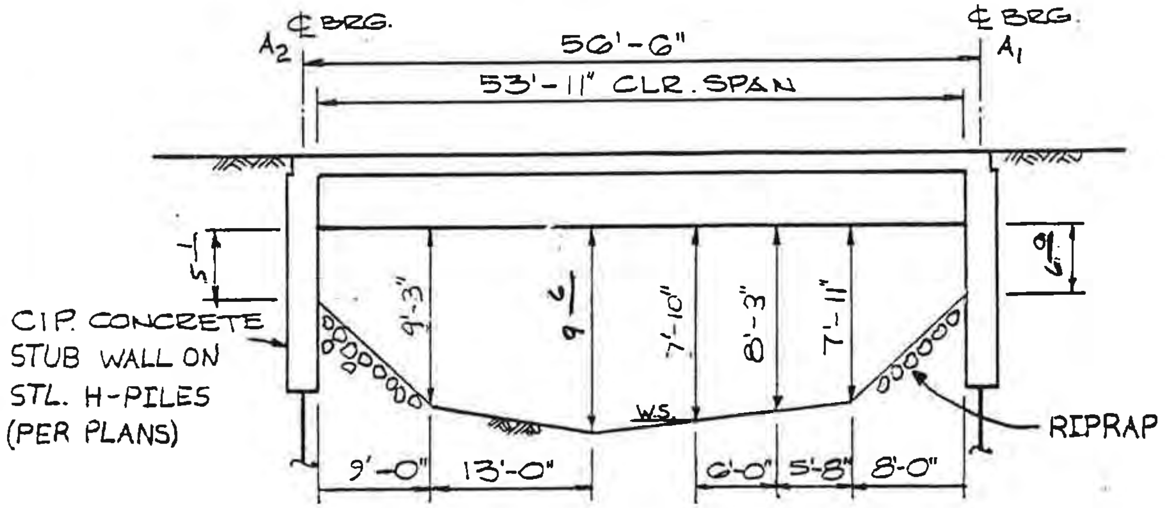
## Bridge Inspection Reports

# 61st Street

KIRKHAM MICHAEL
CONSULTING ENGINEERS

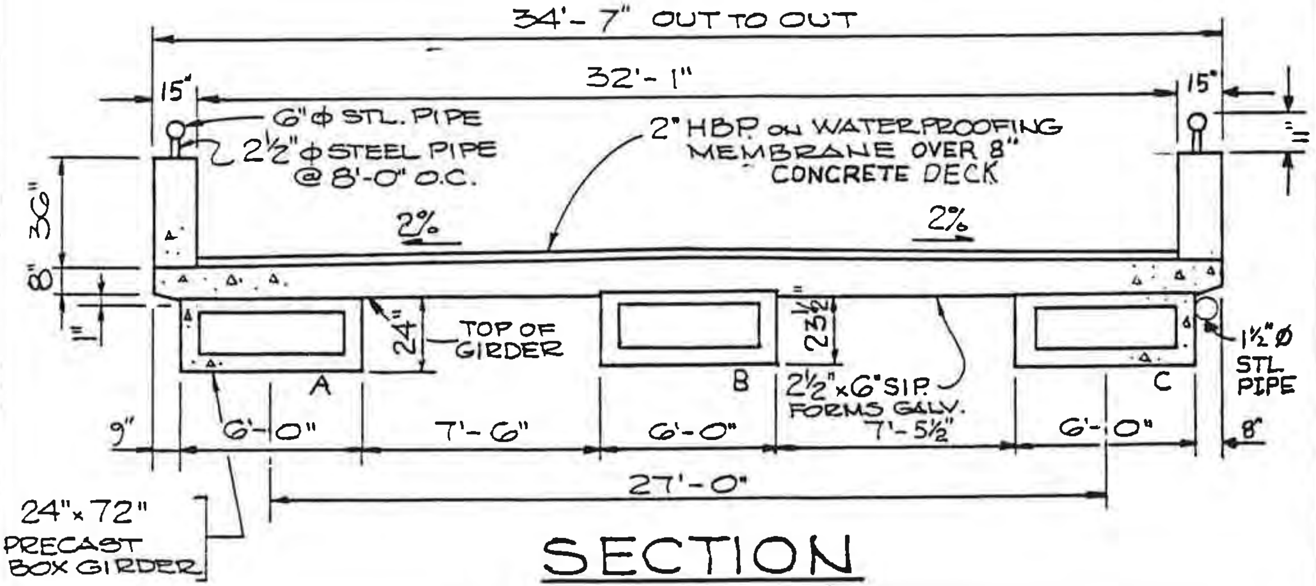


## PLAN



## ELEVATION

(LOOKING SOUTH )

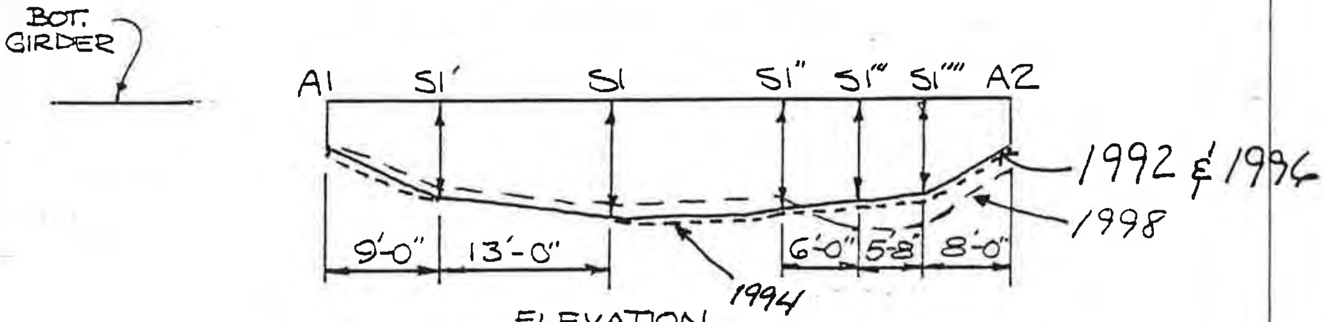


## SECTION

(LOOKING WEST )

SUBJECT STR. NO. BC-41-1.4-SVI BY DATE 12/05/02 SHEET 1 OF 1

## STREAMBED HISTORY



ELEVATION
(LOOKING NORTH)

YEAR BUILT

| LOC. / DATE | A1 | S1' | S1 | S1'' | S1''' | S1'''' | A2 |
|---|---|---|---|---|---|---|---|
| 1991 | 3.0 | 7.3 | 8.5 | 9.2 | 8.5 | 7.3 | 3.0 |
| 1992 | 3.8 | 8.4 | 9.1 | 8.4 | 8.0 | 7.5 | 3.3 |
| 1994 | 4.5 | 8.5 | 9.1 | 8.5 | 8.2 | 7.9 | 3.9 |
| 1996 | 3.8 | 8.4 | 9.1 | 8.4 | 8.0 | 7.5 | 3.3 |
| 1998 | 3.8 | 7.9 | 8.2 | 7.9 | 10.0 | 9.2 | 4.5 |
| LOC / DATE | A1 | | $C_L$ | | | A2 | |
| 2002 | 5.1 | | 9.6 | | | 6.0 | |

Roadway Looking East

Elevation Looking South

**BC-41-1.4-SV1 039**
**County Road 41**
**December 5, 2002**

**General View Looking West**

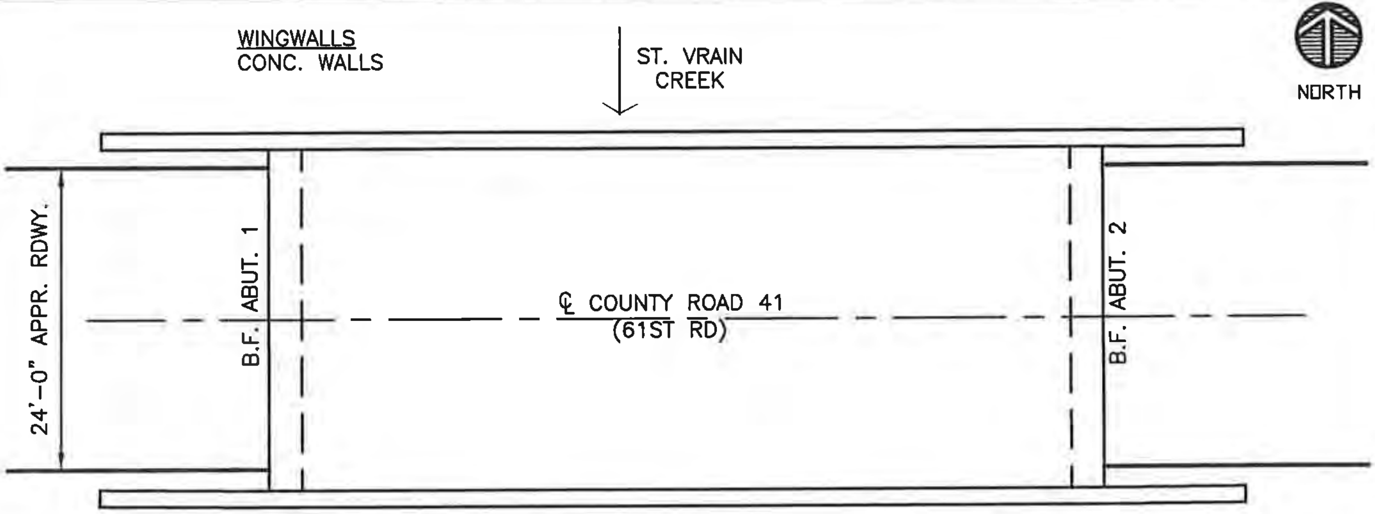
KIRKHAM MICHAEL
CONSULTING ENGINEERS

Channel Upstream Looking North

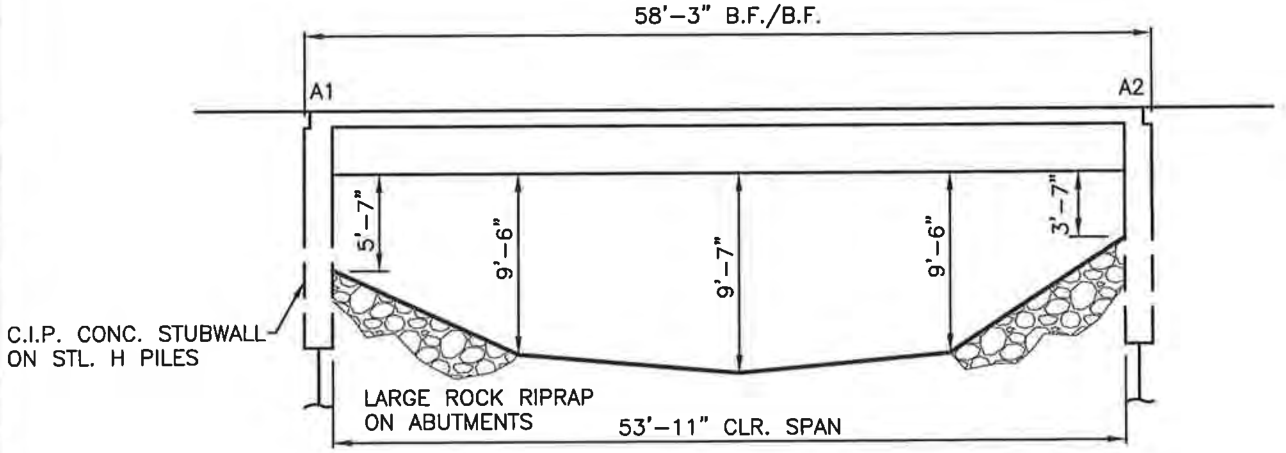
Channel Downstream Looking South

# LONCO, INC.

TITLE: BC-41-1.4-SV1
BY: N.T.I.
ACCOUNT: P10171
DATE: 1/17/11
SHEET NO.: 1

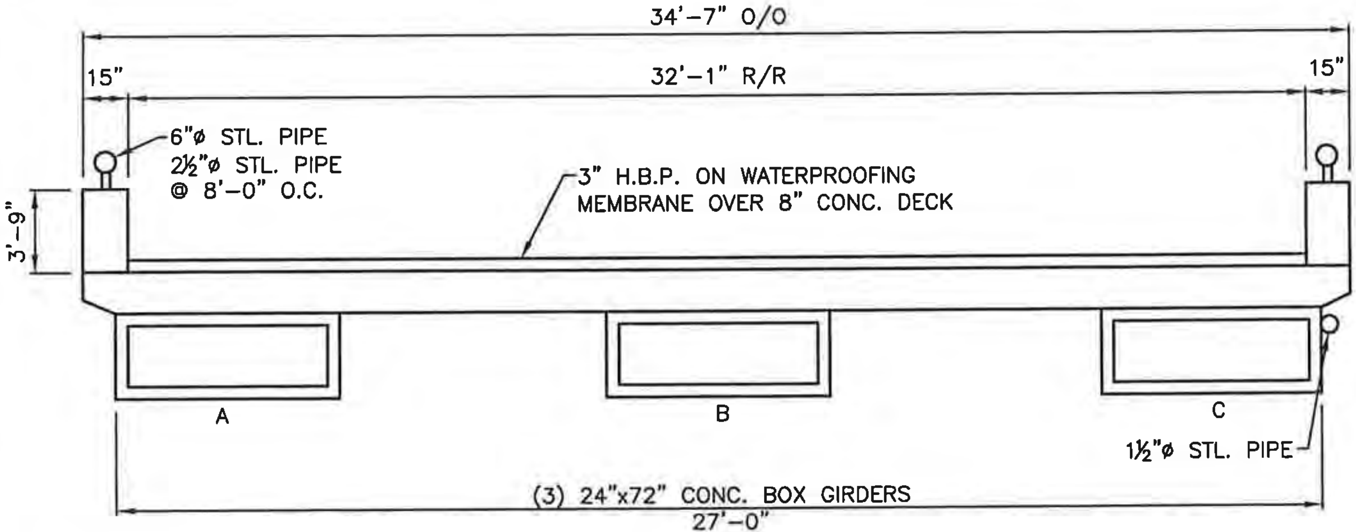


PLAN



ELEVATION

LOOKING NORTH



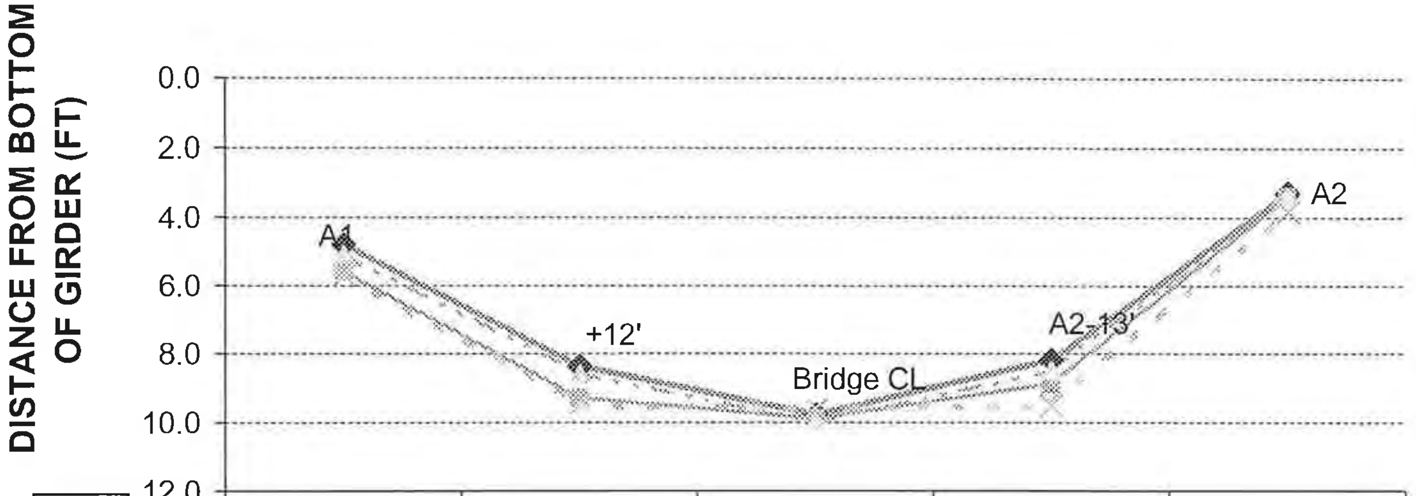
SECTION

LOOKING EAST

Drawing Name: F:\2010\[illegible]71- Northern Area Counties Bridge Inspection Task 5\drawings\Boulder\BC-41-1.4-SV1.dwg - Fri, 1[illegible] 2011

# BOULDER COUNTY INSPECTION

## STREAMBED HISTORY

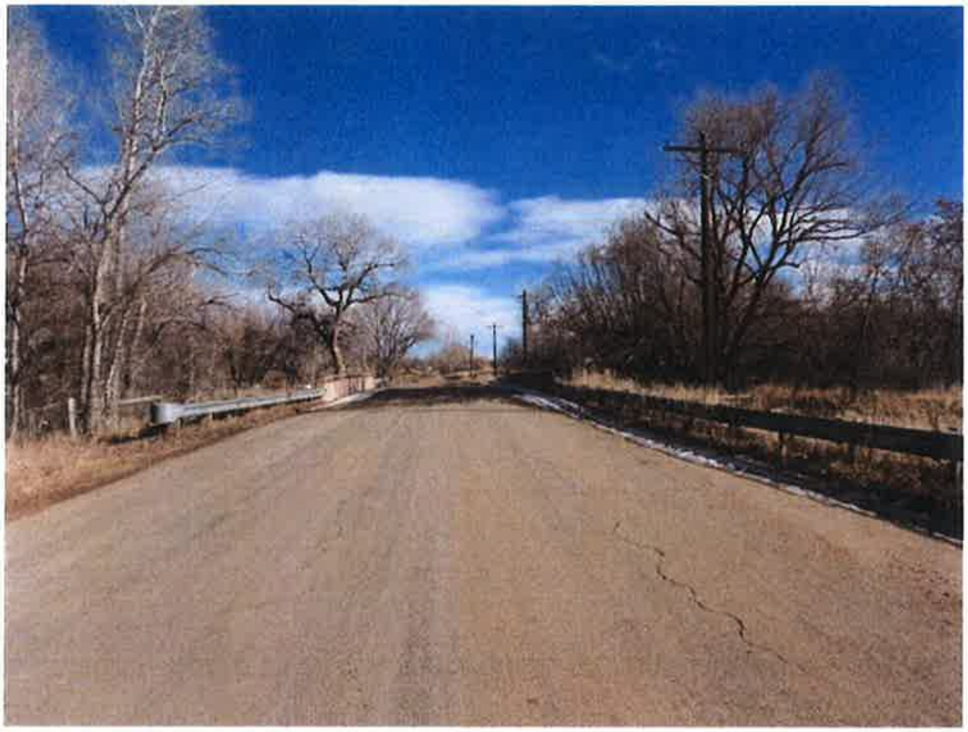


| Year | A1 | +12' | Bridge CL | A2-13' | A2 |
|---|---|---|---|---|---|
| ◆ 2004 | 4.8 | 8.4 | 9.8 | 8.2 | 3.3 |
| ■ 2007 | 5.6 | 9.3 | 9.9 | 8.9 | 3.4 |
| ▲ 2009 | 5.1 | 8.6 | 10.0 | 8.5 | 3.4 |
| ✕ 2011 | 5.7 | 9.5 | 9.6 | 9.5 | 3.8 |
| ✱ | | | | | |

Structure Number: BC-41-1.4-SV1

Performed By: NTI/ZDA for Zach Adkins 10/11

Inspection Date: 1/5/1900



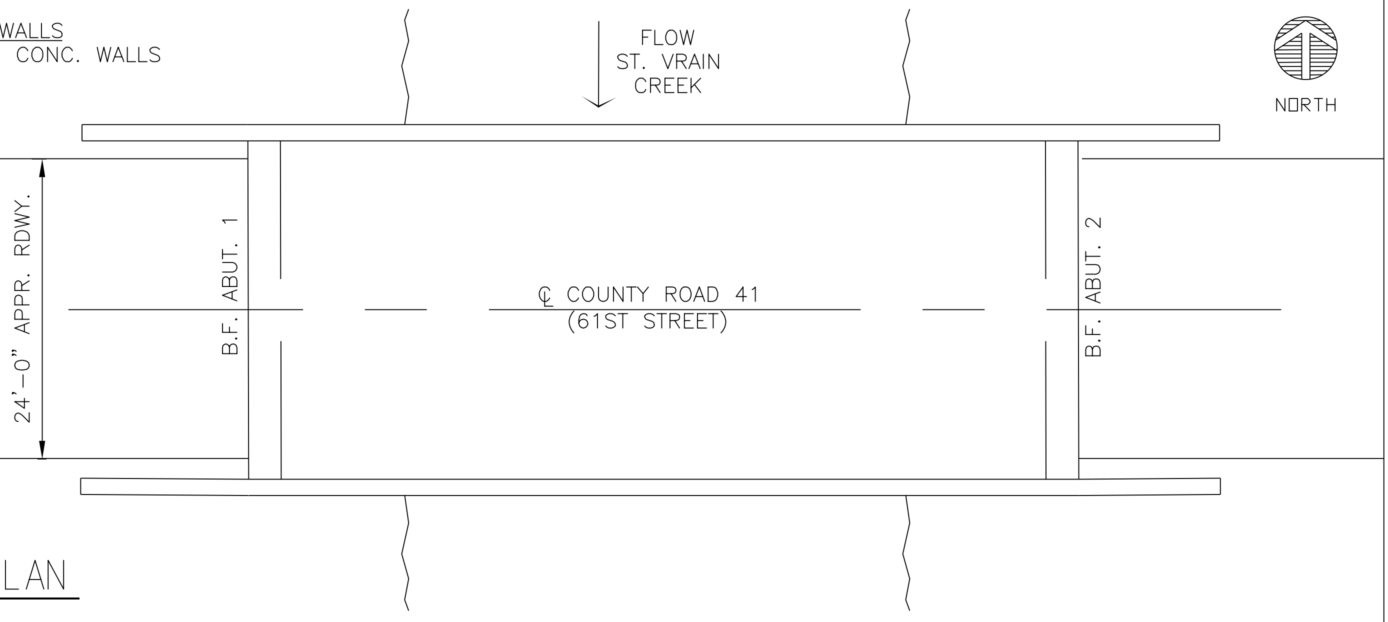
DECK LOOKING EAST

ELEVATION LOOKING SOUTH

UNDERSIDE VIEW LOOKING EAST

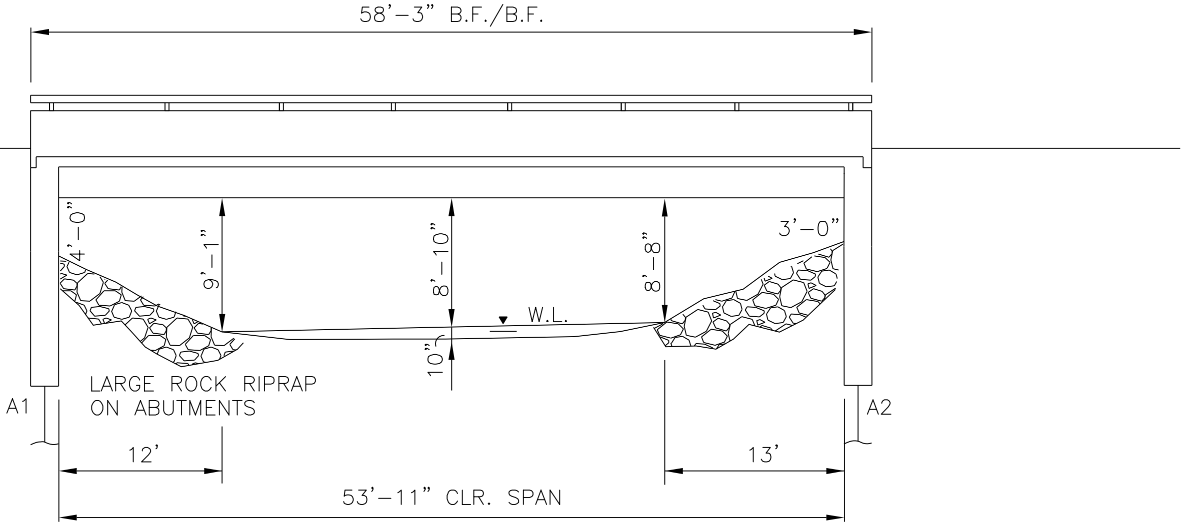
BC-41-1.4-SV1
JAN. 17, 2013

WINGWALLS
C.I.P. CONC. WALLS

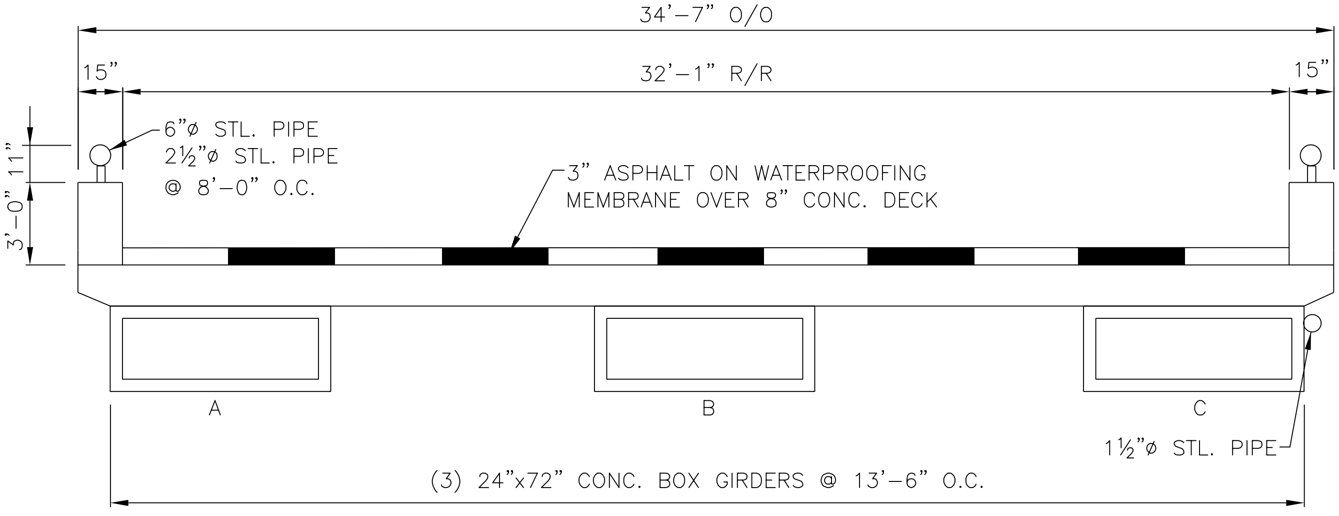


PLAN

ABUTMENTS:
C.I.P. CONC.
STUBWALL ON
STL. H-PILES



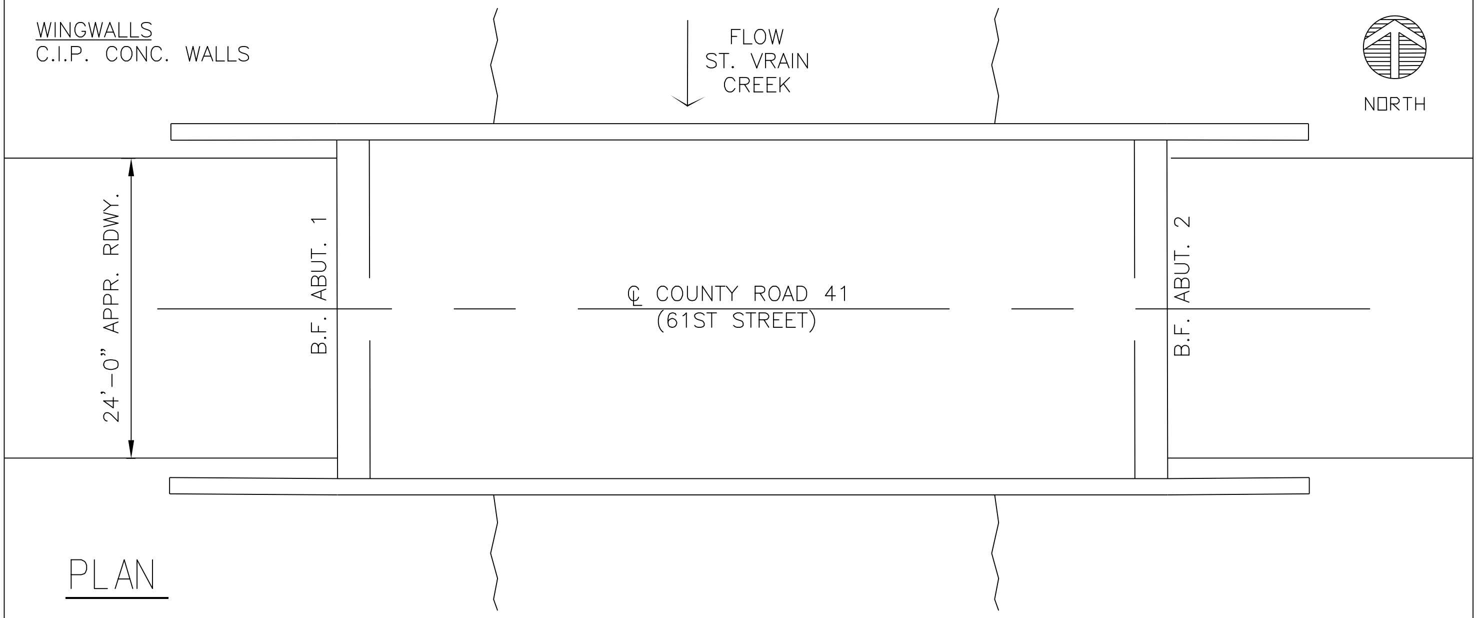
ELEVATION
LOOKING NORTH



SECTION
LOOKING EAST

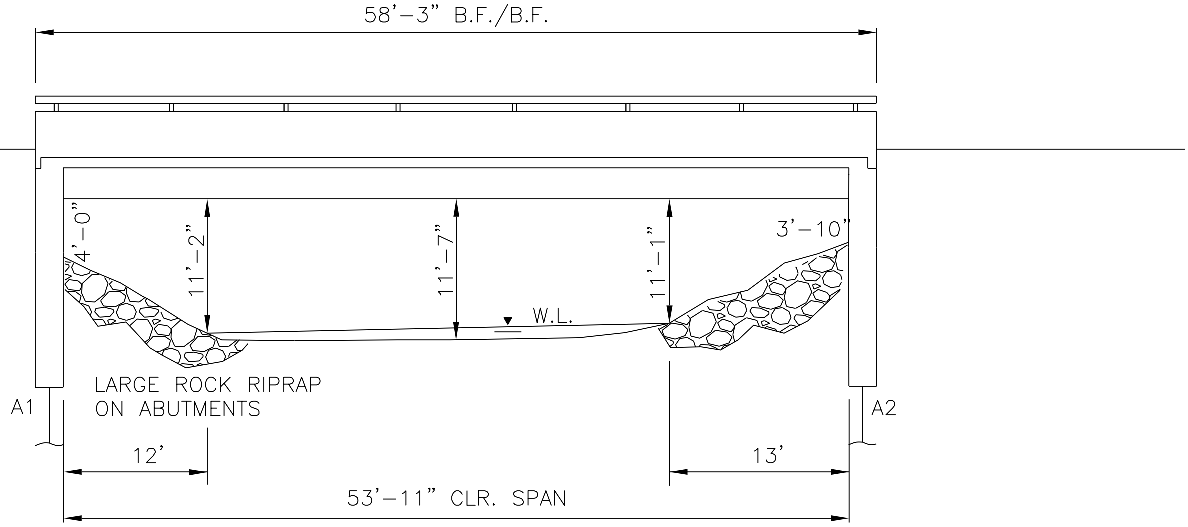
BC-41-1.4-SV1

JAN. 16, 2015



WINGWALLS
C.I.P. CONC. WALLS

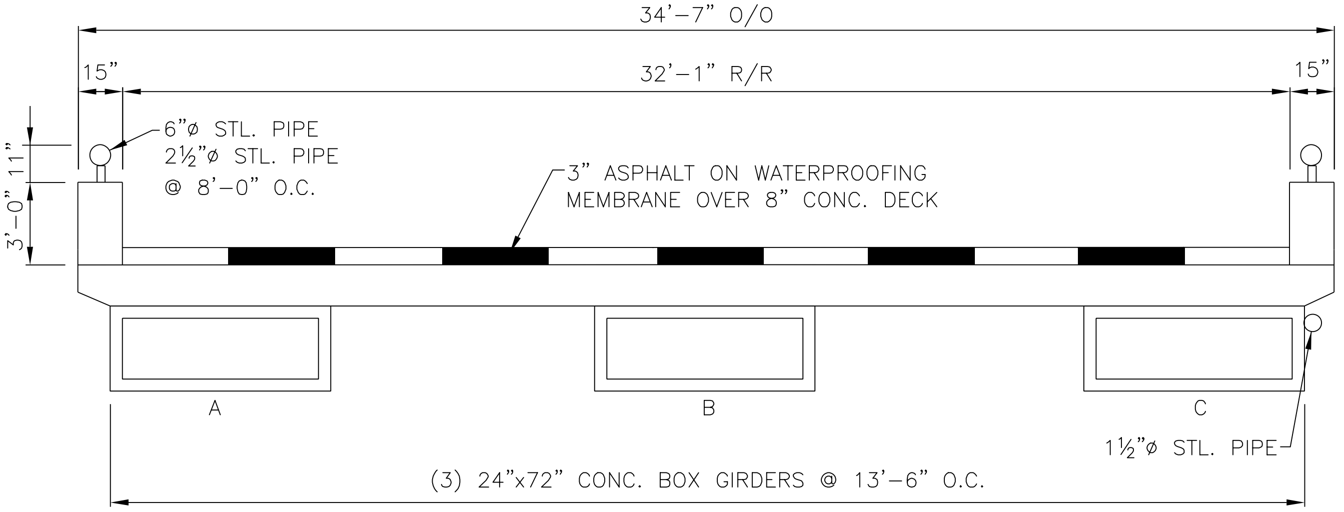
## PLAN



ABUTMENTS:
C.I.P. CONC.
STUBWALL ON
STL. H-PILES

## ELEVATION

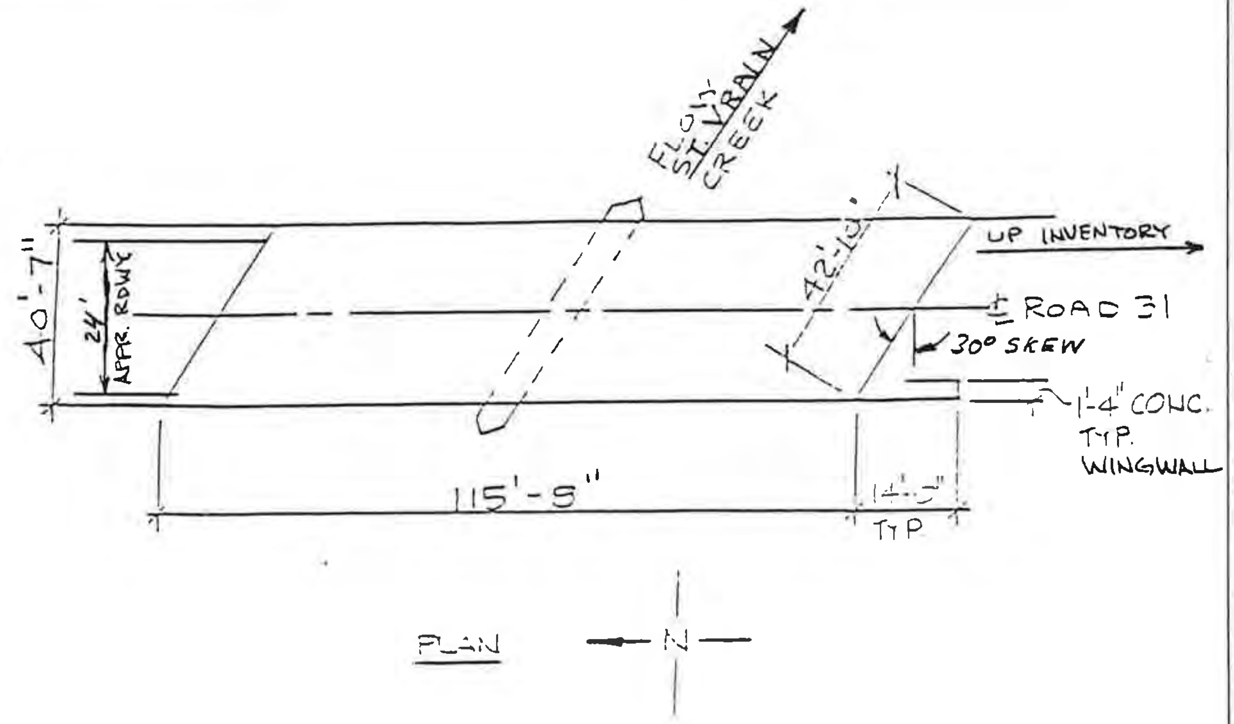
LOOKING NORTH



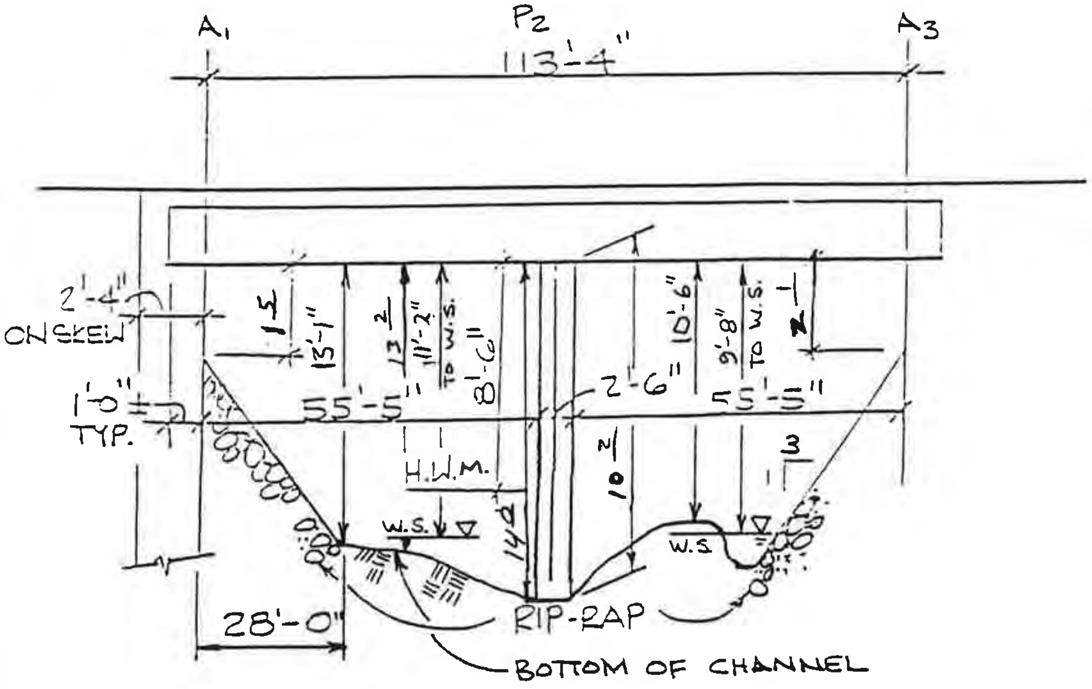
## SECTION

LOOKING EAST

# 75th Street



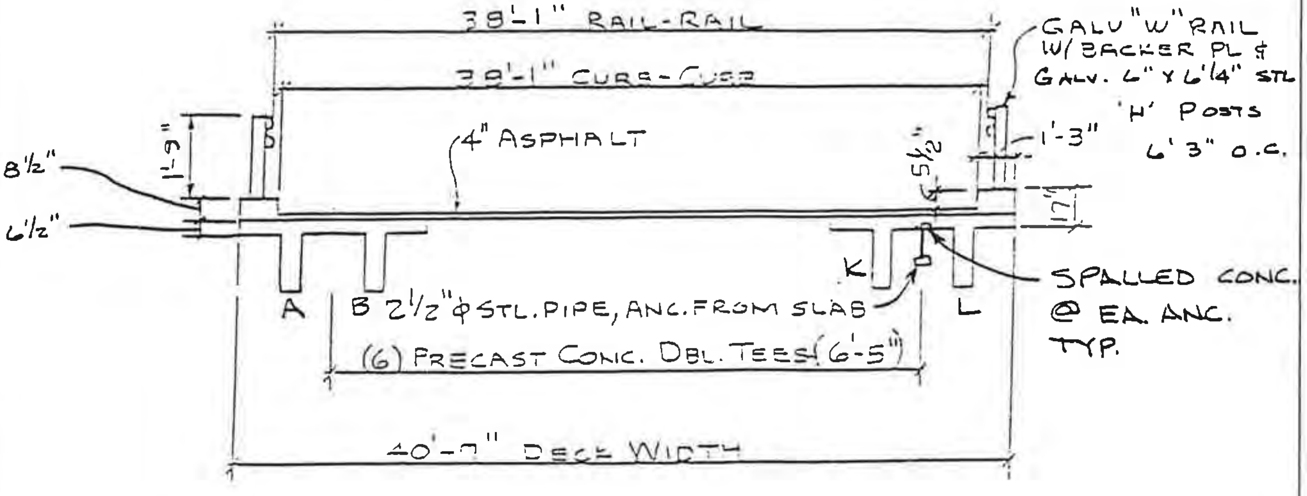
PLAN



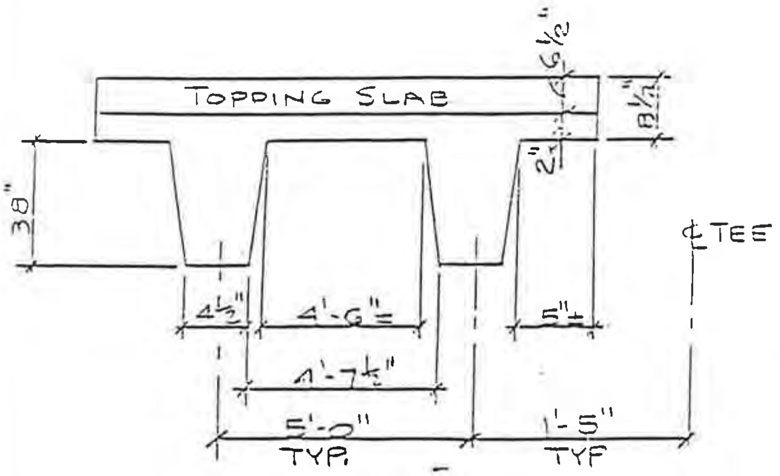
ELEVATION
LOOKING EAST

SUBJECT Str. No. BC-31-3.9A-SV BY DATE 12/5/02 SHEET 1 OF 3

CLIENT Boulder Co. BY DATE



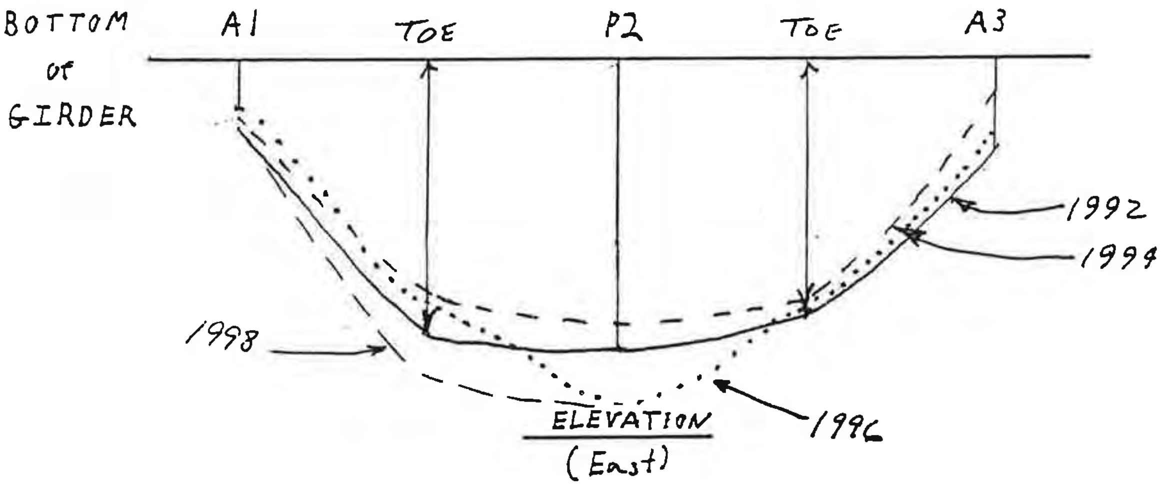
TYPICAL SECTION LOOKING SOUTH



TYP. DBL. TEE SECTION

SUBJECT Str. No. BC-31-3.5A-SV BY DATE 12/5/02 SHEET 2 OF 3
Co. DATE

## STREAMBED HISTORY



ELEVATION
(East)

| DATE \ LOC | A1 | TOE | P2 | TOE | A3 |
|---|---|---|---|---|---|
| 1988 | 3.0 | 12.0 | 12.0 | 12.0 | 3.0 |
| 1990 | 3.0 | 10.8 | 11.4 | 9.8 | 3.0 |
| 1992 | 3.0 | 11.7 | 12.2 | 10.9 | 3.9 |
| 1994 | 2.8 | 10.0 | 11.4 | 10.3 | 1.4 |
| 1996 | 2.3 | 10.3 | 14.6 | 10.5 | 2.9 |
| 1998 | 2.3 | 13.1 | 14.6 | 10.5 | 2.9 |
| 2002 | 1.5 | 13.2 | 14.0 | 10.2 | 2.1 |

SUBJECT STR. NO. BC-31-3.94-SV
CLIENT BOULDER COUNTY
BY
CK
DATE 12/5/02
DATE
SHEET 1 OF 1

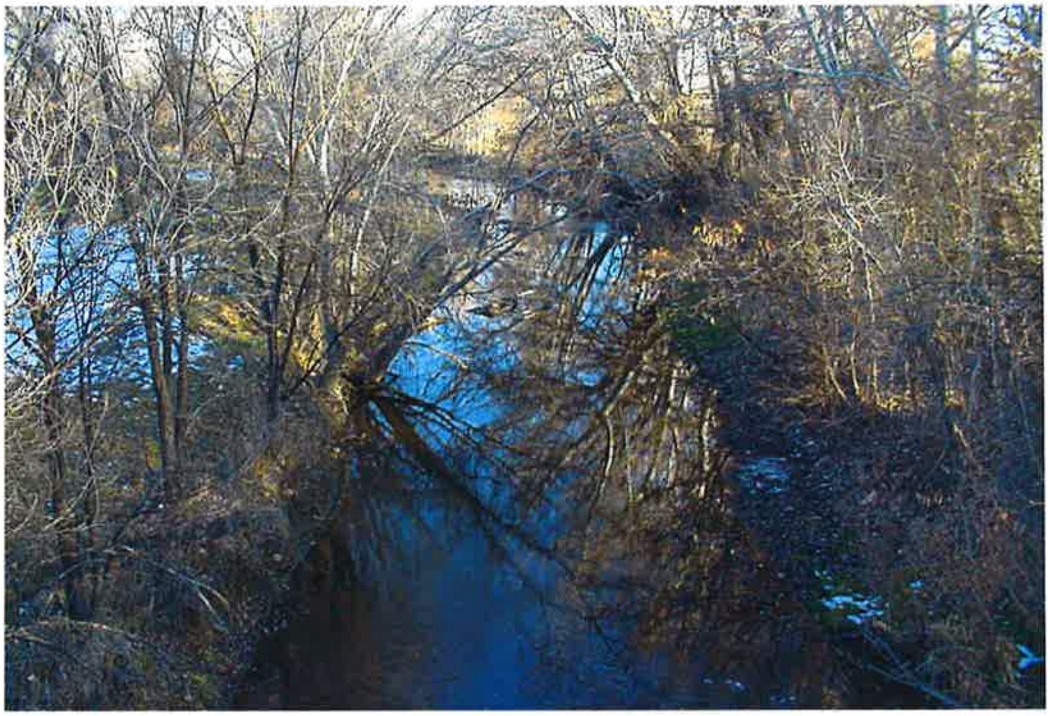
**Roadway Looking South**

**Elevation Looking East**

General View Looking South

**Scour at P1**

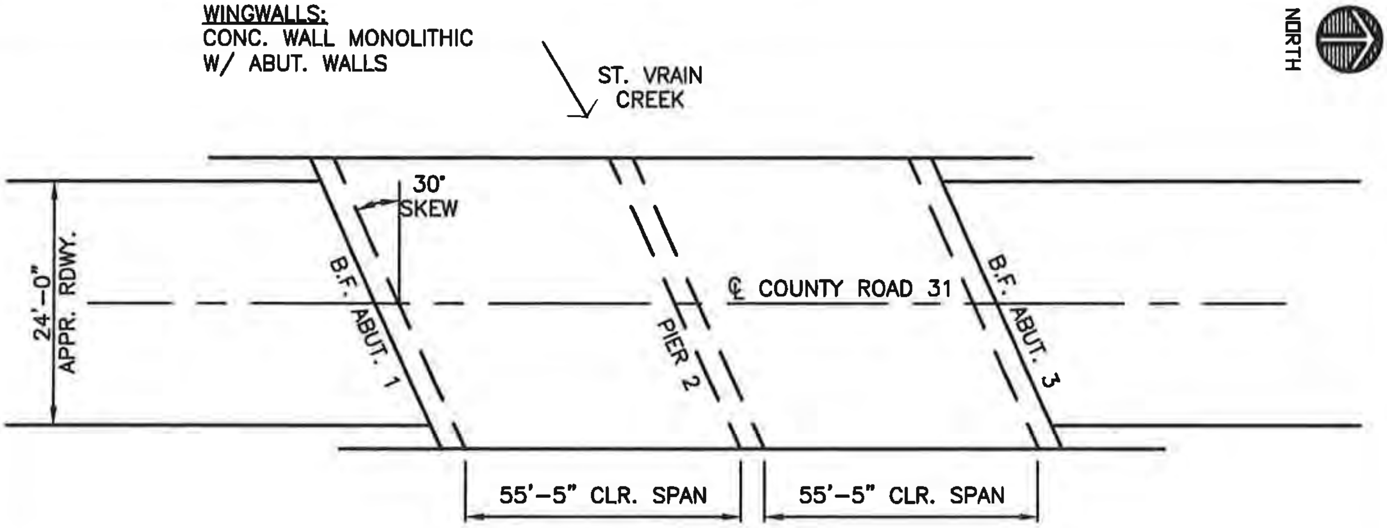
**Channel Upstream Looking West**



**Channel Downstream Looking East**

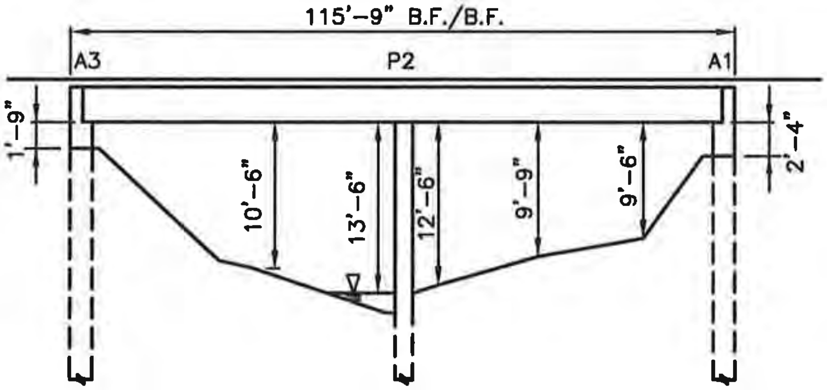
**LONCO, INC.**

TITLE: BC-31-3.9A-SV
BY: N.T.I.
ACCOUNT: P10171
DATE: 1/17/11
SHEET NO.: 1



**WINGWALLS:**
CONC. WALL MONOLITHIC
W/ ABUT. WALLS

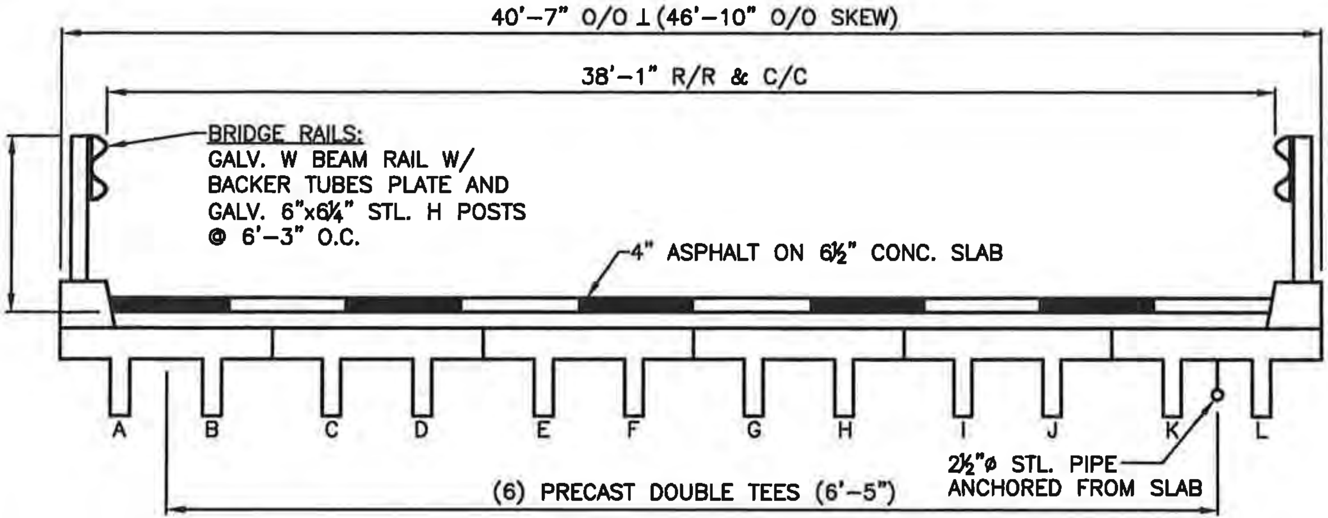
## PLAN



**ABUTMENTS:**
U-SHAPED CONC. WALLS

**PIER:**
CONC. WALL W/ 6"x6" GALV.
STL. L CUTWATER AT UPSTREAM FACE

## ELEVATION
LOOKING EAST



**BRIDGE RAILS:**
GALV. W BEAM RAIL W/
BACKER TUBES PLATE AND
GALV. 6"x6¼" STL. H POSTS
@ 6'-3" O.C.

4" ASPHALT ON 6½" CONC. SLAB

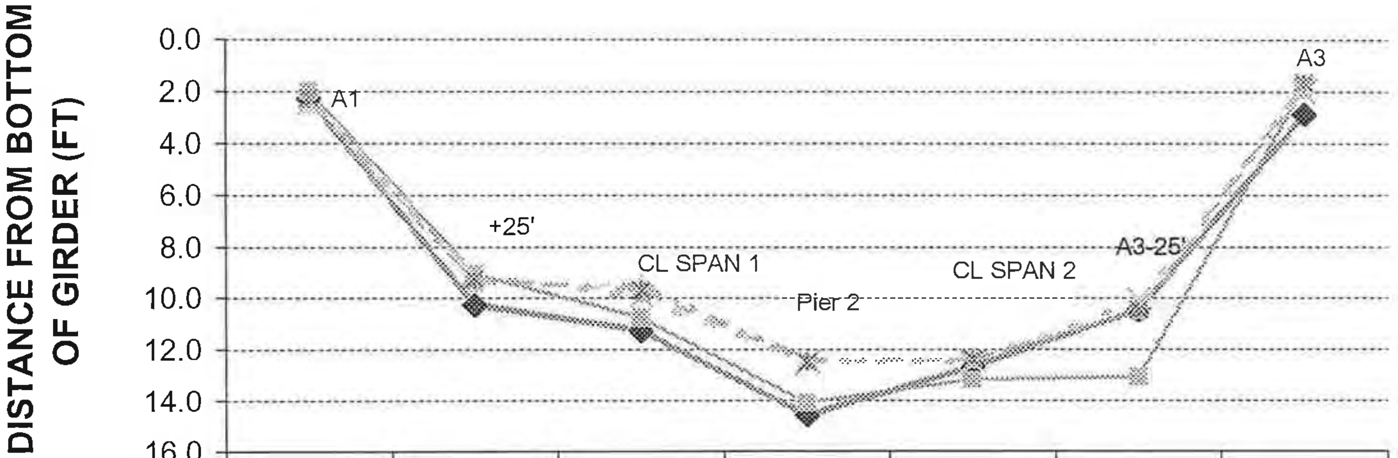
2½"ø STL. PIPE
ANCHORED FROM SLAB

## SECTION
LOOKING NORTH

Drawing Name: F:\20 10171– Northern Area Counties Bridge Inspection Task 5\drawings\Boulder\BC-31-3.9A-SV.dwg – Th Apr 2011

# BOULDER COUNTY INSPECTION

## STREAMBED HISTORY



| Year | A1 | +25' | CL SPAN 1 | Pier 2 | CL SPAN 2 | A3-25' | A3 |
|---|---|---|---|---|---|---|---|
| ◆ 2002 | 2.3 | 10.3 | 11.3 | 14.6 | 12.7 | 10.5 | 2.9 |
| ▨ 2004 | 2.0 | 9.1 | 10.8 | 14.1 | 13.2 | 13.1 | 1.8 |
| ✕ 2007 | 2.5 | 9.4 | 9.5 | 12.4 | 12.4 | 10.5 | 1.9 |
| ✕ 2009 | 2.5 | 9.1 | 10.0 | 12.5 | 12.5 | 10.1 | 2.0 |
| ※ 2011 | 2.3 | 9.3 | 9.7 | 12.5 | 12.4 | 10.5 | 1.7 |

TO ICE 2007

Structure Number: BC-31-3.9A-SV

Performed By: NTI/ZDA for Zach Adkinson

Inspection Date: 1/17/2011

DECK LOOKING NORTH

ELEVATION LOOKING SOUTHEAST

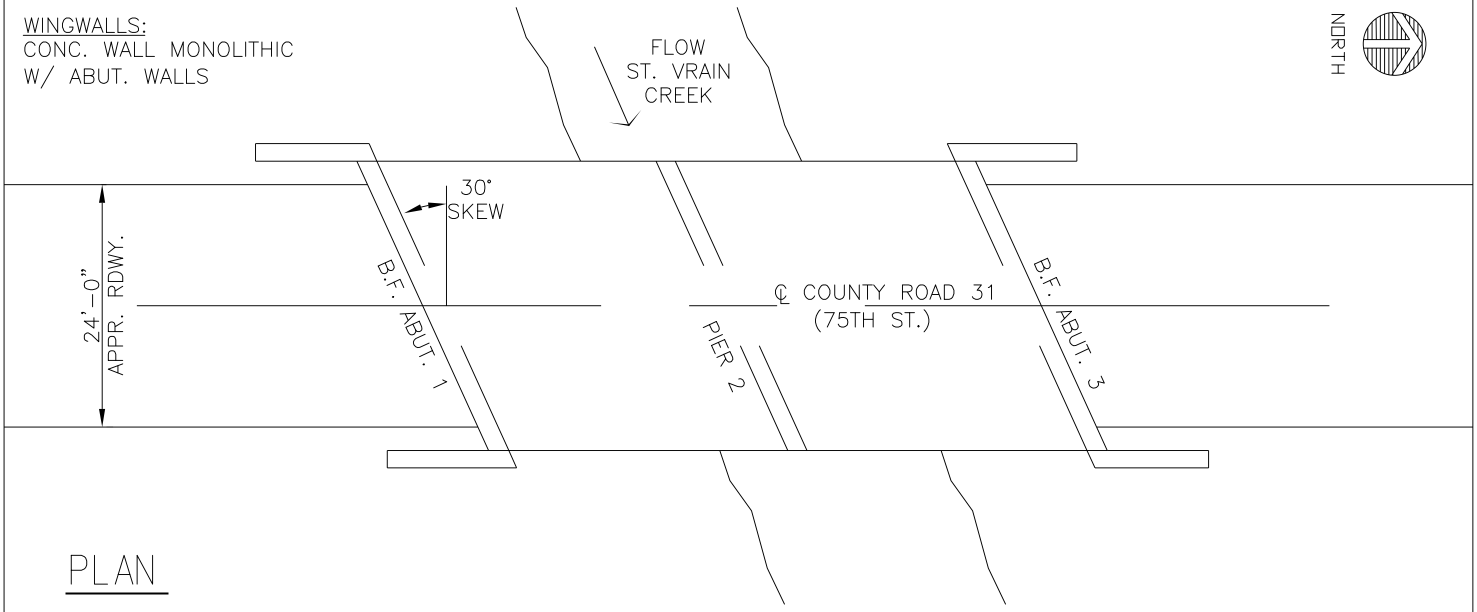
UNDERSIDE VIEW LOOKING NORTH

SMALL HOLE ON WEST SIDE OF FLEX BEAM

P2 CONDITION (AT NORTH FACE (±2 FEET LOCAL SCOUR HOLE IN FRONT OF P2 UPSTREAM SIDE)

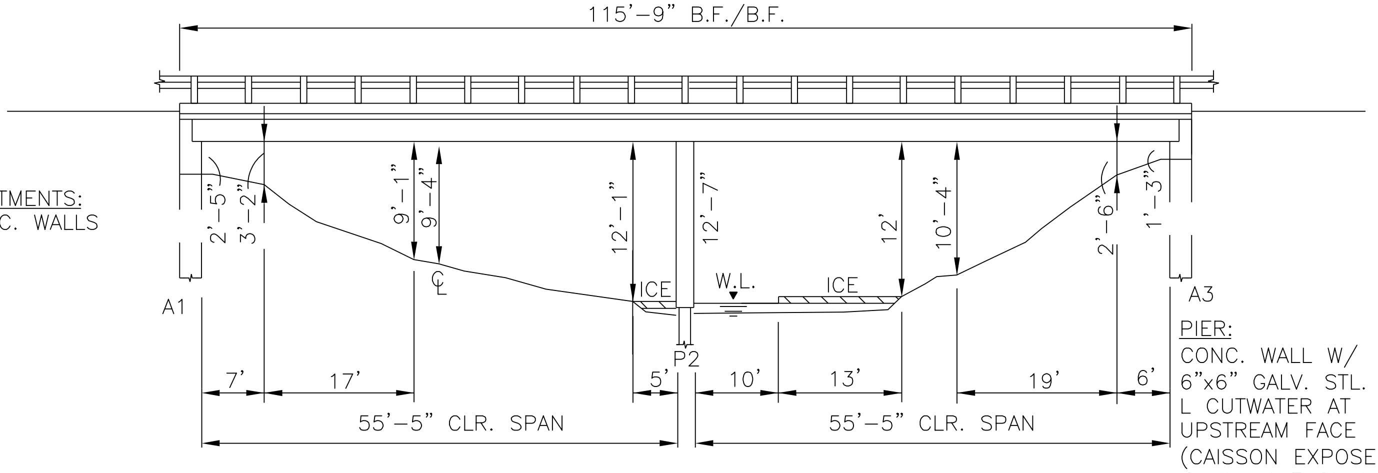
BC-31-3.9A-SV
JAN. 28, 2013

WINGWALLS:
CONC. WALL MONOLITHIC
W/ ABUT. WALLS



## PLAN

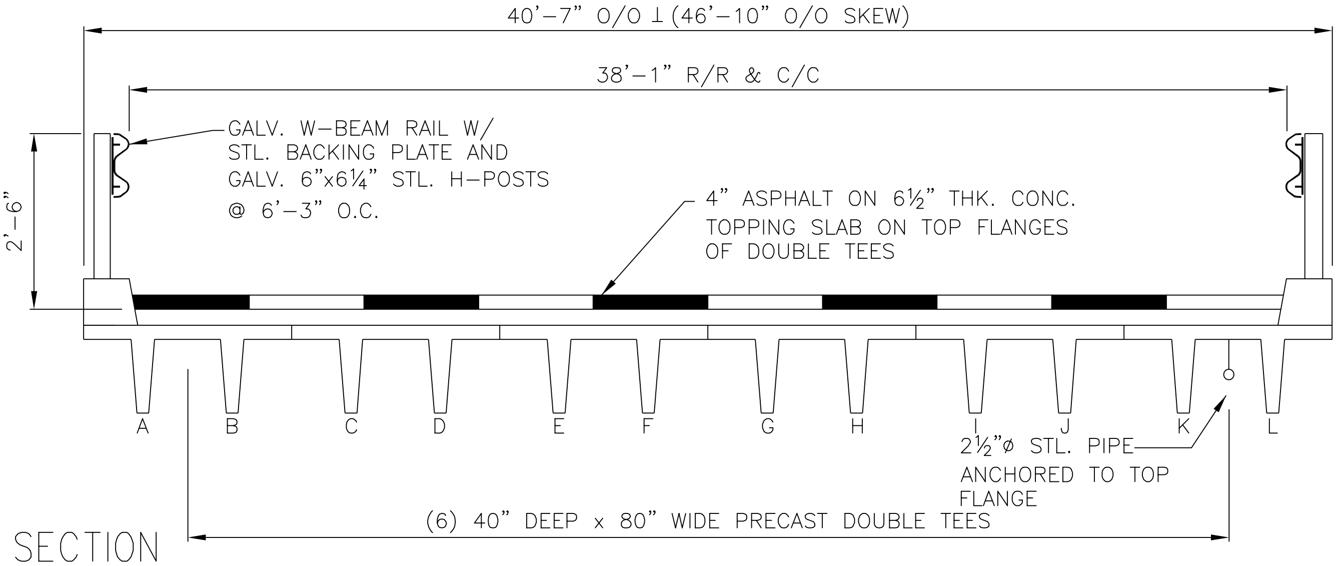
ABUTMENTS:
CONC. WALLS



PIER:
CONC. WALL W/
6"x6" GALV. STL.
L CUTWATER AT
UPSTREAM FACE
(CAISSON EXPOSED
@ W. HALF ON N.
FACE-16" @ UP-
STREAM END)

## ELEVATION

LOOKING WEST

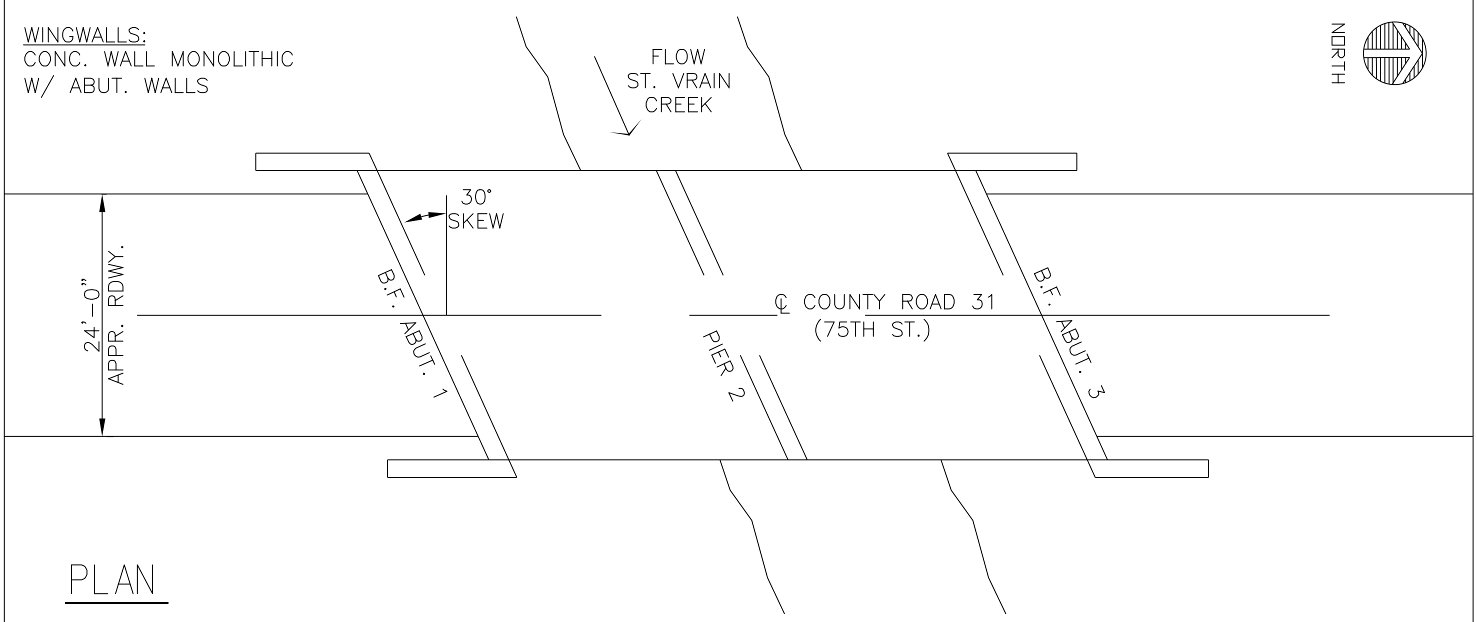


## SECTION

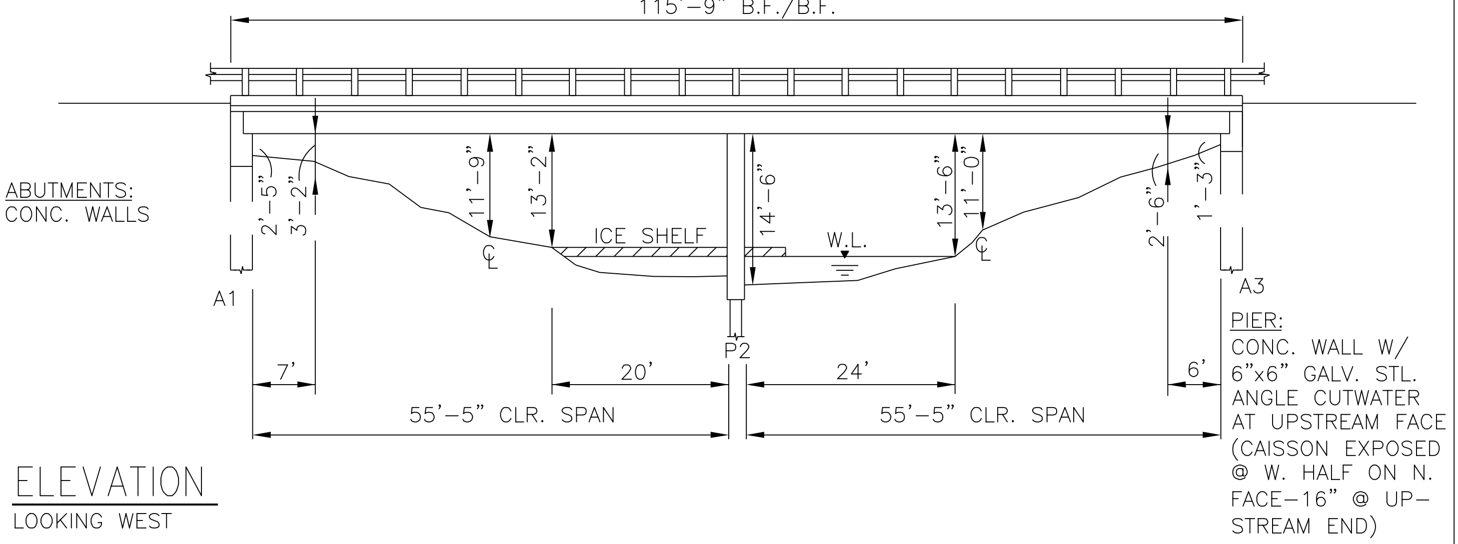
LOOKING NORTH

BC-31-3.9A-SV

JAN. 15, 2015

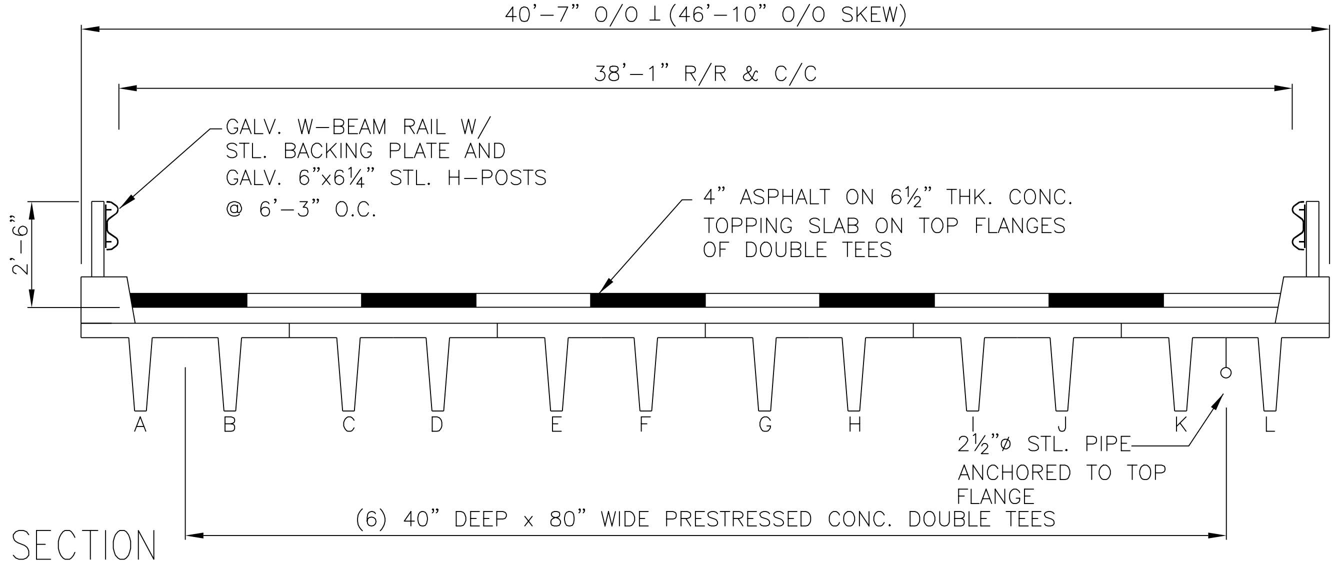


PLAN



ELEVATION

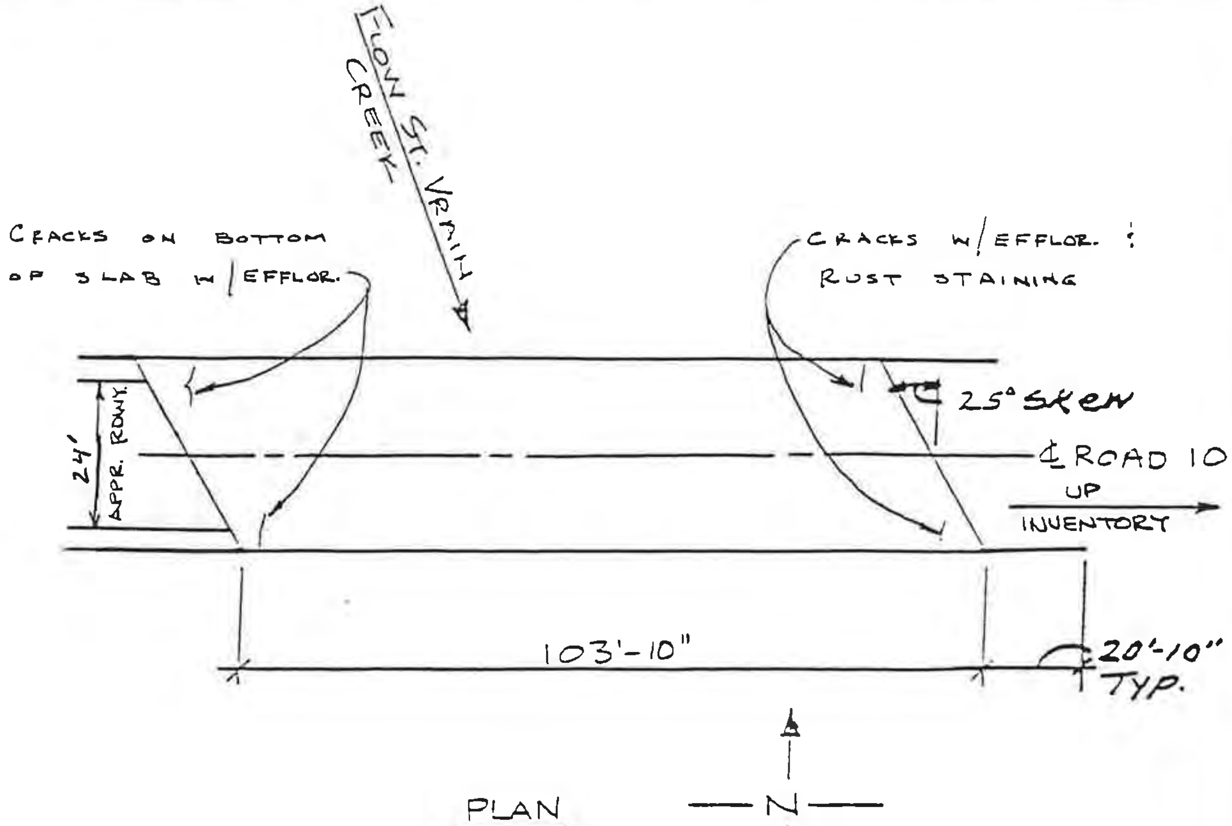
LOOKING WEST



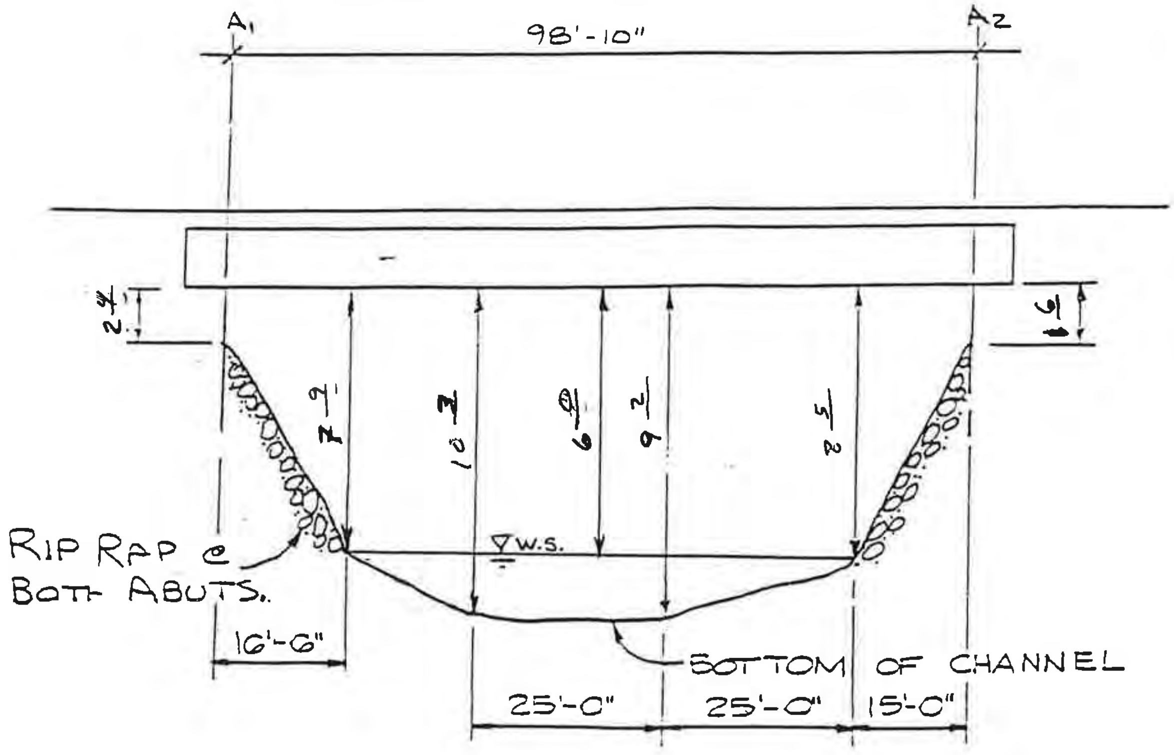
SECTION

LOOKING NORTH

# Hygiene Road



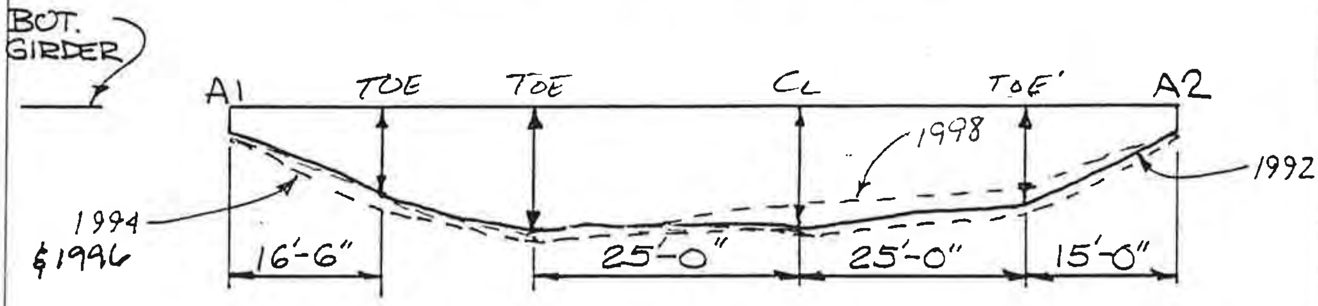
PLAN



ELEVATION
LOOKING NORTH

SUBJECT Str. No. BC - 10 - 3.1 - SV BY DATE 12/5/02 SHEET 1 OF 2

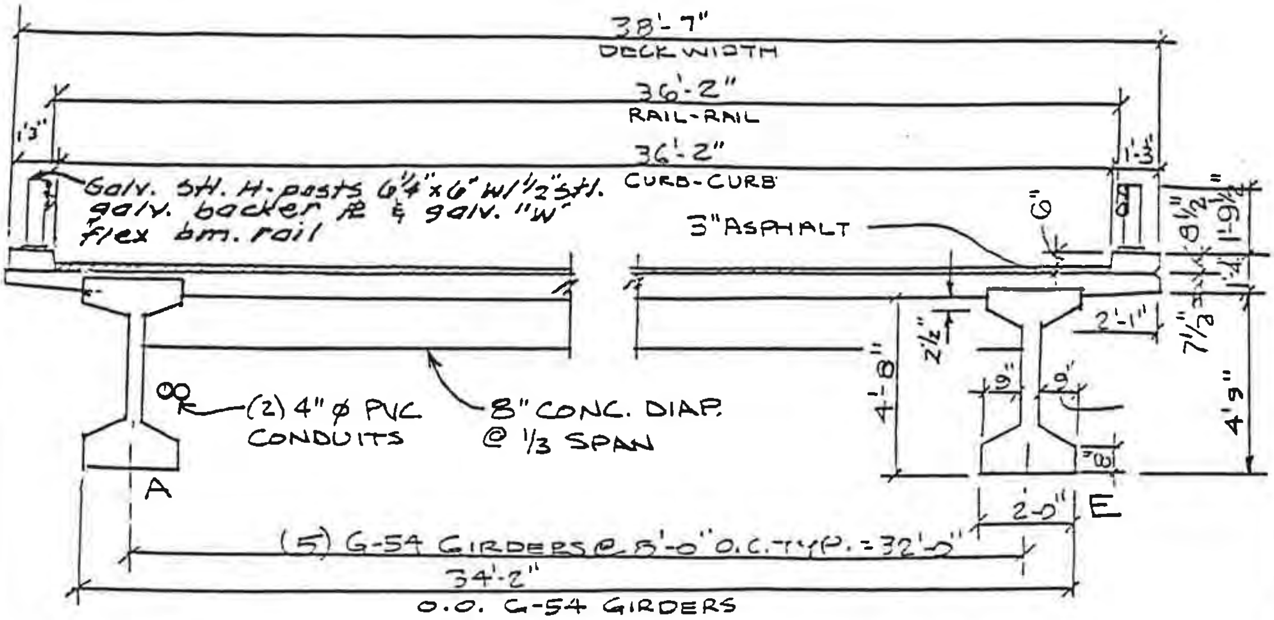
## STREAMBED HISTORY



ELEVATION
(LOOKING NORTH)

| LOC. / DATE | A1 | TOE | TOE | CL | TOE' | A2 |
|---|---|---|---|---|---|---|
| 1988 | 1.0 | 9.0 | 9.0 | 9.0 | 9.0 | 1.0 |
| 1990 | 1.5 | 7.0 | 9.2 | 9.3 | 7.9 | 1.5 |
| 1992 | 1.4 | 7.0 | 8.5 | 8.9 | 7.3 | 1.2 |
| 1994 | 1.7 | 7.8 | 9.0 | 9.2 | 7.8 | 1.3 |
| 1996 | 1.7 | 7.8 | 9.0 | 9.2 | 7.8 | 1.3 |
| 1998 | 1.7 | 7.0 | 8.8 | 7.2 | 6.3 | 1.3 |
| 2002 | 2.4 | 7.9 | 10.3 | 9.2 | 8.5 | 1.6 |

SUBJECT STR. No. BC-10-3.1-SV BY DATE 12/5/02 SHEET 1 OF 1
CLIENT BOULDER COUNTY CK DATE



TYPICAL SECTION LOOKING EAST

NOTE: DIMENSIONS NOTED FOR G-54 GIRDER WERE MEASURED IN THE VICINITY OF ¼ TO ⅓ SPAN AND BEYOND THE START OF THE THICKENED END SECTION.

SUBJECT STR. No. BC - 10 - 3.1 - SV BY DATE 12/05/02 SHEET 2 OF 2

Roadway Looking South

Elevation Looking East

**BC-10-3.1-SV 006**
**County Road 10**
**December 5, 2002**

General View Looking West

BC-10-3.1-SV 006
County Road 10
December 5, 2002

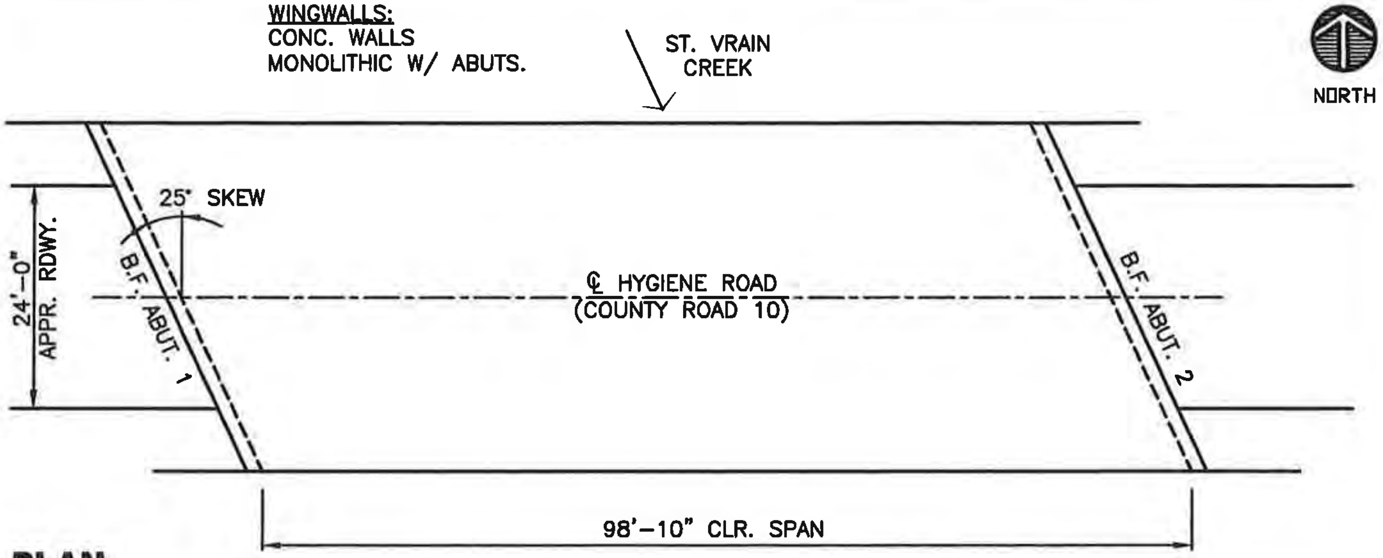
Channel Upstream Looking North

Channel Downstream Looking South

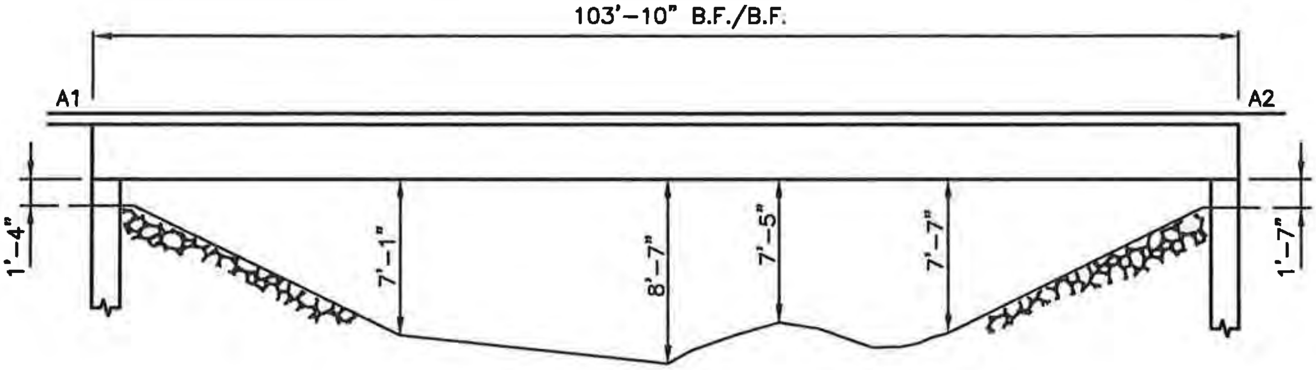
KIRKHAM MICHAEL
CONSULTING ENGINEERS

LONCO, INC.

TITLE: BC-10-3.1-SV
BY: N.T.I. ACCOUNT: P10171
DATE: 1/17/11 SHEET NO.: 1



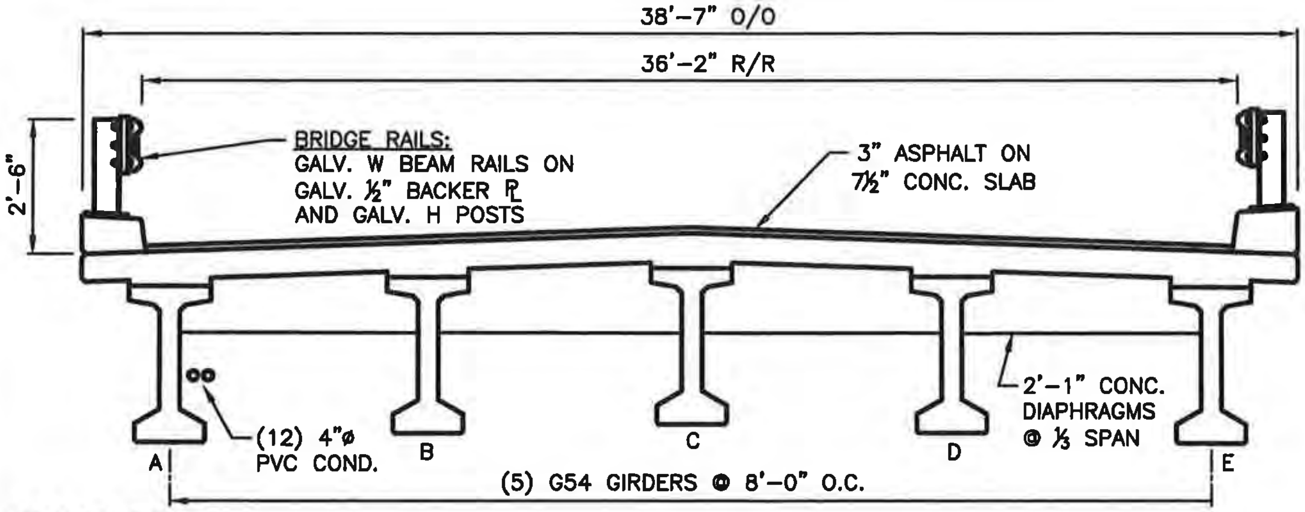
## PLAN



ABUTMENTS:
CONC. WALLS
U-SHAPED DESIGN

## ELEVATION

LOOKING NORTH



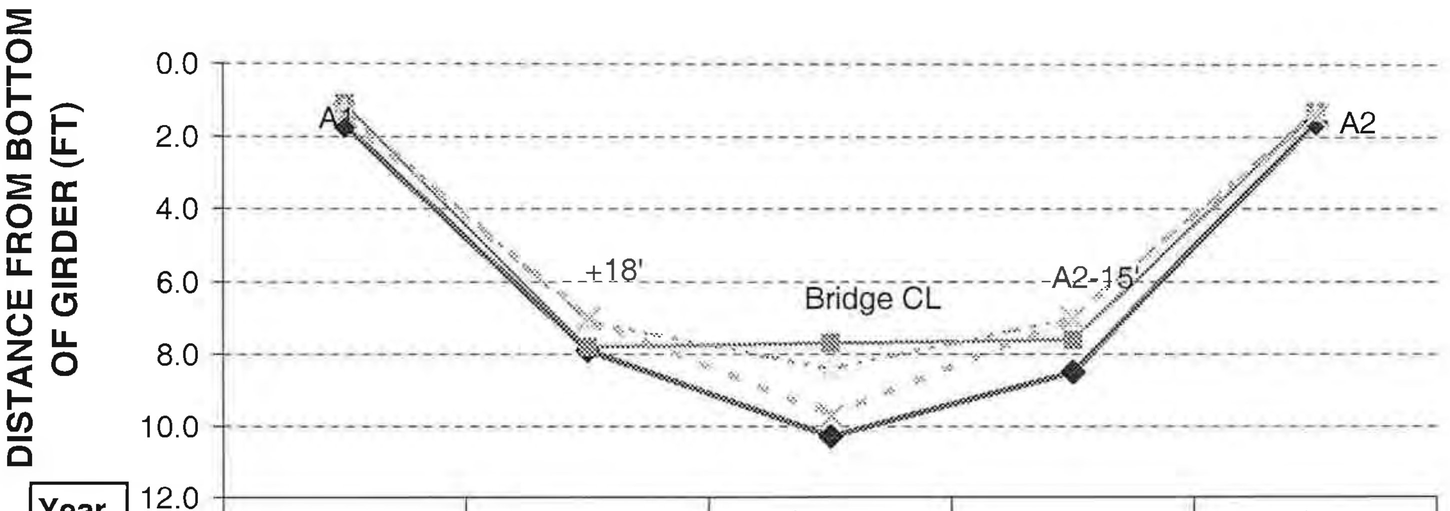
## SECTION

LOOKING EAST

Drawing Name: F:\2010\P10171- Northern Area Counties Bridge Inspection Task 5\drawings\Boulder\BC-10-3.1-SV.dwg - Thu, 07 Apr 2011

# BOULDER COUNTY INSPECTION

## STREAMBED HISTORY

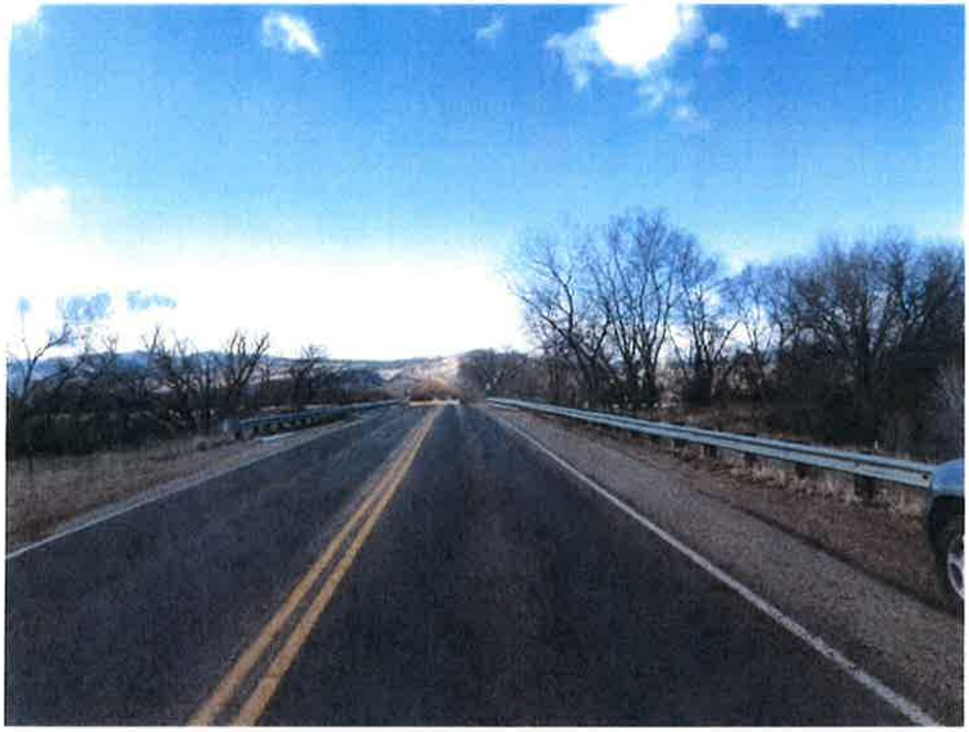


| Year | A1 | +18' | Bridge CL | A2-15' | A2 |
|---|---|---|---|---|---|
| ◆ 2002 | 1.7 | 7.9 | 10.3 | 8.5 | 1.6 |
| ▨ 2004 | 1.1 | 7.8 | 7.7 | 7.6 | 1.3 |
| 2007 | 1.2 | 7.1 | 8.4 | 7.0 | 1.3 |
| ✕ 2011 | 1.4 | 7.0 | 9.7 | 7.0 | 1.4 |
| ✳ | | | | | |

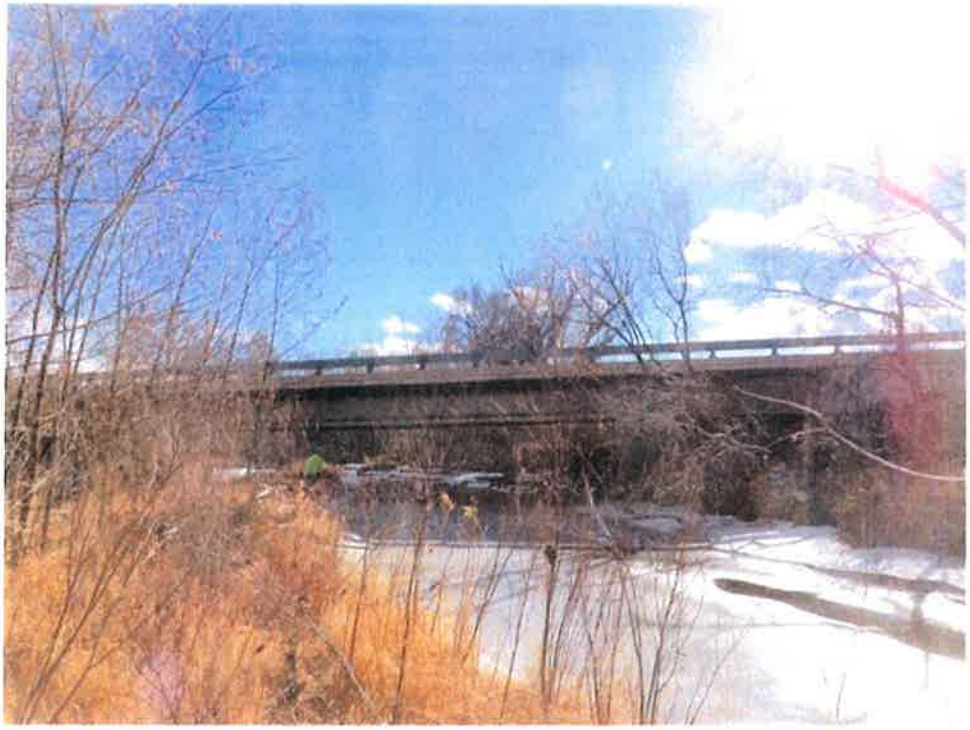
Structure Number: BC-10-3.1-SV

Inspection Date: 1/17/2011

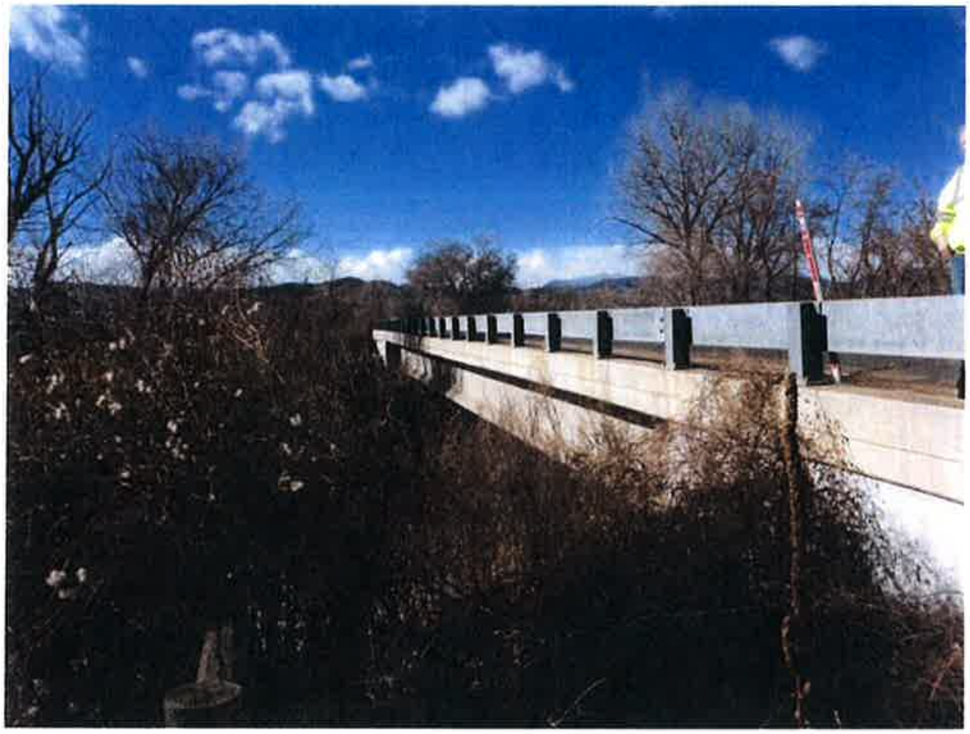
Performed By: NTI/ZDA
WAD (5/6/11)



DECK LOOKING WEST



ELEVATION LOOKING SOUTH



ELEVATION LOOKING NORTHWEST

LIGHT ASPHALT CRACKING ON DECK

UNDERSIDE VIEW LOOKING WEST

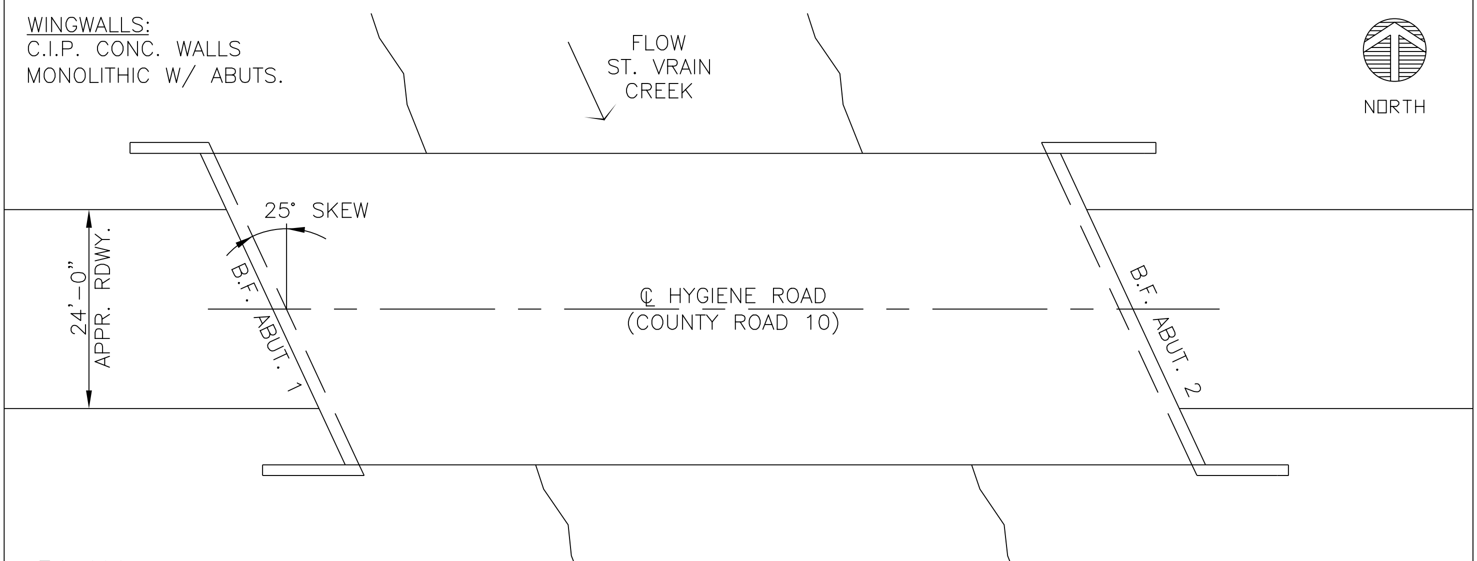
TYPICAL CRACKING WITH LIGHT EFFLORESCENCE AND RUST STAIN IN SOFFIT

CHANNEL LOOKING UPSTREAM

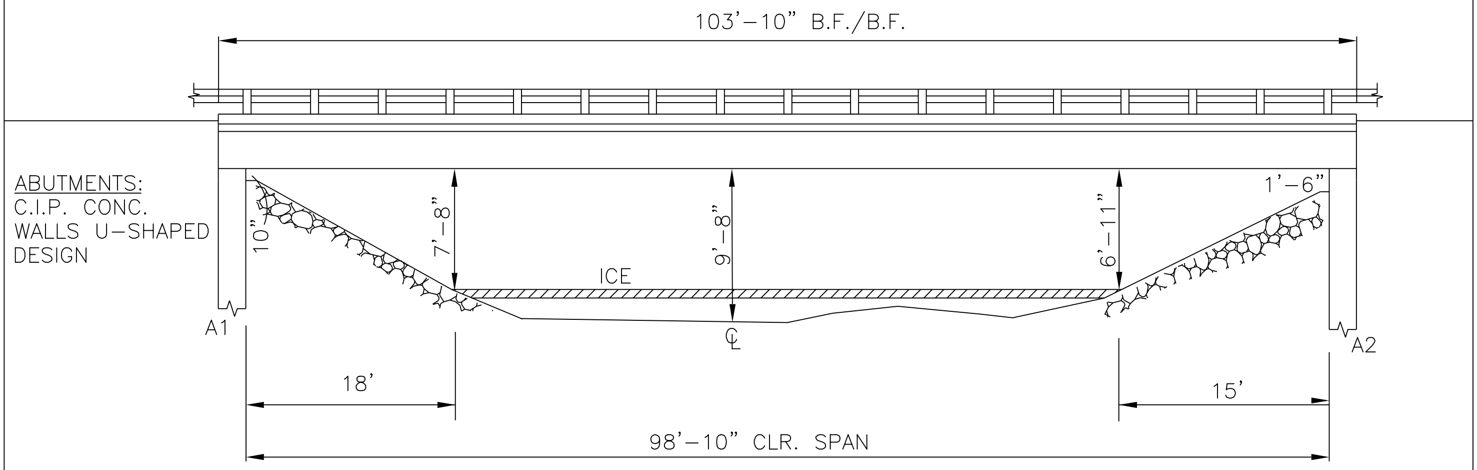
CHANNEL LOOKING DOWNSTREAM

**Short Elliott Hendrickson, Inc.**
2000 S. Colorado Blvd., #6000
Denver, CO 80222-7938
(720) 540-6800 (800) 490-4966
Fax (303) 753-1510

BC-10-3.1-SV
JAN. 17, 2013

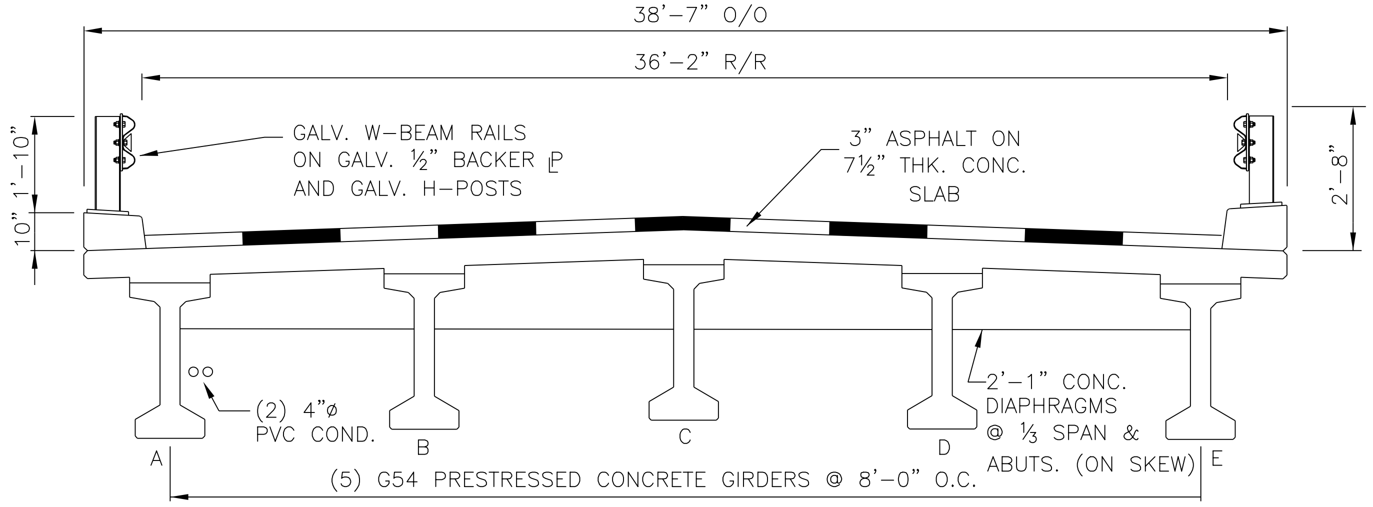


## PLAN



## ELEVATION

LOOKING NORTH

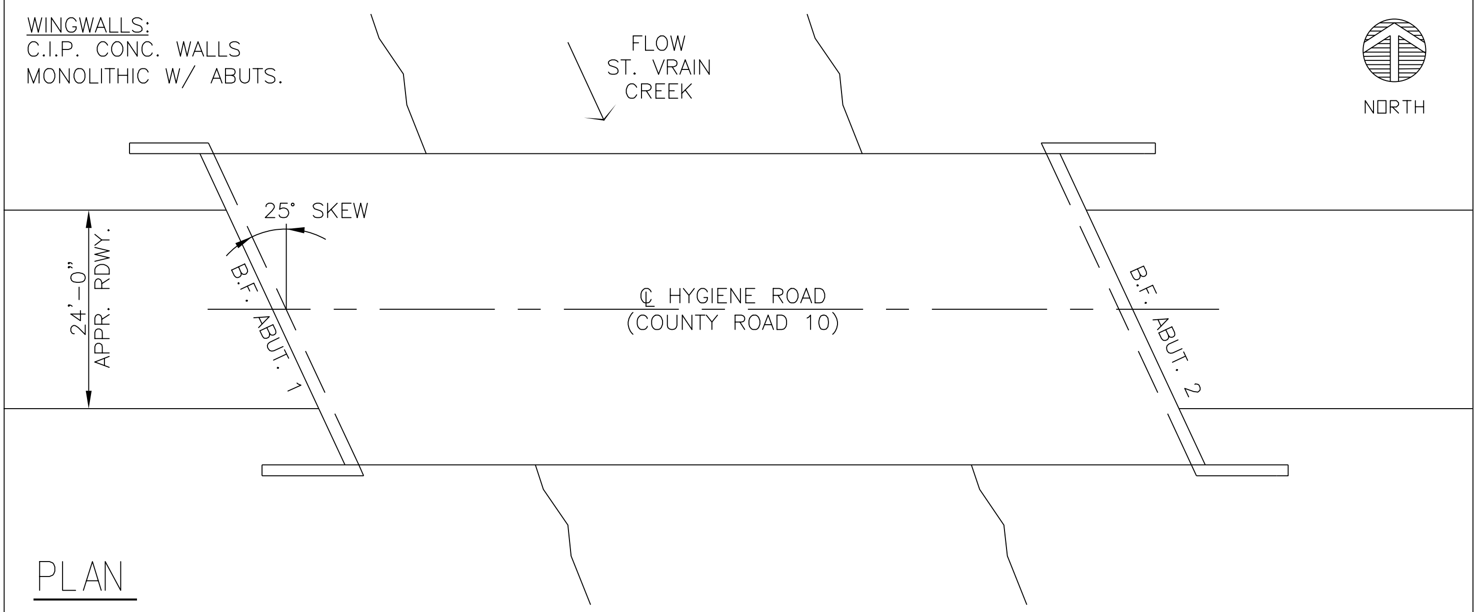


## SECTION

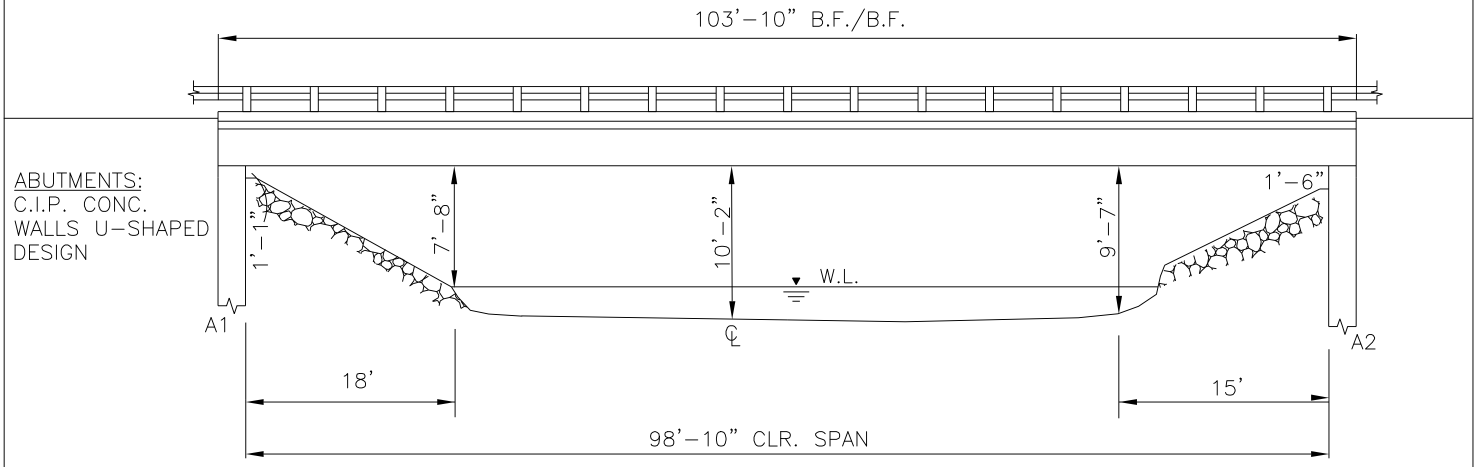
LOOKING EAST

BC-10-3.1-SV

JAN. 16, 2015

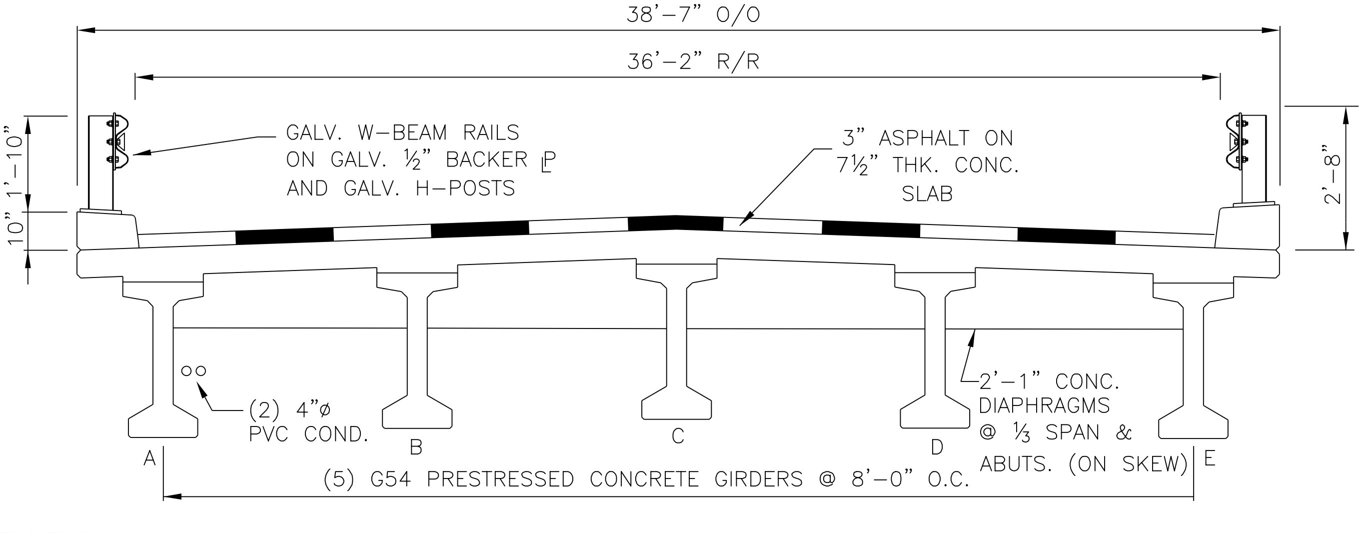


## PLAN



## ELEVATION

LOOKING NORTH



## SECTION

LOOKING EAST

# Appendix D

## Sediment Results

# SUMMARY OF LABORATORY TEST RESULTS

JOB NAME: EA-110666-St. Vrain Breaches JOB NUMBER: 16.037T Date: May-2016

| Depth (ft) | Sample Type | Moisture (%) | Dry Density (pcf) | Atterberg Limits LL / PL / PI * | % Passing 200 Sieve | Grain Size Analysis | Classification USCS | Modified Proctor Max γ (pcf) / Opt. w (%) |
|---|---|---|---|---|---|---|---|---|
| **01-BED 1** | | | | | | | | |
| 0-1 | BKT | | | | 0.1 | (1) | GP | |
| **01-BED 2** | | | | | | | | |
| 0-1 | BKT | | | | 0.4 | (1) | GP | |
| **02-BED 1** | | | | | | | | |
| 0-1 | BKT | | | 30 / NP / NP | 28.5 | (1) | GM | |
| **02-BANK 1** | | | | | | | | |
| 0-1 | BKT | | | | 2.4 | (1) | GP | |
| **03-BED 1** | | | | | | | | |
| 0-1 | BKT | | | | 1.2 | (1) | GP | |
| **03-BANK 1** | | | | | | | | |
| 0-1 | BKT | | | | 3.4 | (1) | SP | |
| **03-BANK 2** | | | | | | | | |
| 0-1 | BKT | | | | 0.9 | (1) | SP | |
| **04-BED 1** | | | | | | | | |
| 0-1 | BKT | | | | 0.0 | (1) | GW | |
| **04-BANK 1** | | | | | | | | |
| 0-1 | BKT | | | | 23.8 | (1) | SM | |
| **04-BED 2** | | | | | | | | |
| 0-1 | BKT | | | | 0.6 | (1) | GP | |

*LL = Liquid Limit PL = Plastic Limit PI = Plasticity Index N.P. = Non Plastic (1) See Attached ** Insufficient Sample

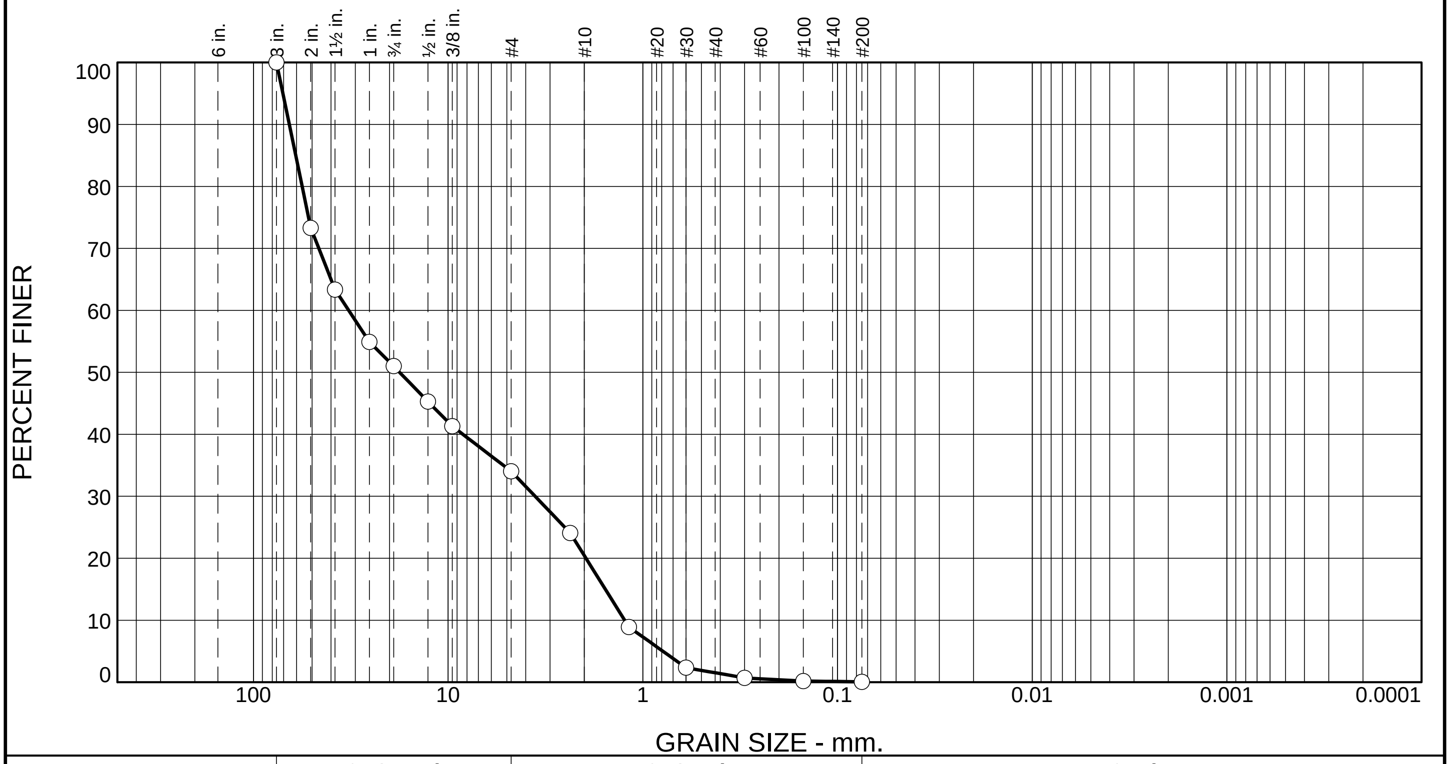
# SUMMARY OF LABORATORY TEST RESULTS

JOB NAME: EA-110666-St. Vrain Breaches JOB NUMBER: 16.037T Date: May-2016

| Depth (ft) | Sample Type | Moisture (%) | Dry Density (pcf) | Atterberg Limits LL / PL / PI * | % Passing 200 Sieve | Grain Size Analysis | Classification USCS | Modified Proctor Max γ (pcf) / Opt. w (%) |
|---|---|---|---|---|---|---|---|---|
| **05-BED 1** | | | | | | | | |
| 0-1 | BKT | | | | 0.0 | (1) | GP | |
| **05-BANK 1** | | | | | | | | |
| 0-1 | BKT | | | | 4.1 | (1) | SP | |
| **06-BED 1** | | | | | | | | |
| 0-1 | BKT | | | | 0.4 | (1) | SP | |
| **06-BANK 1** | | | | | | | | |
| 0-1 | BKT | | | | 11.0 | (1) | SP | |
| **06-BANK 2** | | | | | | | | |
| 0-1 | BKT | | | | 4.1 | (1) | SP-SM | |
| **07-BED 1** | | | | | | | | |
| 0-1 | BKT | | | | 0.0 | (1) | GP-GM | |
| **07-BANK 1** | | | | | | | | |
| 0-1 | BKT | | | | 10.2 | (1) | GP-GM | |
| **08-BED 1** | | | | | | | | |
| 0-1 | BKT | | | | 0.0 | (1) | GW | |

*LL = Liquid Limit PL = Plastic Limit PI = Plasticity Index N.P. = Non Plastic (1) See Attached ** Insufficient Sample

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 49.0 | 17.0 | 13.5 | 19.0 | 1.4 | 0.1 | |

| TEST RESULTS | | | |
|---|---|---|---|
| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
| 3 | 100.0 | | |
| 2 | 73.3 | | |
| 1.5 | 63.4 | | |
| 1 | 54.9 | | |
| .75 | 51.0 | | |
| .5 | 45.3 | | |
| .375 | 41.3 | | |
| #4 | 34.0 | | |
| #8 | 24.1 | | |
| #16 | 8.9 | | |
| #30 | 2.3 | | |
| #50 | 0.7 | | |
| #100 | 0.2 | | |
| #200 | 0.1 | | |

* (no specification provided)

## Material Description

Gravel with Sand, Brown, Moist

## Atterberg Limits (ASTM D 4318)

**PL=** **LL=** **PI=**

## Classification

**USCS (D 2487)=** GP **AASHTO (M 145)=**

## Coefficients

**$D_{90}$=** 65.4640 **$D_{85}$=** 60.6773 **$D_{60}$=** 32.4336
**$D_{50}$=** 17.7439 **$D_{30}$=** 3.5763 **$D_{15}$=** 1.5589
**$D_{10}$=** 1.2406 **$C_u$=** 26.14 **$C_c$=** 0.32

## Remarks

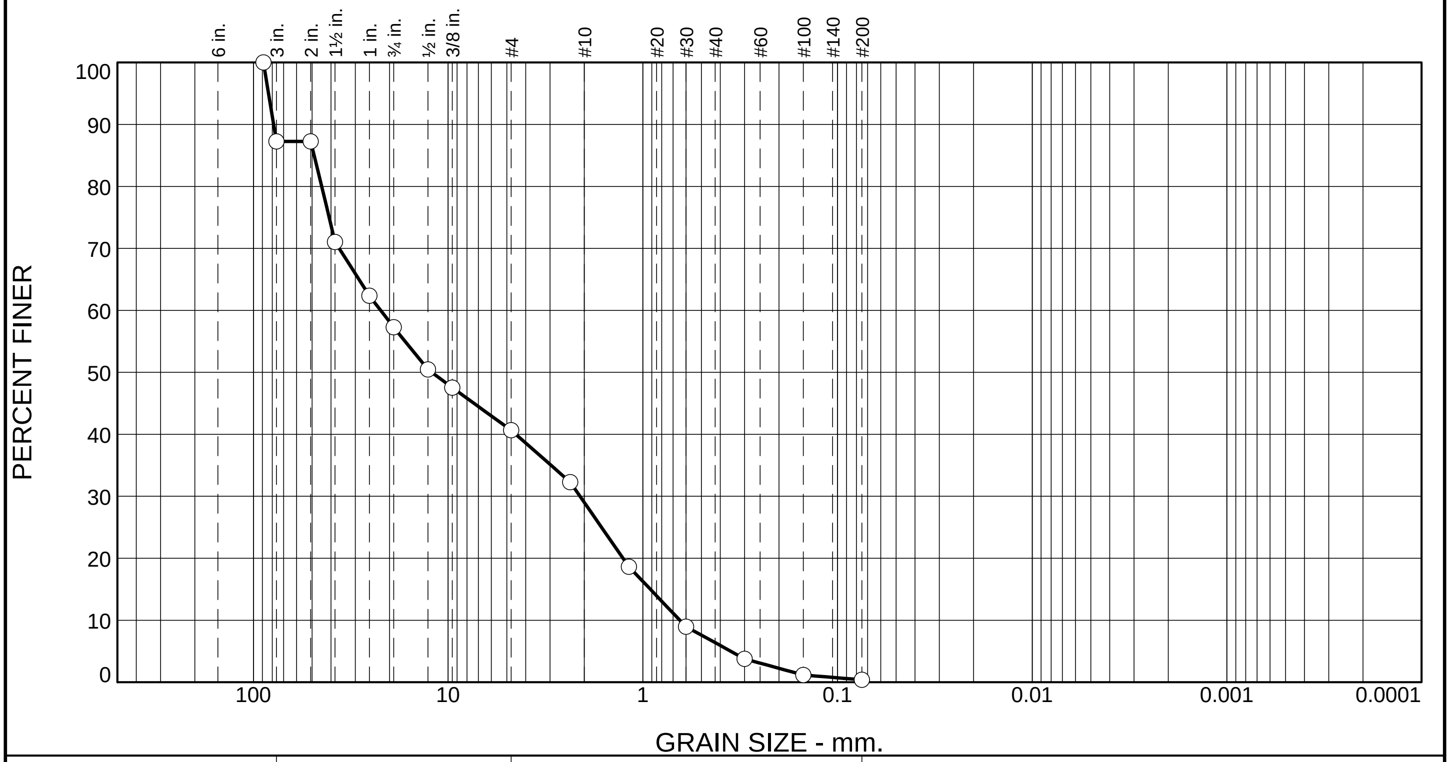
**Date Received:** **Date Tested:** 5/19/2016
**Tested By:** ______________________
**Checked By:** ______________________
**Title:** ______________________

**Source of Sample:** 01-BED 1
**Sample Number:** BKT
**Date Sampled:** 5/16/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches
**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 12.7 | 30.0 | 16.6 | 11.7 | 22.6 | 6.0 | 0.4 | |

| TEST RESULTS | | | |
|---|---|---|---|
| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
| 3.5 | 100.0 | | |
| 3 | 87.3 | | |
| 2 | 87.3 | | |
| 1.5 | 71.0 | | |
| 1 | 62.4 | | |
| .75 | 57.3 | | |
| .5 | 50.5 | | |
| .375 | 47.5 | | |
| #4 | 40.7 | | |
| #8 | 32.3 | | |
| #16 | 18.6 | | |
| #30 | 9.0 | | |
| #50 | 3.8 | | |
| #100 | 1.2 | | |
| #200 | 0.4 | | |

* (no specification provided)

## Material Description

Gravel with Sand, Brown, Moist

## Atterberg Limits (ASTM D 4318)

**PL=** **LL=** **PI=**

## Classification

**USCS (D 2487)=** GP **AASHTO (M 145)=**

## Coefficients

| | | |
|---|---|---|
| $D_{90}$= 78.7585 | $D_{85}$= 48.7933 | $D_{60}$= 22.2163 |
| $D_{50}$= 12.1223 | $D_{30}$= 2.1013 | $D_{15}$= 0.9157 |
| $D_{10}$= 0.6453 | $C_u$= 34.43 | $C_c$= 0.31 |

**Remarks**

**Date Received:** **Date Tested:** 5/23/22016

**Tested By:**

**Checked By:**

**Title:**

**Source of Sample:** 01-BED 2
**Sample Number:** BKT

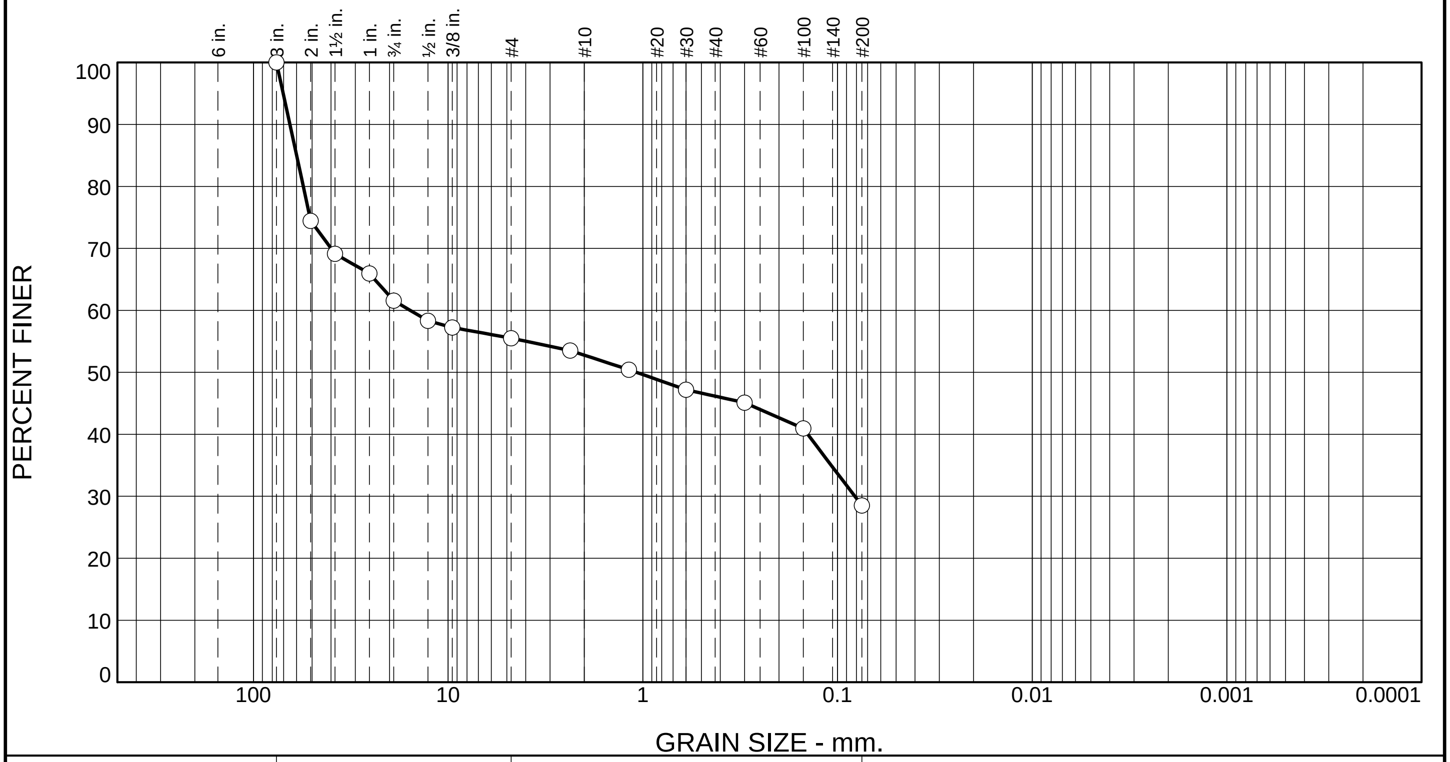
**Date Sampled:** 5/16/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel |  | % Sand |  |  | % Fines |  |
|---|---|---|---|---|---|---|---|
|  | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 38.4 | 6.1 | 2.7 | 6.6 | 17.7 | 28.5 |  |

**TEST RESULTS**

| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
|---|---|---|---|
| 3 | 100.0 |  |  |
| 2 | 74.4 |  |  |
| 1.5 | 69.1 |  |  |
| 1 | 66.0 |  |  |
| .75 | 61.6 |  |  |
| .5 | 58.3 |  |  |
| .375 | 57.2 |  |  |
| #4 | 55.5 |  |  |
| #8 | 53.5 |  |  |
| #16 | 50.4 |  |  |
| #30 | 47.2 |  |  |
| #50 | 45.1 |  |  |
| #100 | 40.9 |  |  |
| #200 | 28.5 |  |  |

* (no specification provided)

## Material Description

Silty Gravel with Sand, Brown, Moist

## Atterberg Limits (ASTM D 4318)

**PL=** NP **LL=** 30 **PI=** NP

## Classification

**USCS (D 2487)=** GM **AASHTO (M 145)=** A-2-4(0)

## Coefficients

|  |  |  |
|---|---|---|
| $D_{90}$= 65.0217 | $D_{85}$= 60.0634 | $D_{60}$= 15.6539 |
| $D_{50}$= 1.0803 | $D_{30}$= 0.0815 | $D_{15}$= |
| $D_{10}$= | $C_u$= | $C_c$= |

**Remarks**

**Date Received:** **Date Tested:** 5/23/2016

**Tested By:** ________________

**Checked By:** ________________

**Title:** ________________

**Source of Sample:** 02-BED 1
**Sample Number:** BKT

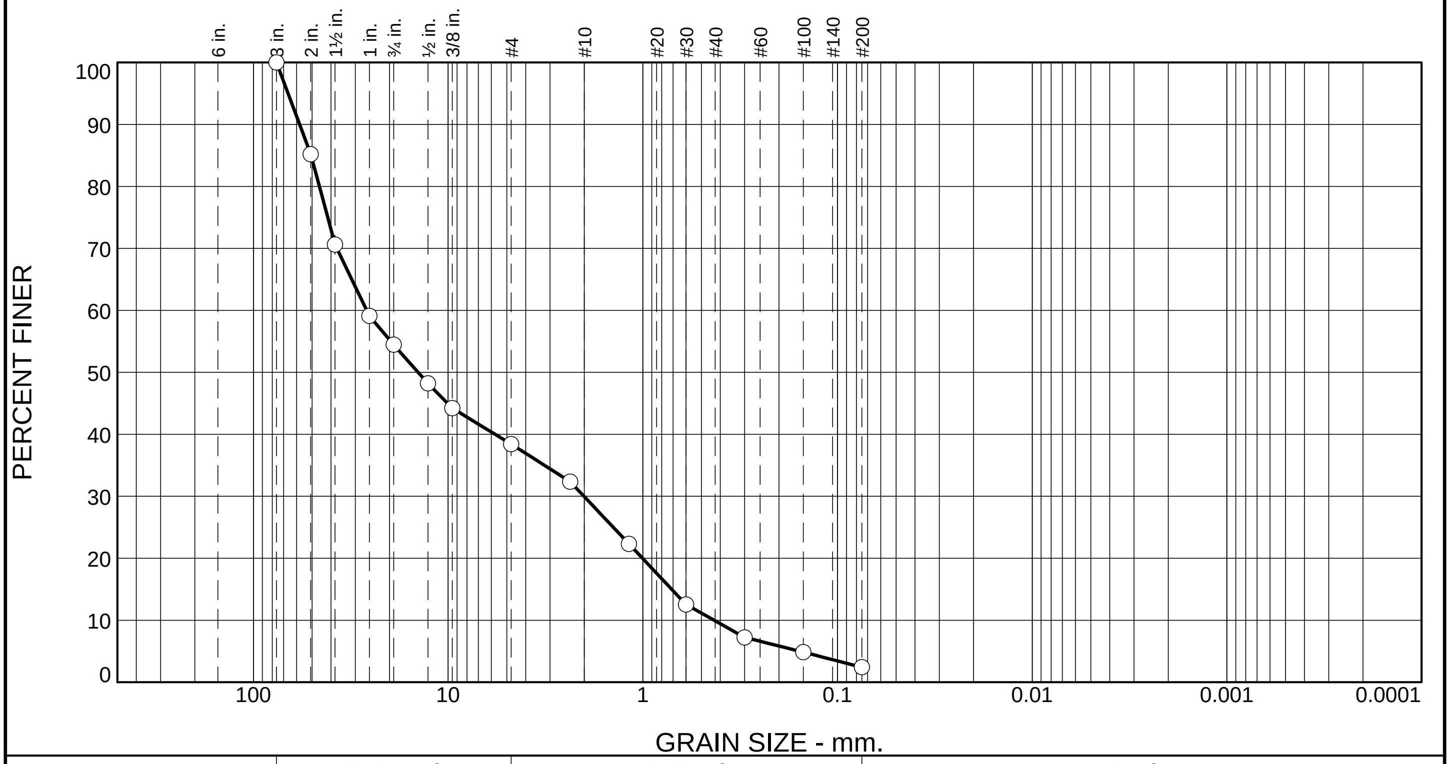
**Date Sampled:** 5/16/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 45.5 | 16.1 | 8.4 | 20.1 | 7.5 | 2.4 | |

| TEST RESULTS | | | |
|---|---|---|---|
| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
| 3 | 100.0 | | |
| 2 | 85.2 | | |
| 1.5 | 70.6 | | |
| 1 | 59.1 | | |
| .75 | 54.5 | | |
| .5 | 48.2 | | |
| .375 | 44.2 | | |
| #4 | 38.4 | | |
| #8 | 32.4 | | |
| #16 | 22.3 | | |
| #30 | 12.5 | | |
| #50 | 7.2 | | |
| #100 | 4.9 | | |
| #200 | 2.4 | | |

* (no specification provided)

## Material Description

Gravel with Sand, Brown, Moist

## Atterberg Limits (ASTM D 4318)

**PL=** **LL=** **PI=**

## Classification

**USCS (D 2487)=** GP **AASHTO (M 145)=**

## Coefficients

| | | |
|---|---|---|
| $D_{90}$= 57.9517 | $D_{85}$= 50.6113 | $D_{60}$= 26.2164 |
| $D_{50}$= 14.2600 | $D_{30}$= 2.0053 | $D_{15}$= 0.7112 |
| $D_{10}$= 0.4306 | $C_u$= 60.89 | $C_c$= 0.36 |

**Remarks**

**Date Received:** **Date Tested:** 5/18/2016

**Tested By:** ____________________

**Checked By:** ____________________

**Title:** ____________________

**Source of Sample:** 02-BANK 1
**Sample Number:** BKT

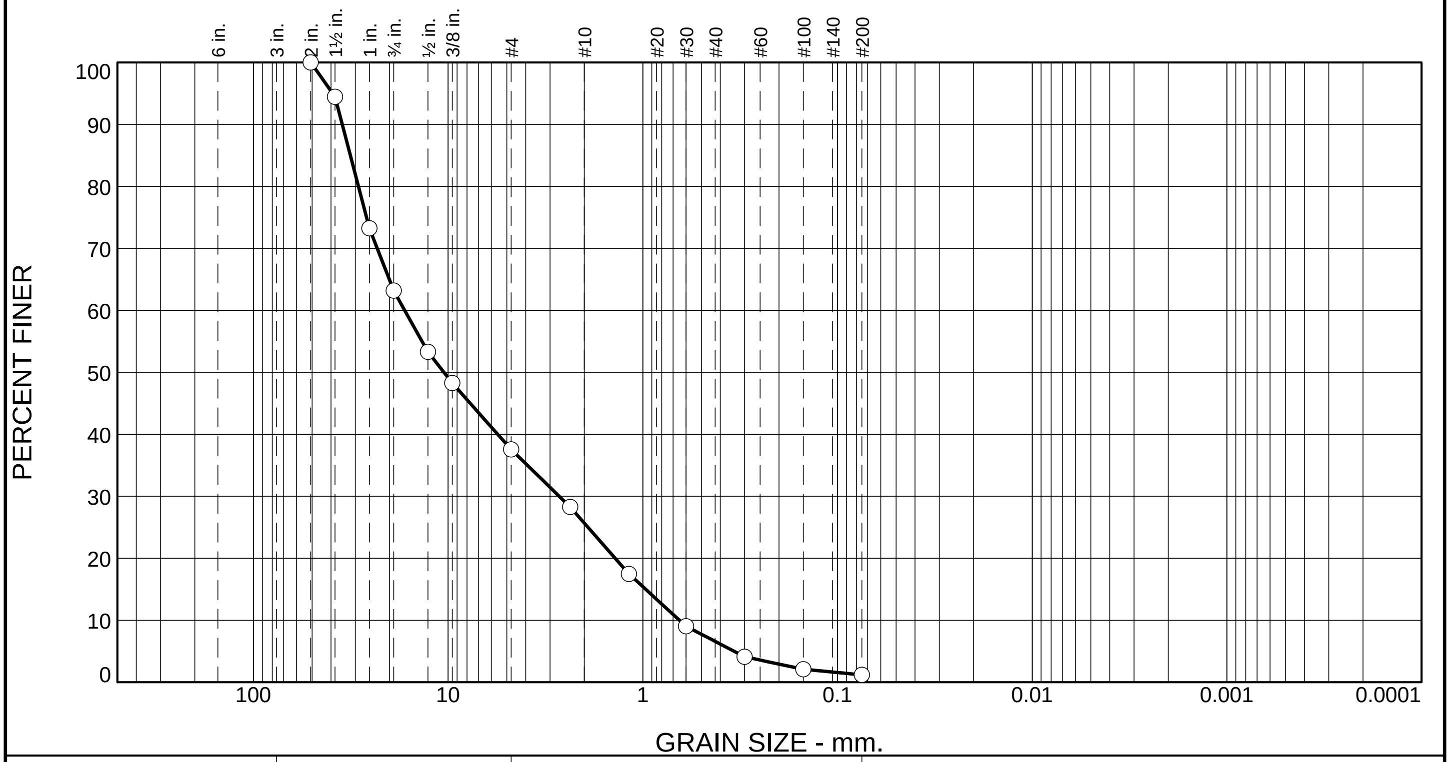
**Date Sampled:** 5/16/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel |  | % Sand |  |  | % Fines |  |
|---|---|---|---|---|---|---|---|
|  | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 36.8 | 25.6 | 11.9 | 19.1 | 5.4 | 1.2 |  |

**TEST RESULTS**

| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
|---|---|---|---|
| 2 | 100.0 |  |  |
| 1.5 | 94.5 |  |  |
| 1 | 73.3 |  |  |
| .75 | 63.2 |  |  |
| .5 | 53.3 |  |  |
| .375 | 48.3 |  |  |
| #4 | 37.6 |  |  |
| #8 | 28.3 |  |  |
| #16 | 17.5 |  |  |
| #30 | 9.0 |  |  |
| #50 | 4.1 |  |  |
| #100 | 2.1 |  |  |
| #200 | 1.2 |  |  |

* (no specification provided)

## Material Description

Gravel with Sand, Brown, Moist

## Atterberg Limits (ASTM D 4318)

**PL=** **LL=** **PI=**

## Classification

**USCS (D 2487)=** GP **AASHTO (M 145)=**

## Coefficients

| | | |
|---|---|---|
| $D_{90}$= 34.9834 | $D_{85}$= 31.7925 | $D_{60}$= 16.7184 |
| $D_{50}$= 10.5127 | $D_{30}$= 2.6882 | $D_{15}$= 0.9673 |
| $D_{10}$= 0.6482 | $C_u$= 25.79 | $C_c$= 0.67 |

**Remarks**

**Date Received:** **Date Tested:** 5/18/2016

**Tested By:** ____________

**Checked By:** ____________

**Title:** ____________

**Source of Sample:** 03-BED 1
**Sample Number:** BKT

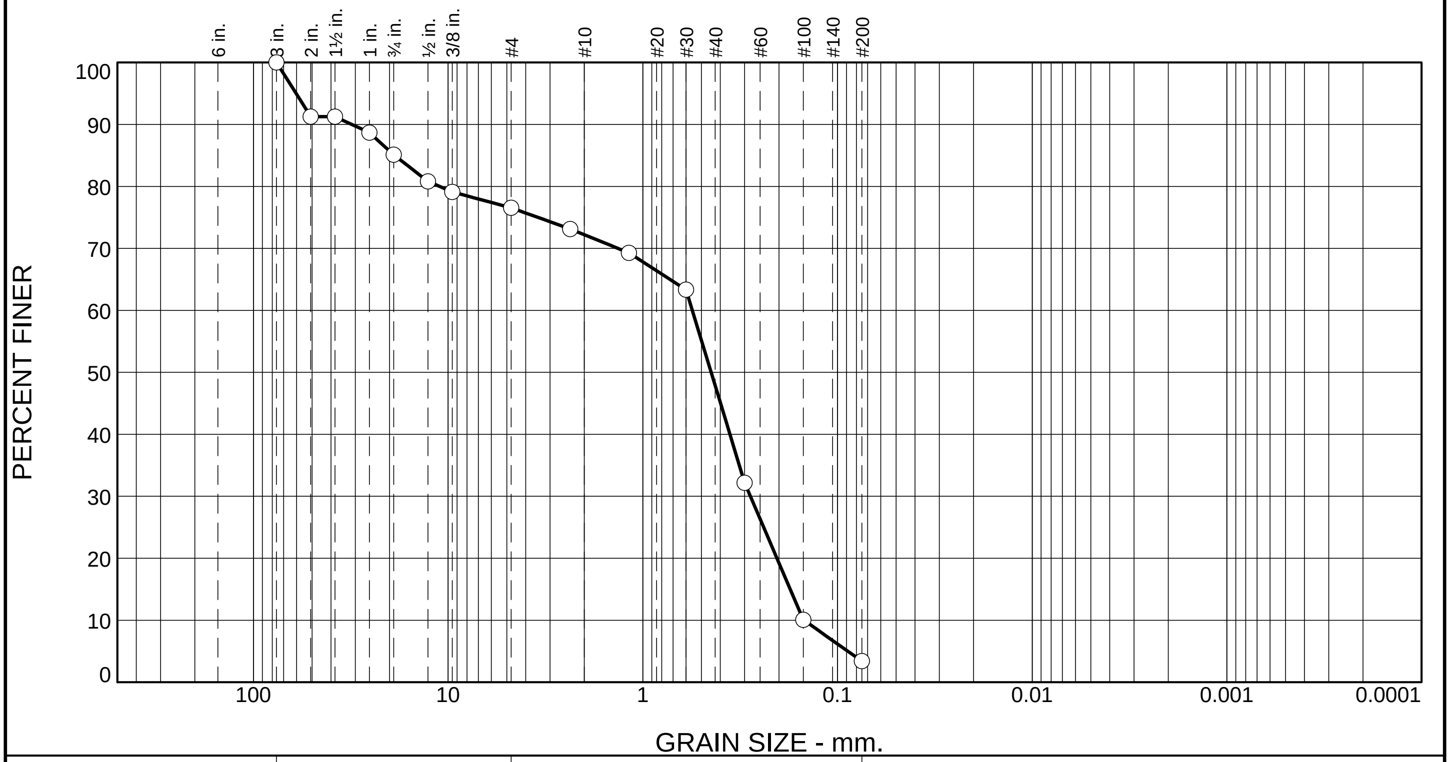
**Date Sampled:** 5/16/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel |  | % Sand |  |  | % Fines |  |
|---|---|---|---|---|---|---|---|
|  | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 14.9 | 8.5 | 4.4 | 24.4 | 44.4 | 3.4 |  |

| TEST RESULTS |  |  |  |
|---|---|---|---|
| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
| 3 | 100.0 |  |  |
| 2 | 91.3 |  |  |
| 1.5 | 91.3 |  |  |
| 1 | 88.7 |  |  |
| .75 | 85.1 |  |  |
| .5 | 80.8 |  |  |
| .375 | 79.1 |  |  |
| #4 | 76.6 |  |  |
| #8 | 73.1 |  |  |
| #16 | 69.3 |  |  |
| #30 | 63.3 |  |  |
| #50 | 32.2 |  |  |
| #100 | 10.1 |  |  |
| #200 | 3.4 |  |  |

* (no specification provided)

## Material Description

Sand with Gravel, Brown, Moist

## Atterberg Limits (ASTM D 4318)

**PL=** **LL=** **PI=**

## Classification

**USCS (D 2487)=** SP **AASHTO (M 145)=**

## Coefficients

|  |  |  |
|---|---|---|
| $D_{90}$= 31.2593 | $D_{85}$= 18.8464 | $D_{60}$= 0.5571 |
| $D_{50}$= 0.4460 | $D_{30}$= 0.2801 | $D_{15}$= 0.1750 |
| $D_{10}$= 0.1488 | $C_u$= 3.74 | $C_c$= 0.95 |

**Remarks**

**Date Received:** **Date Tested:** 5/18/2016

**Tested By:**

**Checked By:**

**Title:**

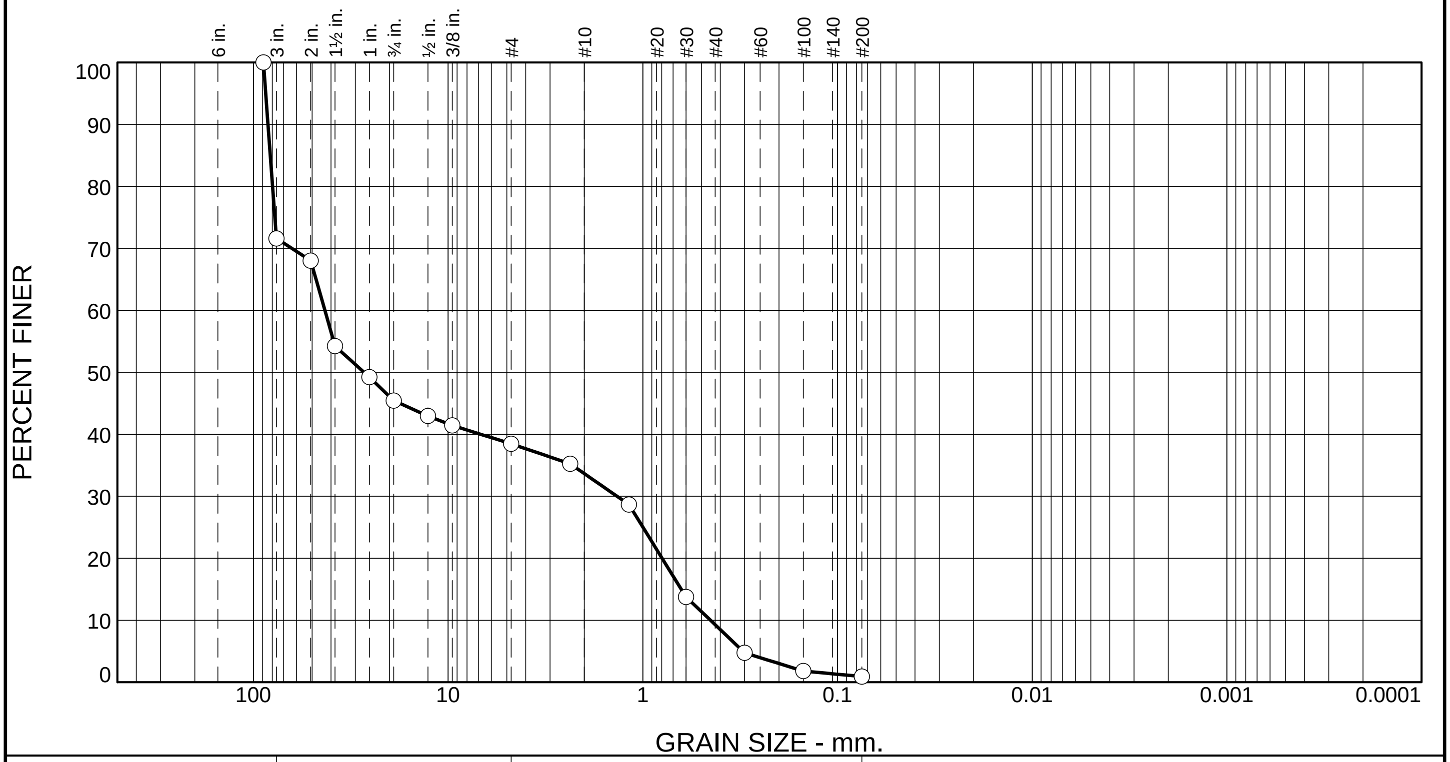
**Source of Sample:** 03-BANK 1
**Sample Number:** BKT
**Date Sampled:** 5/16/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 28.4 | 26.2 | 6.9 | 4.8 | 24.4 | 8.4 | 0.9 | |

| TEST RESULTS | | | |
|---|---|---|---|
| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
| 3.5 | 100.0 | | |
| 3 | 71.6 | | |
| 2 | 68.0 | | |
| 1.5 | 54.2 | | |
| 1 | 49.2 | | |
| .75 | 45.4 | | |
| .5 | 43.0 | | |
| .375 | 41.4 | | |
| #4 | 38.5 | | |
| #8 | 35.2 | | |
| #16 | 28.7 | | |
| #30 | 13.8 | | |
| #50 | 4.7 | | |
| #100 | 1.8 | | |
| #200 | 0.9 | | |

* (no specification provided)

## Material Description

Sand with Gravel, Brown, Moist

## Atterberg Limits (ASTM D 4318)

**PL=** **LL=** **PI=**

## Classification

**USCS (D 2487)=** SP **AASHTO (M 145)=**

## Coefficients

| | | |
|---|---|---|
| $D_{90}$= 84.2013 | $D_{85}$= 81.9459 | $D_{60}$= 42.9770 |
| $D_{50}$= 27.0362 | $D_{30}$= 1.3578 | $D_{15}$= 0.6348 |
| $D_{10}$= 0.4495 | $C_u$= 95.62 | $C_c$= 0.10 |

**Remarks**

**Date Received:** **Date Tested:** 5/18/2016

**Tested By:** ____________________

**Checked By:** ____________________

**Title:** ____________________

**Source of Sample:** 03-BANK 2
**Sample Number:** BKT

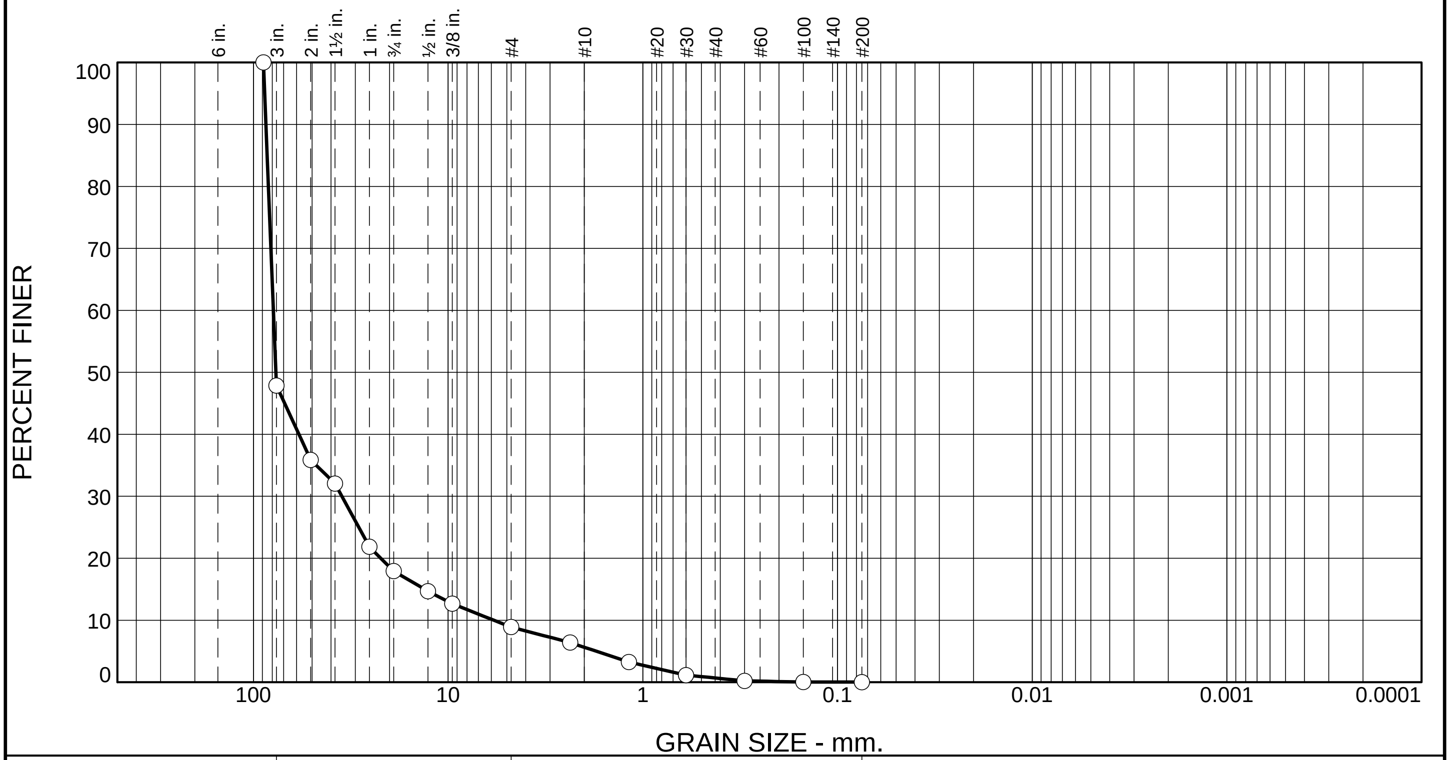
**Date Sampled:** 5/16/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 52.1 | 30.0 | 9.0 | 3.3 | 4.9 | 0.7 | 0.0 | |

| TEST RESULTS | | | |
|---|---|---|---|
| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
| 3.5 | 100.0 | | |
| 3 | 47.9 | | |
| 2 | 35.9 | | |
| 1.5 | 32.0 | | |
| 1 | 21.8 | | |
| .75 | 17.9 | | |
| .5 | 14.7 | | |
| .375 | 12.7 | | |
| #4 | 8.9 | | |
| #8 | 6.4 | | |
| #16 | 3.3 | | |
| #30 | 1.1 | | |
| #50 | 0.2 | | |
| #100 | 0.0 | | |
| #200 | 0.0 | | |

* (no specification provided)

## Material Description

Gravel with Sand, Brown, Moist

## Atterberg Limits (ASTM D 4318)

**PL=** **LL=** **PI=**

## Classification

**USCS (D 2487)=** GW **AASHTO (M 145)=**

## Coefficients

| | | |
|---|---|---|
| $D_{90}$= 86.3104 | $D_{85}$= 85.0441 | $D_{60}$= 78.9856 |
| $D_{50}$= 76.6848 | $D_{30}$= 35.1235 | $D_{15}$= 13.1997 |
| $D_{10}$= 5.8228 | $C_u$= 13.56 | $C_c$= 2.68 |

## Remarks

**Date Received:** **Date Tested:** 5/18/2016

**Tested By:**

**Checked By:**

**Title:**

**Source of Sample:** 04-BED 1
**Sample Number:** BKT

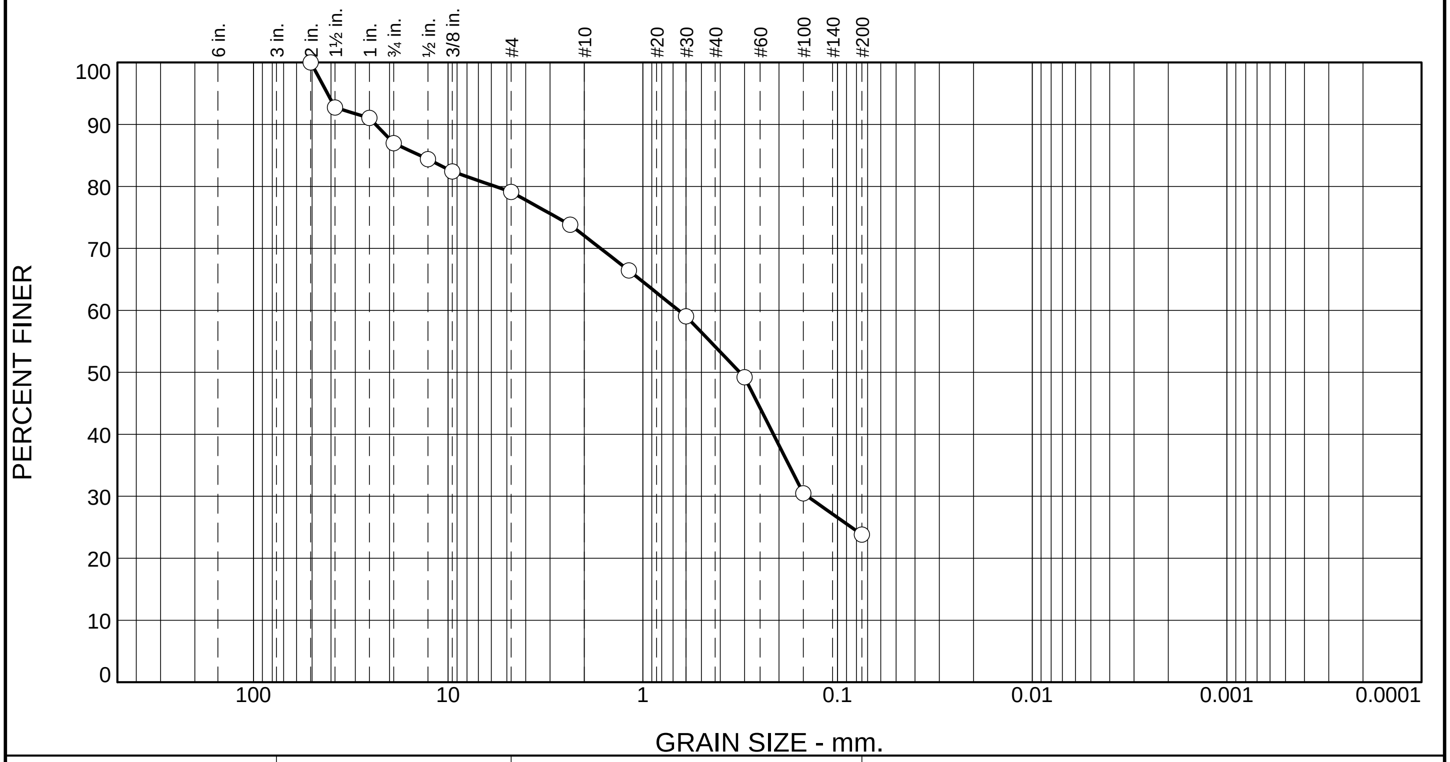
**Date Sampled:** 5/16/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 13.0 | 7.9 | 7.0 | 18.0 | 30.3 | 23.8 | |

| TEST RESULTS | | | |
|---|---|---|---|
| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
| 2 | 100.0 | | |
| 1.5 | 92.7 | | |
| 1 | 91.0 | | |
| .75 | 87.0 | | |
| .5 | 84.4 | | |
| .375 | 82.4 | | |
| #4 | 79.1 | | |
| #8 | 73.8 | | |
| #16 | 66.4 | | |
| #30 | 59.0 | | |
| #50 | 49.2 | | |
| #100 | 30.5 | | |
| #200 | 23.8 | | |

* (no specification provided)

**Material Description**

Silty Sand with Gravel, Brown, Moist

**Atterberg Limits (ASTM D 4318)**

**PL=** NP **LL=** NV **PI=** NP

**Classification**

**USCS (D 2487)=** SM **AASHTO (M 145)=** A-2-4(0)

**Coefficients**

$D_{90}$= 23.5887 $D_{85}$= 13.9478 $D_{60}$= 0.6548
$D_{50}$= 0.3174 $D_{30}$= 0.1428 $D_{15}$=
$D_{10}$= $C_u$= $C_c$=

**Remarks**

**Date Received:** **Date Tested:** 5/25/2016
**Tested By:** ____________
**Checked By:** ____________
**Title:** ____________

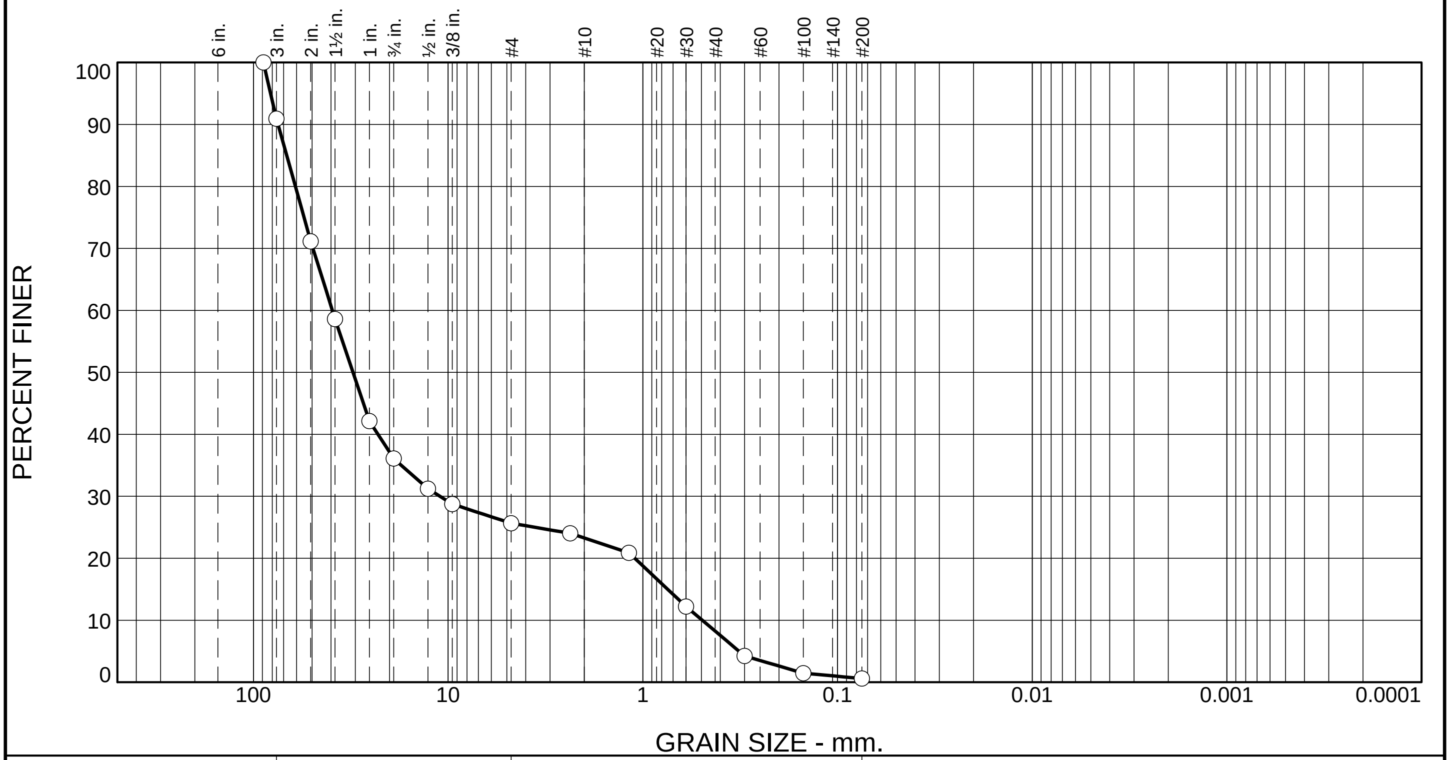
**Source of Sample:** 04-BANK 1 **Date Sampled:** 5/16/2016
**Sample Number:** BKT

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 9.1 | 54.8 | 10.4 | 2.4 | 15.1 | 7.6 | 0.6 | |

| TEST RESULTS | | | |
|---|---|---|---|
| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
| 3.5 | 100.0 | | |
| 3 | 90.9 | | |
| 2 | 71.1 | | |
| 1.5 | 58.6 | | |
| 1 | 42.1 | | |
| .75 | 36.1 | | |
| .5 | 31.2 | | |
| .375 | 28.8 | | |
| #4 | 25.7 | | |
| #8 | 24.0 | | |
| #16 | 20.9 | | |
| #30 | 12.2 | | |
| #50 | 4.2 | | |
| #100 | 1.5 | | |
| #200 | 0.6 | | |

* (no specification provided)

## Material Description

Gravel with Sand, Brown, Moist

## Atterberg Limits (ASTM D 4318)

**PL=** **LL=** **PI=**

## Classification

**USCS (D 2487)=** GP **AASHTO (M 145)=**

## Coefficients

$D_{90}$= 74.7739 $D_{85}$= 67.4954 $D_{60}$= 39.3447
$D_{50}$= 30.8251 $D_{30}$= 11.0182 $D_{15}$= 0.7454
$D_{10}$= 0.4949 $C_u$= 79.51 $C_c$= 6.24

**Remarks**

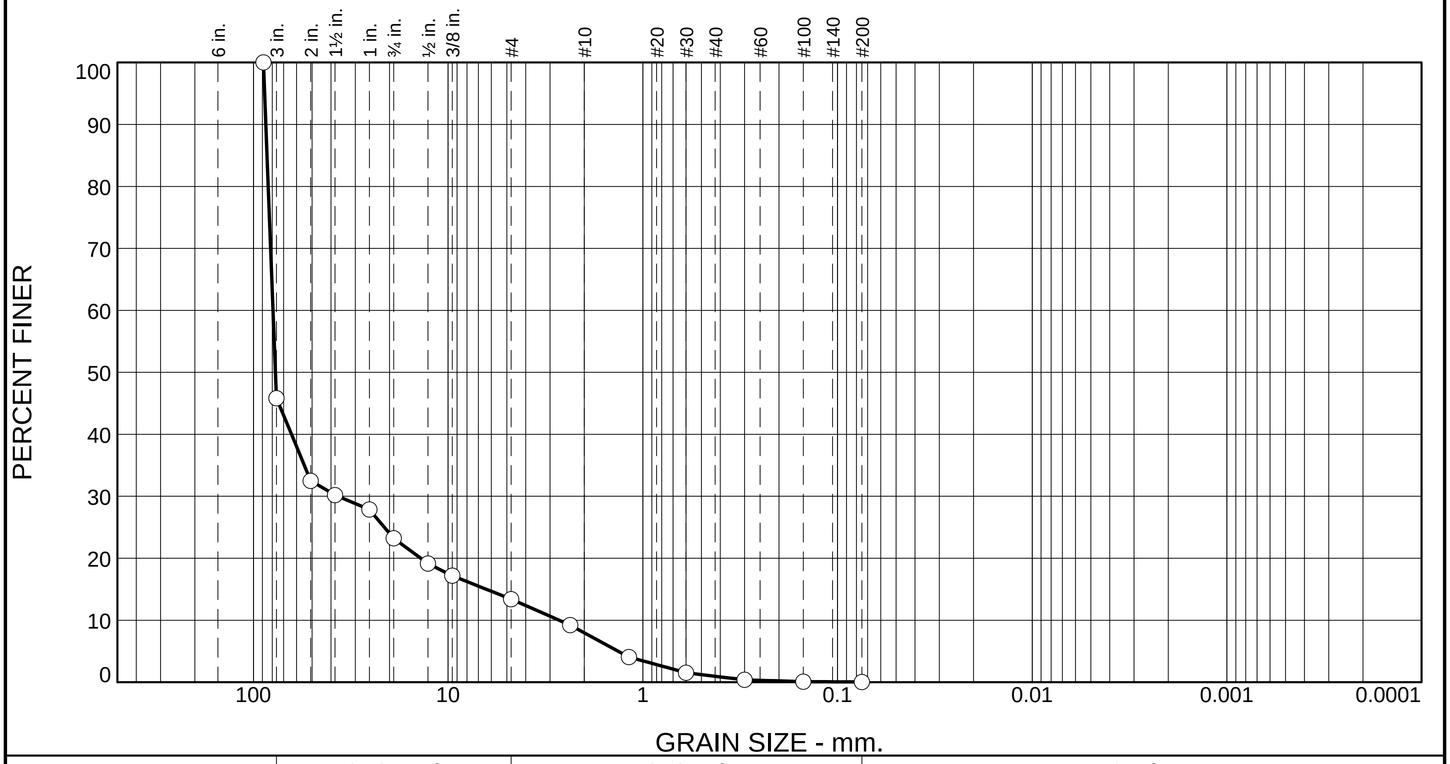
**Date Received:** **Date Tested:** 5/18/2016
**Tested By:**
**Checked By:**
**Title:**

**Source of Sample:** 04-BED 2 **Date Sampled:** 5/16/2016
**Sample Number:** BKT

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches
**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 54.2 | 22.6 | 9.8 | 5.4 | 7.0 | 1.0 | 0.0 | |

**TEST RESULTS**

| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
|---|---|---|---|
| 3.5 | 100.0 | | |
| 3 | 45.8 | | |
| 2 | 32.5 | | |
| 1.5 | 30.2 | | |
| 1 | 27.9 | | |
| .75 | 23.2 | | |
| .5 | 19.1 | | |
| .375 | 17.2 | | |
| #4 | 13.4 | | |
| #8 | 9.2 | | |
| #16 | 4.1 | | |
| #30 | 1.5 | | |
| #50 | 0.4 | | |
| #100 | 0.1 | | |
| #200 | 0.0 | | |

* (no specification provided)

## Material Description

Gravel with Sand, Brown, Moist

**Atterberg Limits (ASTM D 4318)**

**PL=** **LL=** **PI=**

**Classification**

**USCS (D 2487)=** GP **AASHTO (M 145)=**

**Coefficients**

| | | |
|---|---|---|
| $D_{90}$= 86.4062 | $D_{85}$= 85.1856 | $D_{60}$= 79.3366 |
| $D_{50}$= 77.1111 | $D_{30}$= 36.7877 | $D_{15}$= 6.3774 |
| $D_{10}$= 2.6959 | $C_u$= 29.43 | $C_c$= 6.33 |

**Remarks**

**Date Received:** **Date Tested:** 5/19/2016

**Tested By:** ____________________

**Checked By:** ____________________

**Title:** ____________________

**Source of Sample:** 05-BED 1
**Sample Number:** BKT

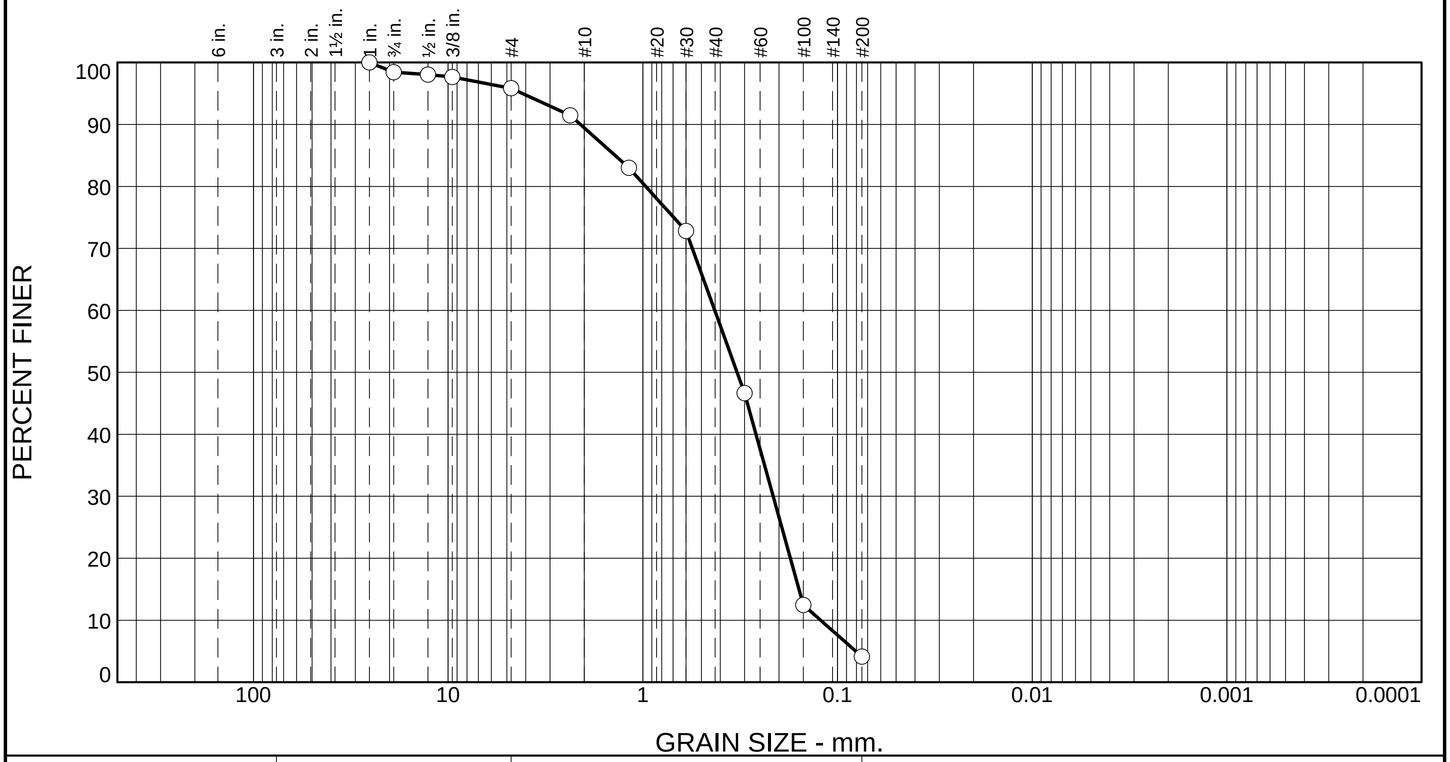
**Date Sampled:** 5/16/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 1.6 | 2.6 | 6.3 | 29.7 | 55.7 | 4.1 | |

| TEST RESULTS | | | |
|---|---|---|---|
| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
| 1 | 100.0 | | |
| .75 | 98.4 | | |
| .5 | 98.1 | | |
| .375 | 97.7 | | |
| #4 | 95.8 | | |
| #8 | 91.5 | | |
| #16 | 83.0 | | |
| #30 | 72.8 | | |
| #50 | 46.6 | | |
| #100 | 12.5 | | |
| #200 | 4.1 | | |

* (no specification provided)

## Material Description

Sand, Brown, Moist

## Atterberg Limits (ASTM D 4318)

**PL=** **LL=** **PI=**

## Classification

**USCS (D 2487)=** SP **AASHTO (M 145)=**

## Coefficients

| | | |
|---|---|---|
| $D_{90}$= 2.0910 | $D_{85}$= 1.3883 | $D_{60}$= 0.4274 |
| $D_{50}$= 0.3279 | $D_{30}$= 0.2140 | $D_{15}$= 0.1579 |
| $D_{10}$= 0.1221 | $C_u$= 3.50 | $C_c$= 0.88 |

**Remarks**

**Date Received:** **Date Tested:** 5/25/2016

**Tested By:**

**Checked By:**

**Title:**

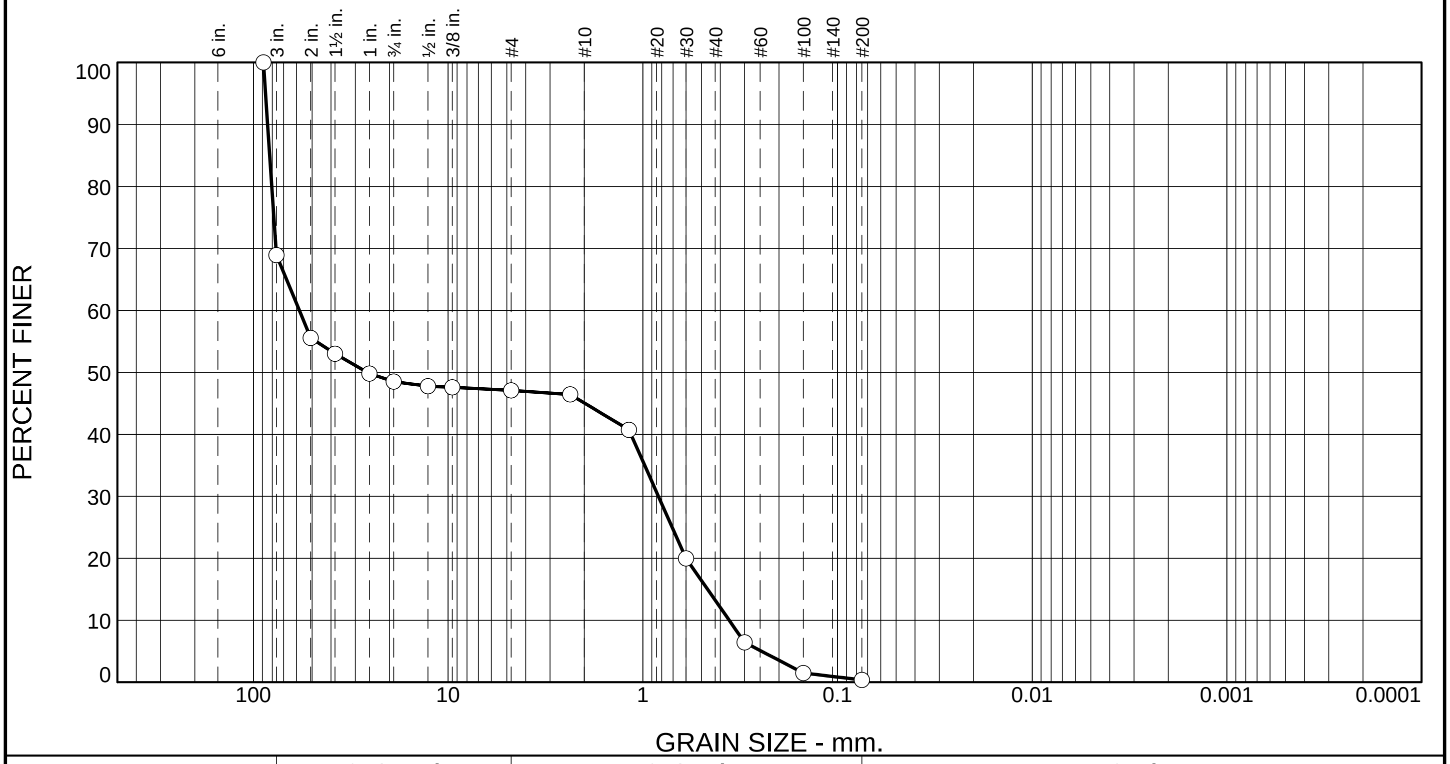
**Source of Sample:** 05-BANK 1 **Date Sampled:** 5/16/2016
**Sample Number:** BKT

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 31.1 | 20.4 | 1.4 | 2.0 | 31.9 | 12.8 | 0.4 | |

| TEST RESULTS | | | |
|---|---|---|---|
| **Opening Size** | **Percent Finer** | **Spec.* (Percent)** | **Pass? (X=Fail)** |
| 3.5 | 100.0 | | |
| 3 | 68.9 | | |
| 2 | 55.5 | | |
| 1.5 | 53.0 | | |
| 1 | 49.8 | | |
| .75 | 48.5 | | |
| .5 | 47.8 | | |
| .375 | 47.6 | | |
| #4 | 47.1 | | |
| #8 | 46.4 | | |
| #16 | 40.7 | | |
| #30 | 20.0 | | |
| #50 | 6.4 | | |
| #100 | 1.5 | | |
| #200 | 0.4 | | |

* (no specification provided)

## Material Description

Sand with Gravel, Brown, Moist

## Atterberg Limits (ASTM D 4318)

**PL=** **LL=** **PI=**

## Classification

**USCS (D 2487)=** SP **AASHTO (M 145)=**

## Coefficients

| | | |
|---|---|---|
| $D_{90}$= 84.5985 | $D_{85}$= 82.5264 | $D_{60}$= 58.1421 |
| $D_{50}$= 26.0246 | $D_{30}$= 0.8320 | $D_{15}$= 0.4653 |
| $D_{10}$= 0.3602 | $C_u$= 161.41 | $C_c$= 0.03 |

**Remarks**

**Date Received:** **Date Tested:** 5/23/2016

**Tested By:**

**Checked By:**

**Title:**

**Source of Sample:** 06-BED 1
**Sample Number:** BKT

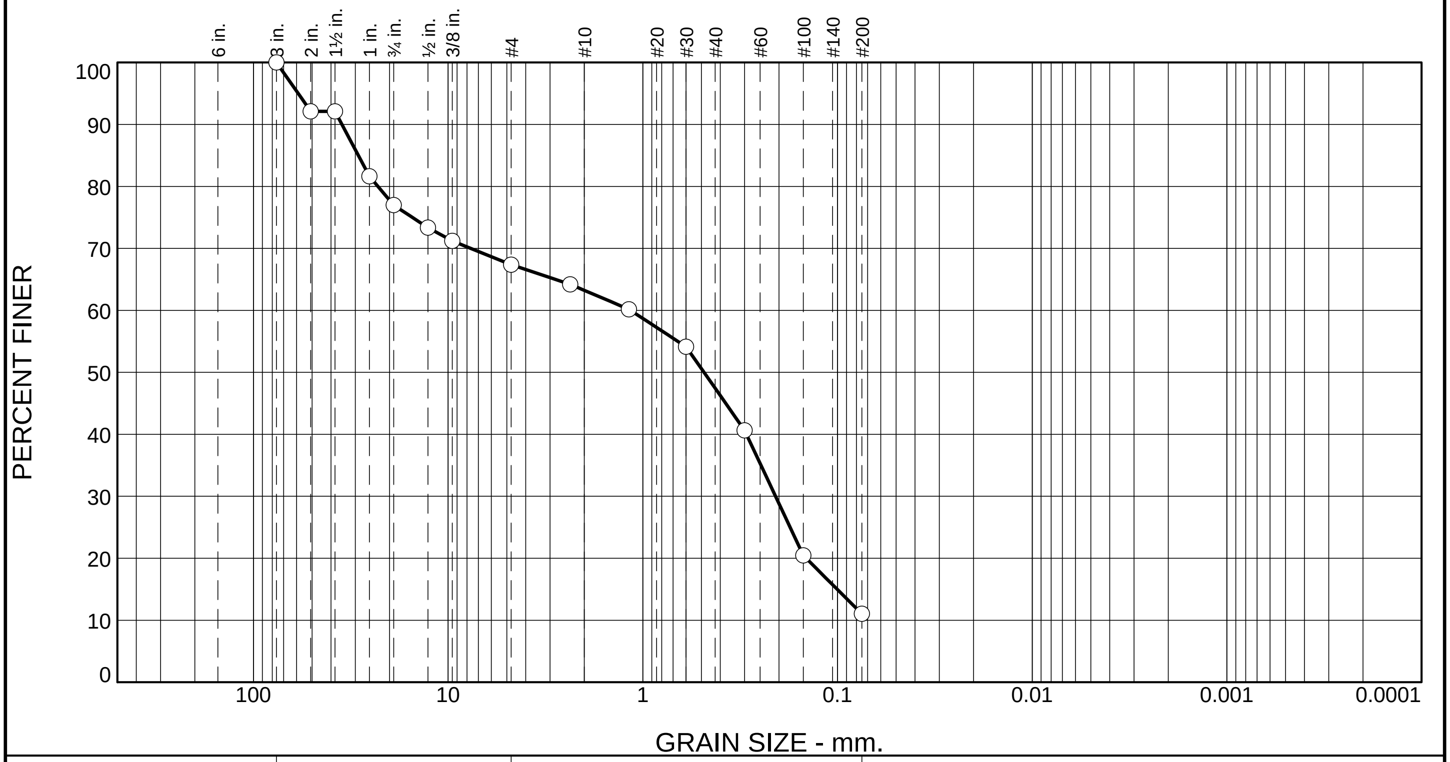
**Date Sampled:** 5/16/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel |  | % Sand |  |  | % Fines |  |
|---|---|---|---|---|---|---|---|
|  | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 23.0 | 9.6 | 4.2 | 15.8 | 36.4 | 11.0 |  |

| TEST RESULTS |  |  |  |
|---|---|---|---|
| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
| 3 | 100.0 |  |  |
| 2 | 92.1 |  |  |
| 1.5 | 92.1 |  |  |
| 1 | 81.6 |  |  |
| .75 | 77.0 |  |  |
| .5 | 73.4 |  |  |
| .375 | 71.2 |  |  |
| #4 | 67.4 |  |  |
| #8 | 64.2 |  |  |
| #16 | 60.2 |  |  |
| #30 | 54.1 |  |  |
| #50 | 40.6 |  |  |
| #100 | 20.5 |  |  |
| #200 | 11.0 |  |  |

* (no specification provided)

**Material Description**

Sand with Silt and Gravel, Brown, Moist

**Atterberg Limits (ASTM D 4318)**

**PL=** NP **LL=** NV **PI=** NP

**Classification**

**USCS (D 2487)=** SP-SM **AASHTO (M 145)=** A-1-b

**Coefficients**

| | | |
|---|---|---|
| $D_{90}$= 35.1151 | $D_{85}$= 28.9302 | $D_{60}$= 1.1575 |
| $D_{50}$= 0.4852 | $D_{30}$= 0.2082 | $D_{15}$= 0.1004 |
| $D_{10}$= | $C_u$= | $C_c$= |

**Remarks**

**Date Received:** **Date Tested:** 5/24/2016

**Tested By:** ______________________

**Checked By:** ______________________

**Title:** ______________________

**Source of Sample:** 06-BANK 1 **Date Sampled:** 5/16/2016

**Sample Number:** BKT

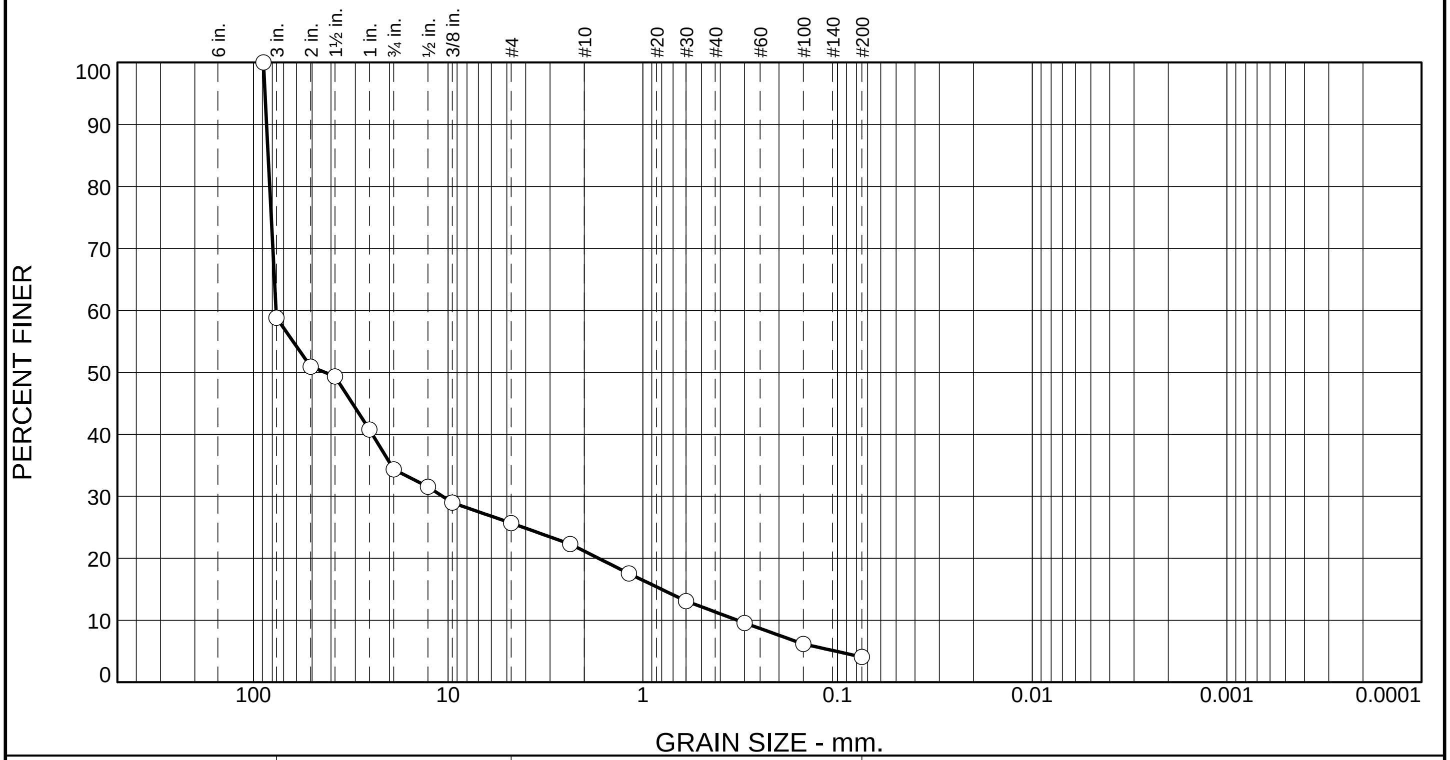
**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.

**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel |  | % Sand |  |  | % Fines |  |
|---|---|---|---|---|---|---|---|
|  | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 41.2 | 24.4 | 8.7 | 4.5 | 9.9 | 7.2 | 4.1 |  |

### TEST RESULTS

| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
|---|---|---|---|
| 3.5 | 100.0 |  |  |
| 3 | 58.8 |  |  |
| 2 | 50.9 |  |  |
| 1.5 | 49.3 |  |  |
| 1 | 40.8 |  |  |
| .75 | 34.4 |  |  |
| .5 | 31.5 |  |  |
| .375 | 29.0 |  |  |
| #4 | 25.7 |  |  |
| #8 | 22.3 |  |  |
| #16 | 17.5 |  |  |
| #30 | 13.1 |  |  |
| #50 | 9.6 |  |  |
| #100 | 6.2 |  |  |
| #200 | 4.1 |  |  |

* (no specification provided)

### Material Description

Gravel with Silt and Sand, Brown, Moist

### Atterberg Limits (ASTM D 4318)

**PL=** NP **LL=** NV **PI=** NP

### Classification

**USCS (D 2487)=** GP-GM **AASHTO (M 145)=** A-1-a

### Coefficients

| | | |
|---|---|---|
| $D_{90}$= 85.6350 | $D_{85}$= 84.0478 | $D_{60}$= 76.5420 |
| $D_{50}$= 43.0584 | $D_{30}$= 10.6916 | $D_{15}$= 0.8017 |
| $D_{10}$= 0.3271 | $C_u$= 234.03 | $C_c$= 4.57 |

**Remarks**

**Date Received:** **Date Tested:** 5/24/2016

**Tested By:** ____________________

**Checked By:** ____________________

**Title:** ____________________

**Source of Sample:** 06-BANK 2 **Date Sampled:** 5/16/2016

**Sample Number:** BKT

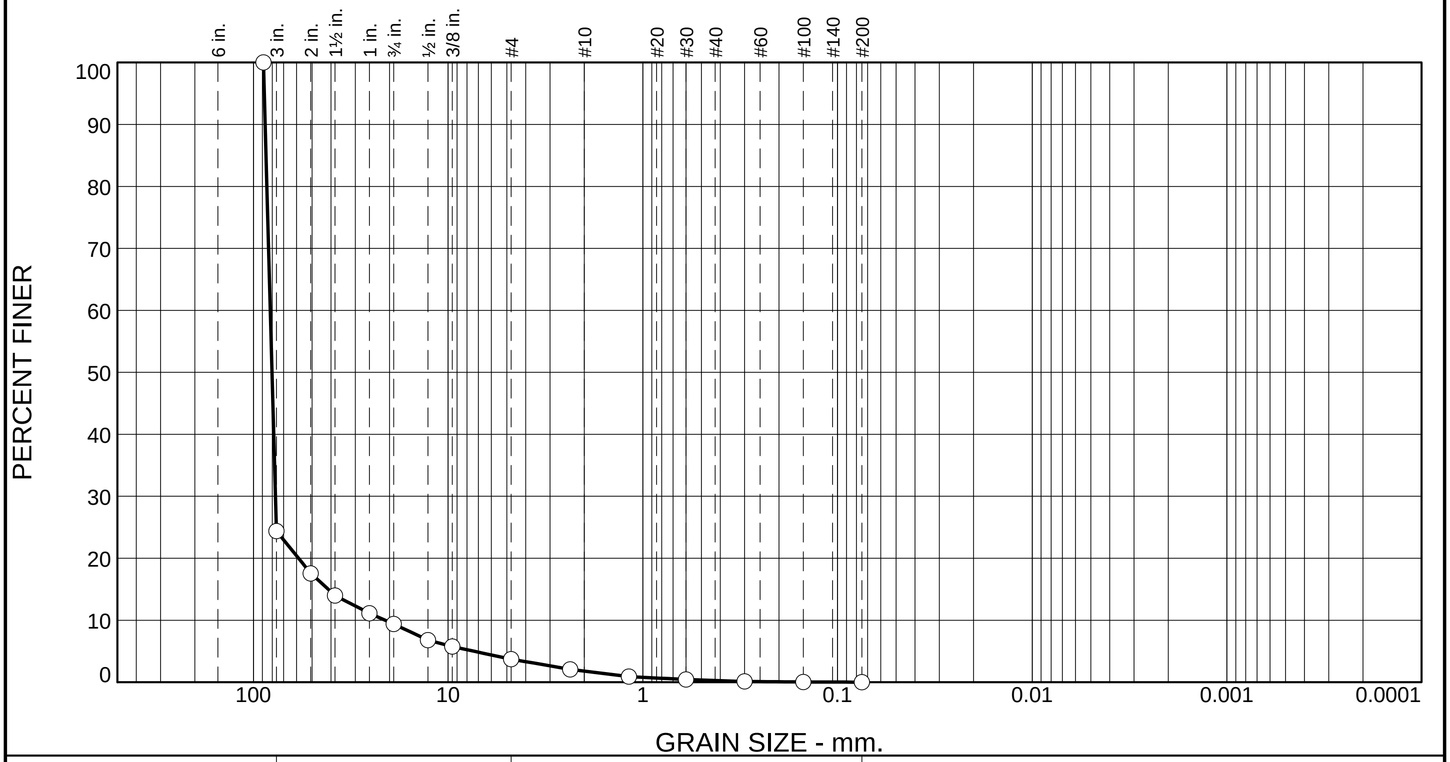
**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.

**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 75.6 | 15.0 | 5.7 | 1.9 | 1.5 | 0.3 | 0.0 | |

| TEST RESULTS | | | |
|---|---|---|---|
| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
| 3.5 | 100.0 | | |
| 3 | 24.4 | | |
| 2 | 17.6 | | |
| 1.5 | 14.0 | | |
| 1 | 11.1 | | |
| .75 | 9.4 | | |
| .5 | 6.8 | | |
| .375 | 5.7 | | |
| #4 | 3.7 | | |
| #8 | 2.1 | | |
| #16 | 0.9 | | |
| #30 | 0.4 | | |
| #50 | 0.1 | | |
| #100 | 0.0 | | |
| #200 | 0.0 | | |

* (no specification provided)

## Material Description

Gravel with Sand, Brown, Moist

## Atterberg Limits (ASTM D 4318)

**PL=** **LL=** **PI=**

## Classification

**USCS (D 2487)=** GP **AASHTO (M 145)=**

## Coefficients

$D_{90}$= 87.1059 $D_{85}$= 86.2224 $D_{60}$= 81.9378

$D_{50}$= 80.2841 $D_{30}$= 77.0763 $D_{15}$= 41.3400

$D_{10}$= 21.0553 $C_u$= 3.89 $C_c$= 3.44

**Remarks**

**Date Received:** **Date Tested:** 5/19/2016

**Tested By:** ______________________

**Checked By:** ______________________

**Title:** ______________________

**Source of Sample:** 07-BED 1

**Sample Number:** BKT

**Date Sampled:** 5/16/2016

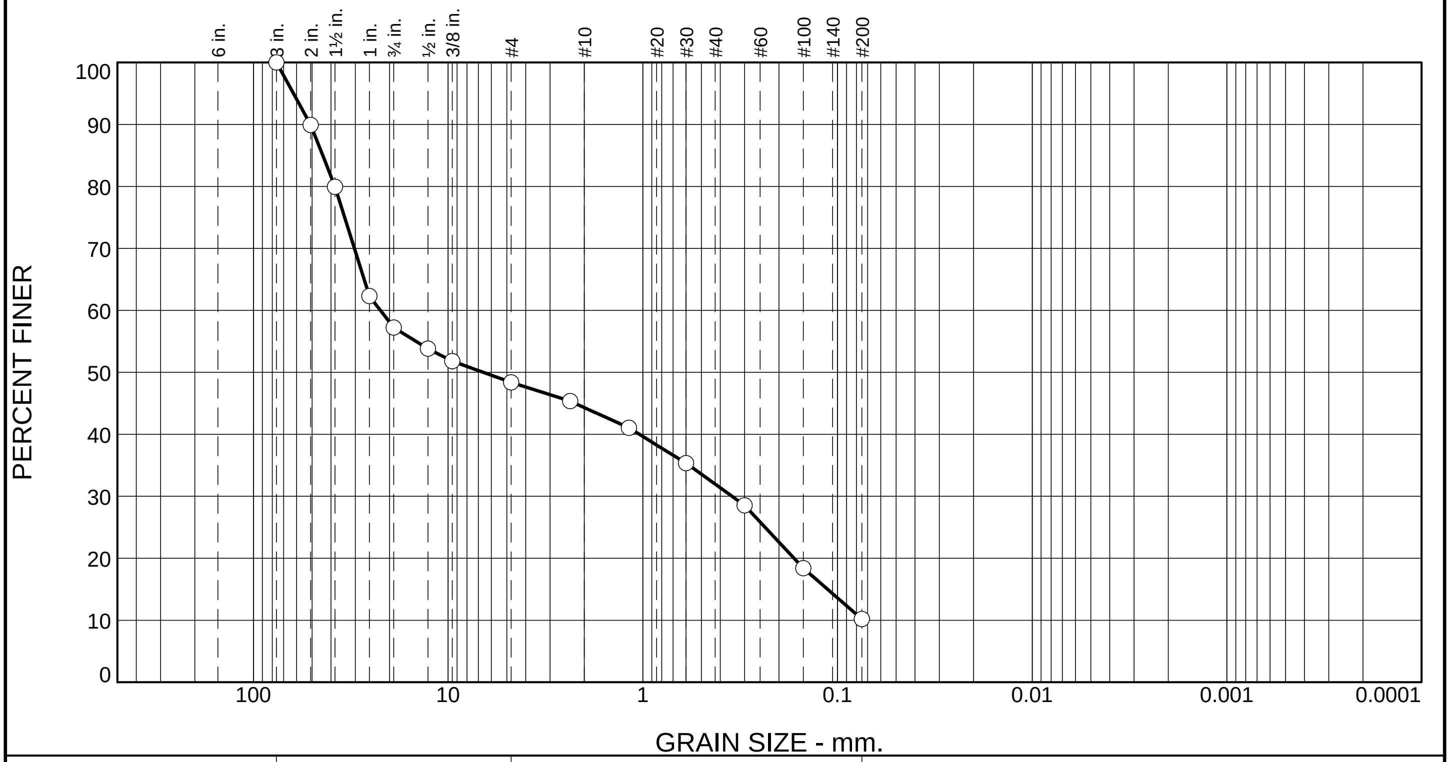
**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.

**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 0.0 | 42.8 | 8.8 | 4.1 | 12.3 | 21.8 | 10.2 | |

**TEST RESULTS**

| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
|---|---|---|---|
| 3 | 100.0 | | |
| 2 | 89.9 | | |
| 1.5 | 79.9 | | |
| 1 | 62.3 | | |
| .75 | 57.2 | | |
| .5 | 53.8 | | |
| .375 | 51.8 | | |
| #4 | 48.4 | | |
| #8 | 45.4 | | |
| #16 | 41.0 | | |
| #30 | 35.3 | | |
| #50 | 28.5 | | |
| #100 | 18.4 | | |
| #200 | 10.2 | | |

* (no specification provided)

**Material Description**

Gravel with Silt and Sand, Brown, Moist

**Atterberg Limits (ASTM D 4318)**

**PL=** NP **LL=** NV **PI=** NP

**Classification**

**USCS (D 2487)=** GP-GM **AASHTO (M 145)=** A-1-b

**Coefficients**

| | | |
|---|---|---|
| $D_{90}$= 50.9805 | $D_{85}$= 44.0910 | $D_{60}$= 22.2805 |
| $D_{50}$= 6.5938 | $D_{30}$= 0.3480 | $D_{15}$= 0.1125 |
| $D_{10}$= | $C_u$= | $C_c$= |

**Remarks**

**Date Received:** **Date Tested:** 5/25/2016

**Tested By:** ____________________

**Checked By:** ____________________

**Title:** ____________________

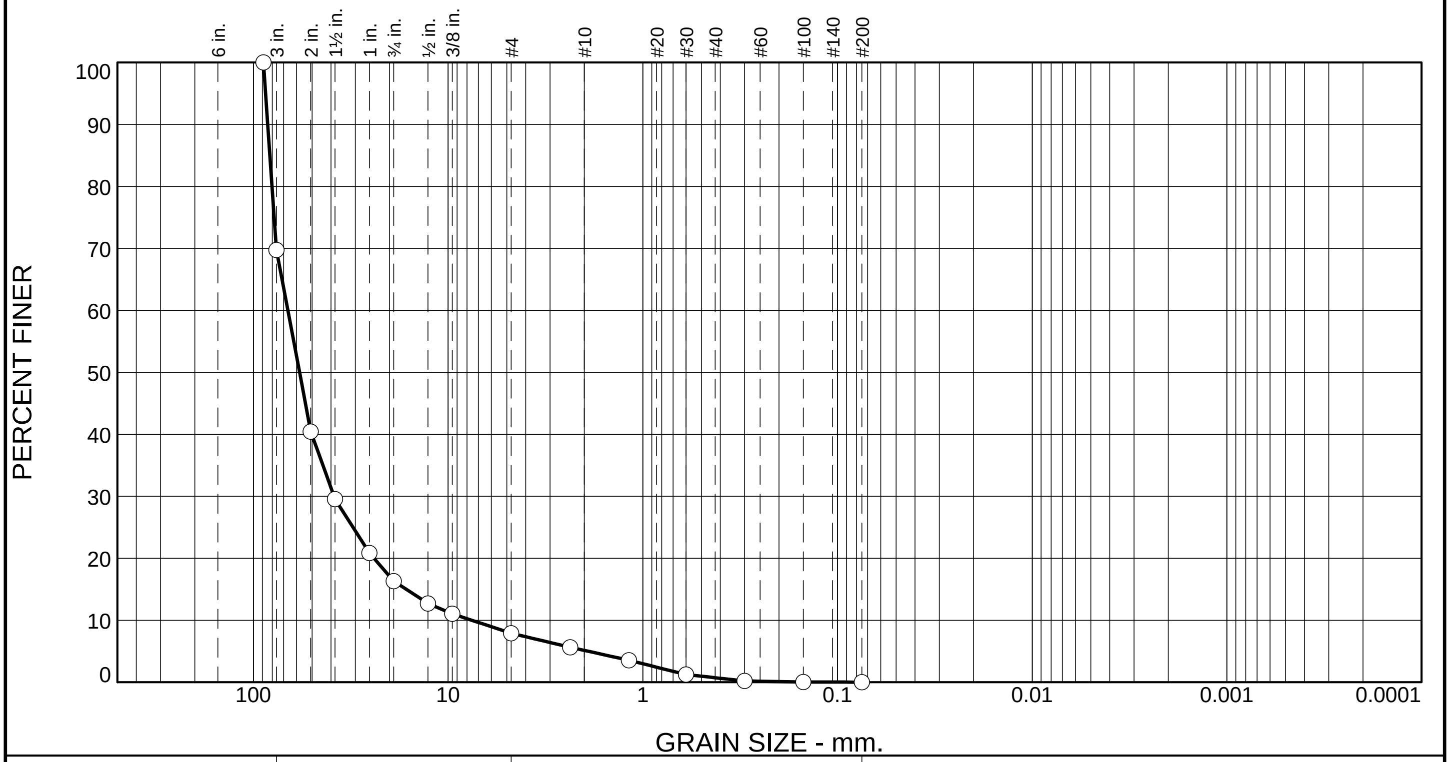
**Source of Sample:** 07-BANK 1
**Sample Number:** BKT
**Date Sampled:** 5/16/2016

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.
**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**

# Particle Size Distribution Report



| % +3" | % Gravel | | % Sand | | | % Fines | |
|---|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | Silt | Clay |
| 30.3 | 53.4 | 8.4 | 2.8 | 4.4 | 0.7 | 0.0 | |

| TEST RESULTS | | | |
|---|---|---|---|
| Opening Size | Percent Finer | Spec.* (Percent) | Pass? (X=Fail) |
| 3.5 | 100.0 | | |
| 3 | 69.7 | | |
| 2 | 40.4 | | |
| 1.5 | 29.5 | | |
| 1 | 20.9 | | |
| .75 | 16.3 | | |
| .5 | 12.7 | | |
| .375 | 11.0 | | |
| #4 | 7.9 | | |
| #8 | 5.6 | | |
| #16 | 3.5 | | |
| #30 | 1.2 | | |
| #50 | 0.2 | | |
| #100 | 0.0 | | |
| #200 | 0.0 | | |

* (no specification provided)

## Material Description

Gravel, Tan, Moist

## Atterberg Limits (ASTM D 4318)

**PL=** **LL=** **PI=**

## Classification

**USCS (D 2487)=** GW **AASHTO (M 145)=**

## Coefficients

| | | |
|---|---|---|
| $D_{90}$= 84.4834 | $D_{85}$= 82.3580 | $D_{60}$= 66.5856 |
| $D_{50}$= 57.9828 | $D_{30}$= 38.5666 | $D_{15}$= 16.4228 |
| $D_{10}$= 7.5647 | $C_u$= 8.80 | $C_c$= 2.95 |

**Remarks**

**Date Received:** **Date Tested:** 5/19/2016

**Tested By:** __________

**Checked By:** __________

**Title:** __________

**Source of Sample:** 08-BED 1 **Date Sampled:** 5/16/2016

**Sample Number:** BKT

**SMITH GEOTECHNICAL**

**Client:** Engineering Analytics, Inc.

**Project:** EA-110666-St. Vrain Breaches

**Project No:** 16.037T **Figure**