CHERRY CREEK BASELINE CHANNEL MONITORING REPORT

Reservoir to State Park Boundary

November 2022

Prepared for:

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MULLER
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1 INTRODUCTION

1.1 Background

Cherry Creek through Cherry Creek State Park is currently experiencing some areas of severe erosion and downcutting while other areas are experiencing excessive sediment deposition causing the channel to avulse and change flow paths to lower areas in the valley floor. The Cherry Creek Basin Water Quality Authority (CCBWQA) has concerns that the instability of Cherry Creek from Cherry Creek Reservoir to the State Park boundary is contributing to water quality issues in the Reservoir and that the erosion and deposition occurring in the park is becoming a threat to existing infrastructure. To better understand the instability and potential threats, the CCBWQA sponsored an initial channel monitoring effort to document the existing conditions of Cherry Creek and a portion of Piney Creek within the Cherry Creek State Park boundary. This initial channel monitoring effort will serve as a baseline for comparison to future monitoring efforts which will help to identify which areas are more unstable and the rate at which they are changing. Eventually, we can use this information to inform other efforts like the water quality benefits from stream reclamation and the corresponding Phosphorus reduction/immobilization.

1.2 Location

The channel monitoring project limits are located entirely within Cherry Creek State Park in Arapahoe County, Colorado. Approximately 18,500 feet of the Cherry Creek channel was included in the monitoring effort between the reservoir and the southern state park boundary. Piney Creek, located within the state park boundary, is also included in the channel monitoring project. Approximately 2,000 feet of the Piney Creek channel was included in the monitoring effort between the confluence with Cherry Creek to the Piney Creek trail crossing just east of south Fraser St. See Figure 1 for a vicinity map showing the project limits.

1.3 Purpose

The purpose of the channel monitoring project is to establish baseline channel conditions for comparison to future channel monitoring efforts and to develop recommendations for the frequency and types of channel monitoring activities to include in future monitoring efforts. Goals for this project include developing the ability to better quantify the physical changes to the channel through identification of channel bed erosion, streambank erosion, and sediment deposition. This information will help inform the CCBWQA, and other potential stakeholders, of the magnitude and rates of erosion and sediment deposition and will provide an estimated phosphorus loading that will potentially be transported to the reservoir or will potential be trapped within the floodplain downstream of the dog park. This will allow the CCBWQA, and other stakeholders, to make more informed decisions on channel restoration priorities through Cherry Creek State Park.

Figure 1: Vicinity Map

2 FIELD INSPECTION

The channel monitoring project reach has been divided into four separate sub-reaches based on similar geomorphic attributes which match the sub-reaches identified in the Cherry Creek Channel and Water Quality Assessment also completed in 2022. Reach 1 spans from the Reservoir to Lakeview Road and is characterized by channel downcutting with large areas of lateral stream bank erosion. Reach 2 spans from Lakeview Road to the 12-Mile Dog Off-Leash Area and is characterized by heavy sediment deposition through most of this reach. Reach 3 spans from the 12-Mile Dog Park to the assessment limits at the State Park boundary and is characterized by channel downcutting and lateral stream bank erosion. Reach 4, a reach of Piney Creek beginning at the confluence with Cherry Creek and extending upstream to an existing pedestrian crossing, was also included in the site reconnaissance, and is characterized by channel downcutting with extensive areas of lateral stream bank erosion. Figure 2 summarizes the geomorphic conditions and shows the limits of all four reaches.

An initial reconnaissance site visit was performed on April 28, 2020. This site visit was done for the preparation of the Cherry Creek Stream and Water Quality Assessment (Muller, 2022). The information gathered at that site visit was used to supplement this channel monitoring effort. The team consisted of Muller Engineering Company (lead engineer), ERO Resources Corporation (environmental consultant), Tetra Tech, Inc (sediment transport consultant), and CCBWQA project sponsors. The purpose of the site visit was to walk the entire length of the project to assess the existing condition of the creek.

In April 2021, Muller conducted a second site visit with Topographic Land Surveyors. The purpose of this site visit was to identify permanent locations for channel monitoring cross sections. The coordinates of the beginning and end points of the cross sections were documented and memorialized with rebar posts. These cross sections are intended to be used in future monitoring efforts to observe geometric changes to the bankfull channel of both Cherry Creek and Piney Creek within the Cherry Creek State Park. See *Ground Survey* below for more information.

On June 10, 2021, a third site visit was conducted to collect data for a lateral stream bank erosion assessment using the Bank Assessment for Non-point source Consequences of Sediment (BANCS) model developed by Dave Rosgen and Wildland Hydrology. Measurements for this analysis including limits of eroding bank sections, bank height, bank angle and several other physical properties described later in this report were documented during this site visit. A photo log of this site visit is provided in Appendix A.

REACH 1

REACH 2

REACH 3

REACH 4

S. Parker Rd.

S. Chambers Rd.

E. Orchard Rd.

Piney Creek

Pedestrian Bridge

PINEY CREEK LIMITS OF STUDY

CHERRY CREEK LIMITS OF STUDY

Shop Creek

Cherry Creek

Cherry Creek Reservoir

Historic Bridge

Pipeline Trail

E. Lakeview Rd.

E. Arapahoe Rd.

Pedestrian Bridge

WATER GRAB 1

BANK EROSION 1

CC-10

SEDIMENT 6

OVERBANK 6

OVERBANK 3

BANK EROSION 2

STATION. 42+53
AURORA WATERLINE CROSSING

OVERBANK 5

MW-9

OVERBANK 2

OVERBANK 4

WATER GRAB 2

OVERBANK 1

BANK EROSION 3

WATER GRAB 3

OVERBANK 7

STATION. 63+60
LAKEVIEW ROAD CROSSING

OVERBANK 10

SEDIMENT 5

WATER GRAB 4

SEDIMENT 7

BANK EROSION 4

OVERBANK 11

WATER GRAB 6

OVERBANK 8

WATER GRAB 5

SEDIMENT 4

BANK EROSION 6

SEDIMENT 1

SEDIMENT 2

CC-8

BANK EROSION 5

SEDIMENT 3

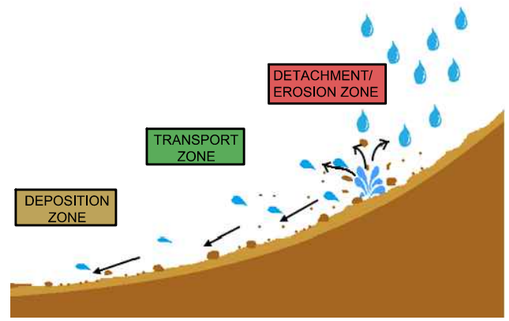
STATION. 170+99
PINEY CREEK CONFLUENCE

Pedestrian Bridge

0' 600' 1200'

LEGEND:

CHANNEL CENTERLINE



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CHERRY CREEK RESERVOIR TO 12 MILE GEOMORPHIC SUMMARY

FIGURE X

DATE
5/20/2021

DRAWING NO.

SHEET NO.
1 OF 1

PLOTTED: 8/12/2022 1:54:26 PM
NAME: P:\2020 PROJECTS\20-023.02 CHERRY CREEK STUDY - RES TO 12 MILE STUDY - CCBWQA\CAD\EXHIBITS\20-023.02_SITE SEDIMENT EXHIBIT 2.DWG

3 CHANNEL MONITORING SURVEY

Several sources of survey were used in this report to analyze the existing conditions of Cherry Creek and Piney Creek and to establish baseline conditions for future monitoring efforts. Some of the surveys are historic and were used to provide an initial channel profile and cross section comparison to the 2021 surveys. The following sources of survey were used in this report:

- LiDAR survey: Post -flood LiDAR data was collected in 2013. This survey consists of 1-foot contours delineated from the LiDAR surface.
- Photogrammetric Point Cloud: a drone flight was conducted in April 2021 to collect Photogrammetric point cloud data. This data was processed into a surface, and 1-foot contours delineated. This flight also included the collection of orthomosaic aerial imagery.
- Ground survey: Ground survey was performed by Topographic Land Surveyors in the spring of 2021 using GPS survey equipment with sub-centimeter accuracy and consisted of:
    - 14 channel cross sections including control points set at each end marked with rebar stakes for reference during future monitoring efforts. Coordinate locations of the control points for each cross section are provided on the Channel Monitoring Plan in Appendix B.
        - 9 cross sections of the main channel only of Cherry Creek
        - 2 cross sections of the main channel only of Piney Creek
        - 3 cross sections that span the entire Cherry Creek Floodplain
    - Thalweg profile. Thalweg survey points were collected approximately every 50-feet along the channel centerline. Profiled reaches include:
        - Cherry Creek: reservoir to E Lakeview Rd
        - Cherry Creek: Cherry Creek Dog Off Leash Area to Southern State Park Boundary
        - Piney Creek: Confluence with Cherry Creek to project boundary

Drone and LiDAR surveys were based on the NAVD 88 datum and translated to the United States Army Corps of Engineers, Omaha District's Cherry Creek Datum (USACE Datum = NAVD88-1.38 ft based on survey control provided by HKS for 2020 Perimeter Road Survey). Ground Survey was conducted in the USACE Datum. Horizontal Datum for all survey is NAD 1983 Colorado State Plane Central.

4 PEAK STREAMFLOW

The Cherry Creek annual and daily peak streamflow data were collected and reviewed from two gages on Cherry Creek to document the number and magnitude of storms that have occurred during the monitoring period leading to the changes observed in the channel and along the streambanks. Annual peak streamflow data was collected from the CCBWQA's stream gage CC-10, located within the project limits, for the past five years, 2017 through 2021. Annual peak streamflow flow data and daily peak streamflow data was also collected from USGS Stream Gage 393109104464500, located in Parker, for the past six years, 2013 through 2019.

Data from the CCBWQA CC-10 gage shows that baseflows are generally between 1- to 40-cfs depending on the season. Most runoff events are between 40- to 279-cfs. Annual peaks ranged from 310-cfs to 606-cfs over the period of analysis. The CC-10 gage has limited historic flow information ranging from 2017 to the present. Also, some storm flows may bypass the gage due to flow spread at Lakeview Road and the Pipeline Trail which was recently identified through hydraulic modeling completed by RESPEC in a separate study. For these reasons, the data from the CC-10 gage may not accurately represent the flows in the channel through the state park and CCBWQA has added an additional gage at Lakeview Drive to determine the effects of the flow split.

Data from the USGS Parker gage shows that baseflows are generally between 1- and 20-cfs depending on the season. Most runoff events are between 20- and 219-cfs. Annual peaks ranged from 228-cfs to 348-cfs over the period of analysis. Since the flowrates from the Parker gage are approximately 8 miles upstream of the project limits, the flowrates will not accurately represent the actual flows in the channel through the state park and the flows through the project area are likely higher than the Parker flowrates.

The CCBWQA CC-10 gage analysis shows that between 2017 and 2021, there were approximately four events equal to or greater than 300-cfs, the estimated bankfull rate through Cherry Creek State Park. The USGS Parker gage analysis shows that between 2013 and 2019, there were approximately nine events equal to or greater than 225-cfs, the estimated bankfull event at the Parker gage. Events greater than bankfull are of interest because they are often responsible for mass bank wasting, deposition, and channel downcutting. The annual rate of events greater than bankfull are in general agreement between the CC-10 and Parker gages, approximately 1 event per year. During the period of analysis, the annual peaks generally stay around the bankfull estimates, however, there was one event on the CC-10 gage coming in at around 600-cfs, two times the estimated bankfull discharge. Graphs of the annual and daily peak streamflow for both gages are provided in Appendix C.

5 LATERAL STREAM BANK STABILITY MONITORING

A lateral stream bank stability assessment using the Bank Assessment for Non-point source Consequences of Sediment (BANCS) model, developed by Dave Rosgen and Wildland Hydrology, was conducted on Cherry Creek and Piney Creek within the channel monitoring limits. The purpose of this assessment is to determine lateral streambank stability ratings, ranging from extreme to very low erosion potential, for eroding banks within the channel monitoring limits. Additionally, these ratings can be used to produce estimates of lateral stream bank erosion rates (feet/year) and then used to predict the annual amount of sediment (tons/year) potentially contributed by lateral streambank erosion. The ratings produced as part of this assessment can serve as a baseline condition for the streambanks within the channel monitoring limits so that future assessments can identify streambanks that are becoming more hazardous and more critical to stabilize. Other benefits of the assessment include helping to inform reach prioritization and for comparison to other soil loss estimation methods to increase confidence levels and develop a range of soil loss estimates.

Two main factors are considered in the BANCS model to predict the erosion potential. The first factor, the Bank Erosion Hazard Index (BEHI), estimates the tendency of a given streambank to erode based on the following:

- Bank angle
- Riparian vegetation
- Rooting depth and density
- Surface protection
- Bank height relative to bankfull height

Some of the data required for the BEHI assessment is shown in Figure 3 and was collected on the June 2021 site visit. Brief descriptions of the data are also provided below.

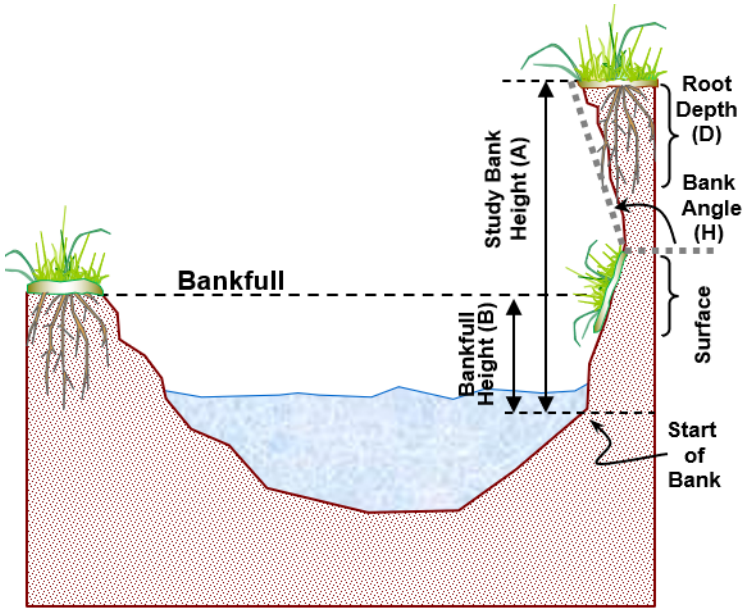


Figure 3: BANCS Field Measurements

- Study Bank height (A): Height of bank from toe of bank to top of bank.
- Bankfull Height (B): Bankfull mean depth measured from toe of bank up to bankfull stage.
    - The bankfull mean depth is estimated to be 3' for entire study area based on a hydraulic analysis of a reference reach section located upstream of the dog park performed as part of the Cherry Creek Stream and Water Quality Assessment (Muller, 2022).
- Root Depth (D): Maximum depth of roots from the vegetation along the top of bank.
- Root Density (F) (Not labeled in Figure 3): Estimated density of roots from the vegetation along the top of bank.
- Bank Angle (H): Bank angle as measured from horizontal towards the creek.
- Surface Protection (I) (Not labeled in Figure 3): Percent of bank surface covered by vegetation.
- Bank Materials (Not shown in Figure 3): Type of materials that makeup the bank (bedrock, boulders, cobble, gravel, sand, silt/clay).

The second factor used to estimate erosion potential is Near-Bank Stress (NBS), which is an estimate of the severity of shear stress exerted by flowing water on the near bank region (the one third of the channel cross section associated with the bank being evaluated) which can accelerate streambank erosion. There are seven methods for estimating NBS, see Figure 4. The NBS should be estimated using the method that most closely represents the on-site conditions.

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar, or central bar creating NBS	Level I	Reconaissance
(2)	Radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General Prediction
(3)	Pool slope to average water surface slope (S_p / S)	Level II	General Prediction
(4)	Pool slope to riffle slope (S_p / S_{rif})	Level II	General Prediction
(5)	Near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed Prediction
(6)	Near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed Prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I — (1)

Transverse or central bars - short or discontinuous ..... NBS = *High / Very High*

Extensive deposition (continuous, cross-channel) ..... NBS = *Extreme*

Chute cutoffs, down-valley meander migration, converging flow ..... NBS = *Extreme*

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	**Bank Stress (NBS)**	
(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	**Bank Stress (NBS)**	**Dominant Near-Bank Stress**
(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	**Bank Stress (NBS)**	

Level III

(5)	Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	**Bank Stress (NBS)**					
(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear τ_{nb} (lb/ft^2	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	*Ratio* τ_{nb} / τ_{bkf}	**Near-Bank Stress (NBS)**	

Level IV

(7)	Velocity Gradient (ft / sec / ft)	**Bank Stress (NBS)**	

Figure 4: Near Bank Stress Estimation Methods

The severe channel degradation throughout the channel monitoring reach has created a high ratio of near-bank maximum depth to bankfull mean depth which is driving the increased shear stress along the eroded banks, so method number 5 was used for the analysis.

To determine the BEHI ratings for an eroding bank, scores are calculated based on field measurements and a scoring system developed by Dave Rosgen and Wildland Hydrology, see Figure 5 and Figure 6. The total BEHI score is then compared to the adjective rating table in Figure 5, to determine the BEHI risk rating, ranging from extreme through very low erosion potential.

Bank Erosion Hazard Index (BEHI)

Stream: **Teton Creek** Location: **Idaho (the state)**

Station: Observers: **Team 1**

Date: **7/25/2019** Stream Type: **C4** Landscape Type: **U-LA_LD**

BEHI Score (Fig. 3-7)

Study Bank Height to Bankfull Height (C)

Study Bank Height (ft) =	(A)	Bankfull Height (ft) =	(B)	(A) / (B) =	(C)

Root Depth to Study Bank Height (E)

Root Depth (ft) =	(D)	Study Bank Height (ft) =	(A)	(D) / (A) =	(E)

Weighted Root Density (G)

Root Density as % =	(F)	(F) × (E) =	(G)

Bank Angle (H)

Bank Angle as *Degrees* =	(H)

Surface Protection (I)

Surface Protection as % =	(I)

Bank Material Adjustment:

Bedrock (Overall *Very Low* BEHI)

Boulders (Overall *Low* BEHI)

Cobble (Subtract 10 points if uniform medium to large cobble)

Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)

Sand (Add 10 points)

Silt/Clay (Add 10 points if uniform silt; No adjustment if silt with a mixture of clay; Subtract 10 points if silt/clay mixture with high % of clay; Subtract 20 points if clay)

Bank Material Adjustment

Stratification Adjustment

Add 5–10 points, depending on position of unstable layers in relation to bankfull stage

Very Low	*Low*	*Moderate*	*High*	*Very High*	*Extreme*
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and **Total Score**

Figure 5: BEHI Rating Form

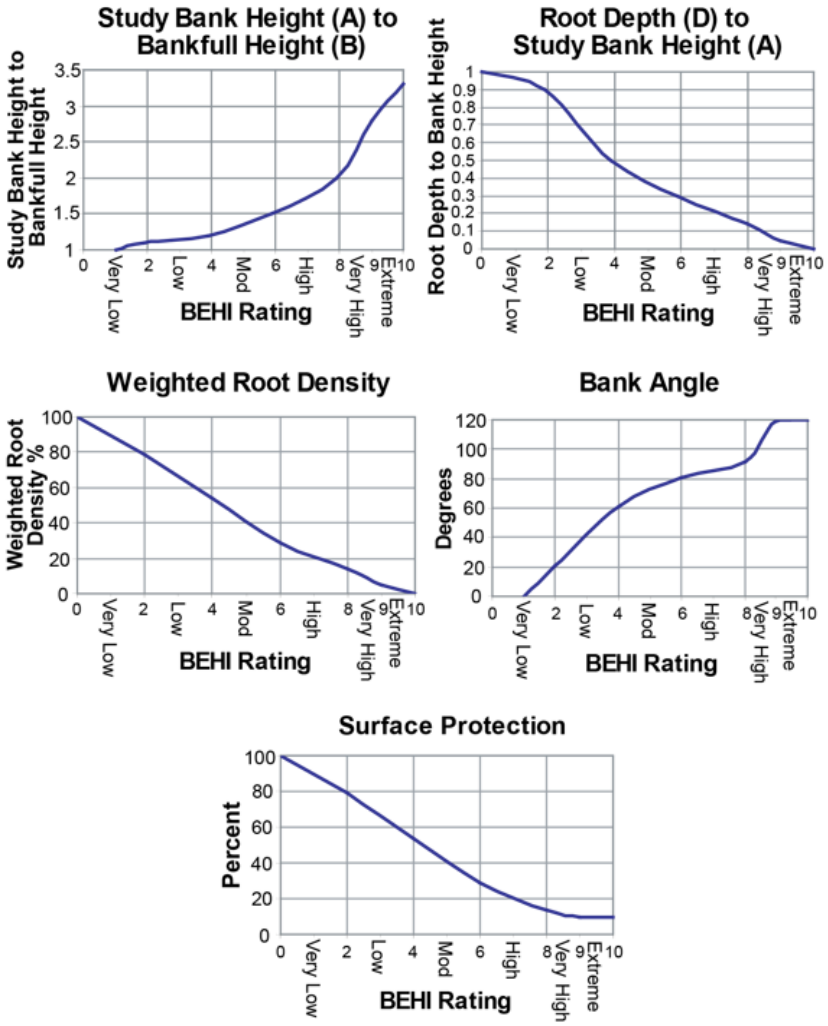


Figure 6: BEHI Scoring Charts

To determine the NBS ratings for an eroding bank, scores are calculated using method 5 and are based on field measurements and a scoring system developed by Dave Rosgen and Wildland Hydrology, see Figure 4. The scores are then compared to a rating table, Figure 7, to determine the NBS rating, ranging from extreme through very low near bank stress.

Converting Values to a Near-Bank Stress (NBS) Rating							
Near-Bank Stress (NBS) Ratings	Method Number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N/A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N/A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N/A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40
	Overall Near-Bank Stress (NBS) Rating						

Figure 7: NBS Rating Table

For the purposes of efficiency, BEHI field measurements, comprehensive scoring and ratings were completed for twelve "representative" bank conditions and heights in the field during the site visit, see Reference Banks: BEHI Rating Calculations table in Appendix D. This representative data was then used as a reference to perform a rapid visual identification of the BEHI ratings for banks with similar conditions. All eroding banks delineated during the site visit were visually rated for BEHI, however, the NBS was calculated later using field measurements of near bank height and an estimate of the bankfull mean depth. The following photos are of a few of the representative bank conditions used to calculate BEHI and they depict a range of BEHI and NBS bank ratings.

Photo 1: CC-8, BEHI - Low, NBS - Very Low (Sta. 43+00)

Photo 2: CC-3, BEHI - Moderate, NBS - Extreme (Sta. 170+00)

Photo 3: CC-1, BEHI - Very High, NBS - High (Sta. 177+00)

The BEHI and NBS ratings determined in the field and through calculations were used to predict annual lateral bank erosion rates in feet per year. Dave Rosgen and Wildland Hydrology developed the chart in Figure 8 which predicts the annual streambank erosion rates using data collected in Colorado for streams found in sedimentary and/or metamorphic geology, which is indicative of Cherry Creek. To predict the annual streambank erosion rates the intersection of the NBS score (x-axis) and the appropriate BEHI trend line is found, then the bank erosion rate (y-axis) is determined. This is repeated for each eroding bank delineated in the study.

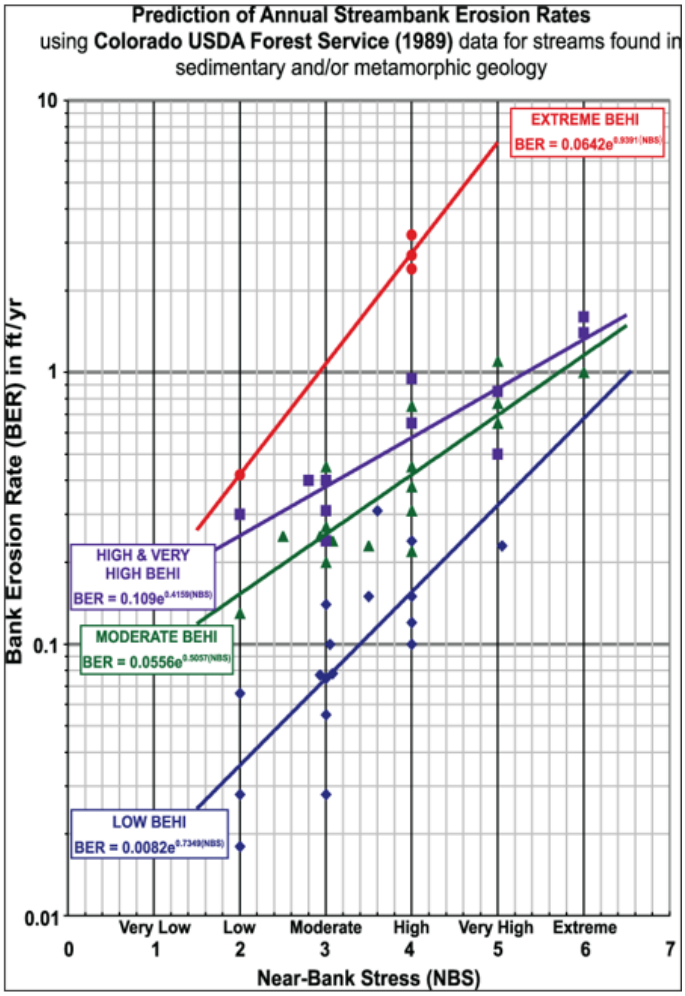


Figure 8: Bank Erosion Rate Chart

The rates for each individual bank were then multiplied by the bank heights and lengths measured in the field to provide a general projection of the tons of sediment potentially contributed by streambanks through the project reach. Additionally, for this study, the total phosphorus contributed by the soil loss is of interest. The phosphorus concentration in the banks adjacent to Cherry Creek was determined in the Cherry Creek Stream and Water Quality Assessment (Muller, 2022) and is summarized in Table 1. The total phosphorus concentration was applied to the estimated erosion rate to estimate the pounds per year of phosphorus potentially contributed by streambank erosion through the channel monitoring reach.

Site	Total P (mg/kg)		
	Average	Min	Max
Streambank	287	37	470
Overbank	393	20	1000

Table 1: Summary of Total Phosphorus Concentrations in the Banks of Cherry Creek

Table 2 summarizes the results of the BANCS analysis including lateral streambank erosion rates, estimated annual soil loss, and the estimated annual total phosphorus loading by reach. The highest soil loss and therefore the highest total phosphorus concentration within the channel monitoring reach are from Reaches 3 and 4, in part because of the higher lateral streambank erosion rates but also because of the long reach lengths in comparison to Reach 1 and 2. It is assumed that most of the soil lost in Reaches 3 and 4 will be deposited in Reach 2, a depositional zone, and will not be transported to Cherry Creek Reservoir. It is assumed, however, that the soil lost in Reach 1 (337 tons/year) will be directly transported to the reservoir resulting in an estimated 193 pounds of total phosphorus contributed annually to the reservoir from lateral streambank erosion. The following sections summarize the BANCS analysis by reach, maps summarizing the BEHI and NBS ratings, erosion rate calculations, and bank summary tables can be found in Appendix D.

Reach	Bank	Length of Bank (ft)	Average Lateral Bank Erosion Rate (ft/yr)	Estimated Annual Soil Loss (ft^3/yr)	Estimated Annual Soil Loss (tons/yr)	Estimated Annual TP Load from Soil Loss (lb/yr)
Reach 1	Left	5800	0.141	4314	160	92
	Right	5800	0.151	4768	177	101
Reach 2	Left	550	0.119	303	11	6
	Right	550	0.140	355	13	8
Reach 3	Left	7400	0.177	9271	343	197
	Right	7400	0.167	7393	274	157
Reach 4	Left	2000	0.371	6305	234	134
	Right	2000	0.313	4287	159	91

Table 2: BANCS Analysis and Total Phosphorus Summary by Reach

Reach 1

The BANCS analysis shows that Reach 1 has an average lateral bank erosion rate of 0.146 feet/year which is the second largest out of the four reaches. The lateral erosion rate combined with a reach length of 5,800 feet estimates that 336 tons of soil will be lost each year producing an estimated 193 pounds of Phosphors per year. The BEHI ratings for individual banks in Reach 1 are generally moderate to high with a few sections of stream banks near the reservoir rating low. NBS ratings for individual banks are generally high with a few sections of stream bank rating from very low to very high. The lateral stream bank erosion rates for each of the individual stream banks within this reach vary from 0.017 feet/year to 0.288 feet/year resulting in an estimated annual soil loss ranging from 1.0 tons/year to 56.0 tons/year. Reach 1 is likely

the largest source of sediment and total phosphorus loading within the channel monitoring reach because the soil lost in this reach will be transported directly to Cherry Creek Reservoir.

Reach 2

Reach 2 is largely depositional and not contributing to the sediment load except for a small length of the channel at the upstream end that recently avulsed and is experiencing some degradation and lateral bank erosion. The BANCS analysis was only performed on the upstream portion of this reach that is currently experiencing lateral bank erosion. The analysis shows that Reach 2 has an average lateral bank erosion rate of 0.129 feet/year which is the second largest out of the four reaches. The lateral erosion rate combined with an eroding reach length of 550 feet is estimated to lose 24 tons of soil per year producing and estimated 14 pounds of Phosphors per year. The BEHI ratings for individual banks in Reach 2 are generally moderate with one bank rating high. NBS ratings for individual banks range from very low to moderate. The lateral stream bank erosion rates for each of the individual stream banks within this reach vary from 0.092 feet/year to 0.218 feet/year resulting in an estimated annual soil loss ranging from 1.0 tons/year to 8.0 tons/year. Since Reach 2 is characterized by a valley floor alluvial fan, it is assumed that most of the soil lost in Reach 2, or in Reaches 3 and 4 upstream, will be deposited in Reach 2 and will not reach Cherry Creek Reservoir, however, there is a limit to the volume of sediment that can be trapped in Reach 2 and eventually the channel in this system will seek a better sediment transport balance and will likely degrade to increase until the sediment carrying capacity resulting in a higher sediment load reaching the reservoir. It is very difficult to predict at which volume or how long it will take for the valley floor in the reach to fill with enough sediment for the channel to shift into a degradation process, it could take many years for this process to take place, or it could happen in one large storm. It is best to continue to monitor this reach to identify any changes to the flow regime early.

Reach 3

The BANCS analysis shows that Reach 3 has an average lateral bank erosion rate of 0.172 feet/year which is the third largest out of the four reaches. The lateral erosion rate combined with a reach length of 7,400 feet is estimated to lose 617 tons of soil per year producing and estimated 354 pounds of Phosphorus per year. The BEHI ratings for individual banks in Reach 3 are generally moderate between stations 116+00 and 154+25, then transition to moderate to high from station 154+25 to station 177+50, and finally to generally low from station 177+50 to station 190+00 at the upstream study limit. NBS ratings for individual banks are generally low between stations 116+00 to 137+25, then transition to high to extreme from station 137+25 to station 179+25, and finally to generally low to very low between stations 179+25 to 190+00 at the upstream study limits. The lateral stream bank erosion rates for each of the individual stream banks within this reach vary from 0.012 feet/year to 0.872 feet/year resulting in an estimated annual soil loss ranging from 0.0 tons/year to 145.0 tons/year. While Reach 3 shows the largest soil loss of all the reaches, it is assumed that most of the soil lost in this reach will be deposited in Reach 2 and therefore will not reach Cherry Creek Reservoir.

Reach 4

The BANCS analysis shows that Reach 4 has an average lateral bank erosion rate of 0.342 feet/year and is the largest out of the four reaches. The lateral erosion rate combined with a reach length of 2,000 feet is estimated to lose 392 tons of soil per year producing and estimated 225 pounds of Phosphors per year.

The BEHI ratings for individual banks in Reach 4 are generally high to very high with only two small sections of stream banks rating low. NBS ratings for individual banks are generally extreme with a few small sections of stream bank rating high to very high. The lateral stream bank erosion rates for each of the individual stream banks within this reach vary from 0.155 feet/year to 0.661 feet/year resulting in an estimated annual soil loss ranging from 2.0 tons/year to 43.0 tons/year. It is assumed that most of the soil lost in Reach 4 will also be deposited in Reach 2 and therefore will not be transported to Cherry Creek Reservoir.

6 OBSERVATIONS AND MAINTENANCE RECOMENDATIONS

Except for Reach 2, most of the channel monitoring reach is characterized by channel downcutting with extensive areas of lateral streambank erosion and is in general beyond the scope of maintenance-level repairs. A larger channel reclamation effort is needed to control channel degradation for Reaches 1, 3 and 4. Reach 2, however, is generally depositional and currently does not require any maintenance or channel reclamation. A summary of the observations and maintenance recommendations from the field reconnaissance and the channel monitoring survey are discussed for each reach in the sections that follow. Monitoring activities and frequencies are also discussed in the following sections and are summarized in Table 3.

6.1 Reach 1 (Sta. 5+00 to Sta. 63+00)

Observations

- The channel is generally stable from the reservoir, station 5+00, to approximately station 16+50.
- The channel is degraded with streambanks increasing in height and generally vertical from station 16+50 to the Pipeline Trail at station 42+50, approximately mid-reach.
- At approximately station 30+00 to the Pipeline Trail, the vertical streambanks increase in height from 6-feet to 8.5-feet resulting in severe lateral streambank erosion and the loss of many mature cottonwood trees.
- The riprap grade control structure installed just downstream of the Pipeline Trail appears to be experiencing some rock movement and minor bank erosion. The scour hole at the bottom of the channel appears to be downcutting with the channel downstream and is threatening the grade control structure.
- The sheet pile installed with the grade control structure is not visible and assumed to be stable.
- The reach above the Pipeline Trail to approximately station 48+00 is very stable. This reach could be considered as a potential reference reach for future reclamation efforts on Cherry Creek through the state park.
- Beavers have inhabited the channel upstream from the Pipeline Trail and are responsible for the loss of multiple cottonwood trees. No beavers were observed during the site visits.
- The streambanks from station 48+00 to Lakeview Road transition from 4.5-feet to 5.5-feet vertical banks resulting in lateral streambank erosion and the loss of more mature cottonwood trees.

Recommendations

Currently, channel downcutting and streambank erosion are beyond the scope of maintenance and will require a larger channel reclamation effort to stabilize this reach. Considering the dynamic nature of the lateral streambank erosion observed through this reach, annual channel monitoring in the form of a site visit, visual inspection, and basic channel top width and depth measurements at each of the monitoring sections supplemented by drone imagery on an annual or bi-annual basis is recommended. More frequent visual monitoring will help identify locations with accelerated erosion that may pose a threat to infrastructure (i.e., CCBWQA CC-10 monitoring station, Pipeline Trail with 40-inch and 54-inch water lines, and Lakeview Road crossing) as the channel downcutting and lateral streambank erosion continues.

Additionally, an annual report including a photo log, notes, measurements, observations, and recommendations from the site visit is recommended.

6.2 Reach 2 (Sta. 63+00 to Sta. 116+00)

Observations

- Reach 2 is characterized as a valley floor alluvial fan and is generally a depositional zone resulting in multiple channel avulsions creating a braided channel planform.
- Cattails are prevalent throughout this reach with cottonwoods lining the western edge along the historic channel alignment.
- Multiple culverts route the creek under Lakeview Road at the downstream limits of this reach. Several culverts have recently undergone maintenance to remove sediment depositions that have blocked or reduced their capacity.
- A channel avulsion has occurred at the upstream limits of this reach and has resulted in downcutting and lateral streambank erosion which is threatening the 12-Mile Dog Off Leash Area infrastructure.

Recommendations

It is Muller's understanding that the CCBWQA is already in the process of addressing the downcutting and lateral stream bank erosion occurring at the upstream limits of this reach. Maintenance was recently performed to remove sediment from blocking some of the culverts under Lake View Road, so no further maintenance is recommended at this time. Considering the dynamic nature of the lateral streambank erosion observed through this reach, annual channel monitoring in the form of a site visit, visual inspection, and basic channel top width and depth measurements at each of the monitoring sections supplemented by drone imagery on an annual or bi-annual basis is recommended. More frequent visual monitoring will help identify locations with excess sediment deposition or channel avulsions with accelerated erosion that may pose a threat to infrastructure. Additionally, an annual report including a photo log, notes, measurements, observations, and recommendations from the site visit is recommended.

6.3 Reach 3 (Sta. 116+00 to Sta. 190+00)

Observations

- From station 116+00 to station 130+00 a grouted boulder wall stabilizes the right bank of the channel through the 12-Mile Dog Off Leash Area. This area is depositional with many central bars, however, there has been some recent channel downcutting or scour near the boulder wall exposing the bottom of the boulders and the bedding below. The downcutting or scour is likely the result of a combination of the channel avulsion and subsequent channel erosion just downstream of the dog park and an increase in channel velocities along the boulder wall.
- From station 130+00 to station 140+00 the channel is in quasi-equilibrium between the depositional zone through the dog park and the erosional zone upstream. While there are still some central bars through this reach indicating some degree of instability, a bankfull channel can

be identified. Streambanks range from 4-feet to 5.5-feet and are predominantly vegetated with willows and herbaceous grasses.

- From station 140+00 to the pedestrian bridge near Sta 158+00 channel downcutting increases and the streambanks become vertical ranging from 5.5-feet to 15-feet. The streambanks are beginning to undercut threatening several mature cottonwood trees that line the top of banks.
- From the pedestrian bridge to the confluence with Piney Creek at station 171+00, channel downcutting increases and streambanks remain vertical with some minor lateral streambank erosion beginning to occur, particularly on the outside bends. In some areas, point bars on the inside of bends have started to form in the channel bottom within the vertical streambanks.
- From the confluence with Piney Creek to the first of two grouted boulder grade control structures, station 180+25, channel downcutting and lateral streambank erosion becomes more prevalent, particularly on the outside bends.
- From station 180+25 to the state park boundary at station 190+00, two grouted boulder drop structures have been constructed for grade control and appear to have arrested the channel downcutting and lateral streambank erosion.

Recommendations

Currently, the channel through the dog park is experiencing degradation due to a recent avulsion at the downstream end of the dog park and has caused several boulders to fall into the channel and has exposed the bedding below much of the remaining boulder edging. A maintenance project is already underway to arrest the erosion at the downstream end of the dog park. This should help to stabilize the boulder edging, however, a larger stream stabilization project through the dog park should be considered in the future to improve sediment transport minimizing both sediment deposition and erosion which threaten the dog park infrastructure. Currently, channel downcutting and streambank erosion between station 140+00 and station 180+25 is beyond the scope of maintenance and will require a larger channel reclamation effort to stabilize this reach. Considering the dynamic nature of the lateral streambank erosion observed through this reach, annual channel monitoring in the form of a site visit, visual inspection, and basic channel top width and depth measurements at each of the monitoring sections supplemented by drone imagery on an annual or bi-annual basis is recommended. More frequent visual monitoring will help identify locations with accelerated erosion that may pose a threat to infrastructure (i.e., Dog Off-Leash Area, the pedestrian trail crossing, and grouted boulder drop structures) as the channel downcutting and lateral streambank erosion continues. Additionally, an annual report including a photo log, notes, measurements, observations, and recommendations from the site visit is recommended.

6.4 Reach 4 (Piney Creek Sta. 0+00 to Sta. 20+00)

Observations

- The channel through this reach is actively downcutting resulting in vertical streambanks with some sluffing occurring. The vertical streambanks vary in height from 6-feet to 13-feet tall.

Recommendations

Currently, channel downcutting and streambank erosion are beyond the scope of maintenance and will require a larger channel reclamation effort to stabilize this reach. Considering the dynamic nature of the lateral streambank erosion observed through this reach, annual channel monitoring in the form of a site visit, visual inspection, and basic channel top width and depth measurements at each of the monitoring sections supplemented by drone imagery on an annual or bi-annual basis is recommended. More frequent visual monitoring will help identify locations with accelerated erosion that may pose a threat to infrastructure (i.e., pedestrian trail crossing, and concrete utility encasement) as the channel downcutting and lateral streambank erosion continues. Additionally, an annual report including a photo log, notes, measurements, observations, and recommendations from the site visit is recommended.

Monitoring Activity	**Reach 1: Cherry Creek 5+00 to 63+00**	**Reach 2: Cherry Creek 63+00 to 116+00**	**Reach 3: Cherry Creek 116+00 to 190+00**	**Reach 4: Piney Creek 0+00 to 20+00**
Site Visit **Visual Assessment, photos, and report**	Annually Post Major Storm Event	Annually Post Major Storm Event	Annually Post Major Storm Event	Annually Post Major Storm Event
Detailed Survey **Monitoring Cross Sections and Channel Profile**	Every 2 to 3 years Post Major Storm Event Observed Significant Erosion or Deposition	Every 2 to 3 years Post Major Storm Event Observed Significant Erosion or Deposition	Every 2 to 3 years Post Major Storm Event Observed Significant Erosion or Deposition	Every 2 to 3 years Post Major Storm Event Observed Significant Erosion or Deposition
Drone **Aerial Imagery**	Every 1 to 2 years Post Major Storm Event	Every 1 to 2 years Post Major Storm Event	Every 1 to 2 years Post Major Storm Event	Every 1 to 2 years Post Major Storm Event
Drone **Aerial Topography**	Every 5 years Post Major Storm Event Observed Significant Erosion or Deposition	Every 5 years Post Major Storm Event Observed Significant Erosion or Deposition	Every 5 years Post Major Storm Event Observed Significant Erosion or Deposition	Every 5 years Post Major Storm Event Observed Significant Erosion or Deposition

Table 3: Summary of Channel Monitoring Activities

Notes:

1. *Frequency of monitoring activities can vary by reach at the discretion of the CCBWQA, this should be further discussed with the Technical Advisory Committee to ensure that this effort aligns with the CCBWQA goals.*
2. *Frequency of detailed cross section and channel profile survey and the aerial topography will be influenced by the annual visual assessment and frequency of storm events since the previous survey.*
3. *This matrix should be re-visited every couple of years or as channel conditions evolve, through channel improvement projects or further degradation, to identify what is working and to make changes that continue to best meet the CCBWQA goals.*

7 FUTURE MONITORING RECOMENDATIONS

A three-part monitoring plan consisting of annual field inspections, channel monitoring survey, and an adaptive management plan is recommended for Cherry Creek due to the dynamic nature of channel downcutting, lateral streambank erosion, and sediment deposition through the state park. The combination of these three monitoring methods will ensure that changes to the channel morphology causing increased erosion rates or threatening infrastructure are identified and quantified in a timely manner allowing for more informed and timely maintenance or planning for larger stream reclamation projects.

7.1 Annual Field Reconnaissance

An annual field reconnaissance is recommended for all four sub-reaches including a site visit to walk the entire channel and record any significant changes to the baseline channel conditions and take field measurements at 14 monitoring cross sections of channel width and depth and drone photography (if practical). Observations to record should include documentation of vertical stability (channel bed erosion/degradation limits and areas of sedimentation/aggradation), lateral stability and streambank erosion, threats to infrastructure, beaver activity, debris issues, and any noticeable changes or damage to adjacent vegetation and trees. Additionally, BEHI and NBS ratings could be incorporated into the annual field reconnaissance with minimal additional effort to identify annual changes to streambank erosion hazards. It is recommended that the information gathered during the field reconnaissance be documented in an annual channel monitoring memorandum and include comparisons to the baseline channel monitoring data where applicable, exhibits/maps documenting field observations by sub-reach (same format as existing conditions assessment), updates to the aggradation/degradation summary exhibit, summary of streamflow conditions and any major storm events during the year, and any maintenance recommendations. It is recommended that the field reconnaissance be completed in the fall after the rainy season and the leaves have fallen to capture any changes in channel from that year's storm events. Drone photography may also be beneficial every 1 to 2 years to observe and monitor the stability and any major vegetation changes in the wide floodplain areas of Cherry Creek that can be difficult to access or observe from the ground.

7.2 Channel Monitoring Survey

Channel Monitoring Survey is recommended for the channel profile and the channel monitoring cross sections established during the baseline survey every two to three years or after large storm events. It is recommended that the channel monitoring survey be completed by a professional land surveyor to match the accuracy of the baseline survey so that the data produced for comparison accurately represents morphology changes and trends. On the years that channel monitoring survey is performed, it is recommended that the channel monitoring survey and comparison data be documented as an additional section in the annual channel monitoring memorandum. It is recommended that channel monitoring survey be completed in the fall after the rainy season and the leaves have fallen to capture any changes in channel from that year's storm events.

7.3 Adaptive Management Plan

Adaptive management can be an effective approach to managing dynamic channels such as Cherry Creek through the state park. Adaptive management plans can minimize costs by first looking at low-cost corrective actions and then escalating the remediation activities as required and outlined in the plan. Adaptive management plans can also help to streamline the decision-making process by developing a decision-making matrix providing possible remediation activities for anticipated issues that can be agreed upon by stakeholders prior to the development of actual issues.

The development of an adaptive management plan is recommended for Cherry Creek through the Cherry Creek State Park. The plan may be most effective for Reach 2 and the downstream portion of Reach 3 through the DOLA, which is more conducive to low-cost corrective actions due to the depositional character of this reach, than for the remaining reaches, which have already experienced severe channel downcutting and lateral streambank erosion and are beyond the scope of low-cost corrective actions. However, the plan could be developed for all reaches and could include provisions for issues that develop in the floodplain outside of the channel.

At a minimum, the adaptive management plan should include channel monitoring as outlined in the previous sections, a decision-making matrix outlining options for remediation activities for anticipated issues in the channel and in the adjacent floodplain, and a schedule to revisit and revise the adaptive management plan to incorporate changes in priorities by participating stakeholders.

8 REFERENCES

Muller Engineering Company, Inc. (2022). *Cherry Creek Stream and Water Quality Assessment Reservoir to State Park Boundary*. Arapahoe County, CO: Cherry Creek Basin Water Quality Authority.

Rosgen, D. (2014). *Applied River Morphology.* Pagosa Springs, CO: Wildland Hydrology.

Rosgen, D. (2014). *River Stability Field Guide.* Fort Collins, CO: Wildland Hydrology.

Appendix A: Photo Log

- Photo Log

Reach 1

(Cherry Creek)

STA. 6+00 | L1.1 & R1.1

STA. 6+00 | L.1.1

STA. 9+50 | L1.1

STA. 12+00 | R1.1

STA. 12+00 | R1.1

STA. 16+50 | R.1.2

STA. 19+00 | L1.4

STA. 21+75 | L1.6

STA. 23+50 | R1.4

STA. 30+00 | R1.6

STA. 31+00 | L1.9

STA. 31+75 | L1.9

STA. 31+75 | L1.9

STA. 32+50 | R1.6

STA. 33+75 | L1.10

STA. 36+00 | L1.10

STA. 37+50 | R1.6

STA. 39+00 | L1.11

STA. 39+00 | L1.11

STA. 40+50 | R1.7

STA. 40+50 | R1.7

STA. 41+50 | R1.7

STA. 43+00 | L1.12 & R1.8

STA. 47+00 | R1.8

STA. 50+00 | R1.9

STA. 55+25 | L1.13

STA. 58+00 | L1.14

Reach 2

(Cherry Creek)

STA. 109+25 | L2.1 & R2.1

Reach 3

(Cherry Creek)

STA. 115+00 | L3.1

STA. 122+00 | L3.1

STA. 123+50 | L3.1

STA. 134+00 | R3.2

STA. 135+00 | R3.2

STA. 135+00 | L3.4

STA. 135+50 | L3.5 & R3.3

STA. 139+00 | L3.6 & R3.4

STA. 144+00 | L3.6 & R3.5

STA. 147+50 | L3.7 & R3.5

STA. 147+50 | L3.7

STA. 151+00 | R3.7

STA. 153+00 | L3.9 & R3.8

STA. 154+25 |L3.9 & R3.9

STA. 156+50 | L3.10

STA. 157+25 | L3.10

STA. 160+00 | L3.11 & R3.9

STA. 163+00 | L3.11

STA. 164+00 | L3.12

STA. 164+00 | R3.10

STA. 168+50 | R3.12

STA. 170+00 | L3.17

STA. 173+50 | L3.19 & R3.14

STA. 174+00 | L3.19 & R3.15

STA. 175+00 | R3.15

STA. 177+00 | L3.20

STA. 180+00 | L3.22

STA. 184+00 | L3.23 & R3.18

Reach 4

(Piney Creek)

STA. 4+00 | R4.1

STA. 5+00 | L4.2

STA. 5+75 | L4.2 & R4.3

STA. 6+50 | L4.2

STA. 11+00 | L4.6 & R4.6

STA. 11+75 | R4.6

STA. 14+50 | L4.7

STA. 16+00 | R4.10

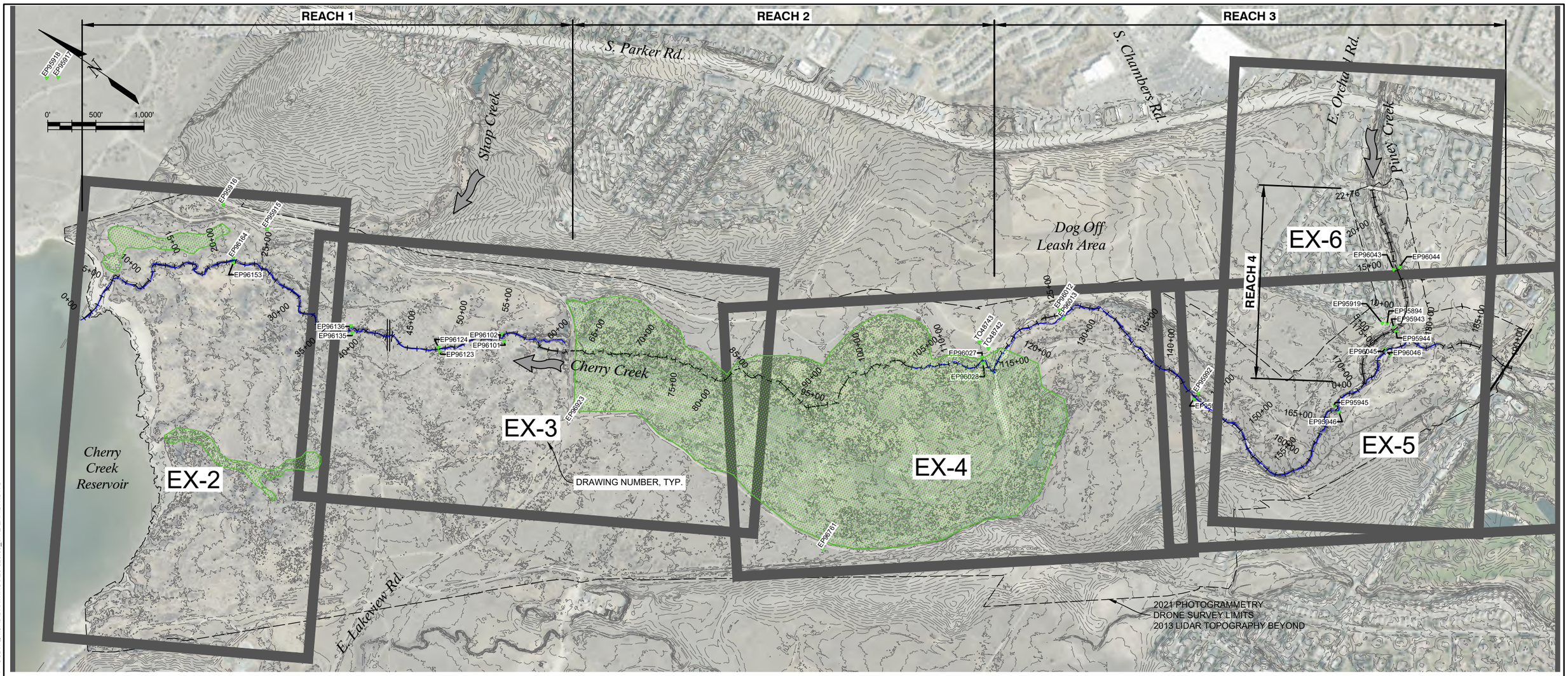
STA. 17+00 | L4.8 & R4.11

STA. 18+50 | R4.12

STA. 18+75 | L4.9 & R4.12

Appendix B: Monitoring Survey

- Channel Monitoring Plan
- Channel Monitoring Profile
- Channel Monitoring Cross Sections



LEGEND

- 2021 THALWEG SURVEY
- CCBWQA MONITORING SECTION LINES
- CONTOURS MAJOR
- CONTOURS MINOR
- EP00000 CONTROL POINT SURVEY

Control Point Table

CP NO.	Elevation	Northing	Easting	DESC.
EP95915	5563.270	1656350.5100	3186830.9300	CP;RTK;Plastic Cap on No. 5;1;Undisturbed;None;GPLC CP200
EP95916	5566.660	1656868.1600	3186781.0200	CP;RTK;Plastic Cap on No. 5;1;Undisturbed;None;GPLC CP199
EP96153	5555.210	1656439.6900	3186339.8400	CP;RTK;Rebar;0.58;Undisturbed;None;XS11 RM
EP96164	5555.450	1656464.1121	3186380.4721	CP;RTK;Rebar;0.58;Undisturbed;None;XS11 RM
EP96101	5568.840	1653661.5100	3187254.8700	CP;RTK;Rebar;0.58;Undisturbed;None;XS8 RM
EP96102	5569.040	1653722.7300	3187309.5800	CP;RTK;Rebar;0.58;Undisturbed;None;XS8 RM
EP96123	5566.590	1654153.8000	3186791.0600	CP;RTK;Rebar;0.58;Undisturbed;None;XS9 RM
EP96124	5566.690	1654188.6300	3186820.6000	CP;RTK;Rebar;0.58;Undisturbed;None;XS9 RM
EP96136	5561.910	1655063.3900	3186491.1400	CP;RTK;Rebar;0.58;Undisturbed;None;XS10 RM
EP96153	5555.210	1656439.6900	3186339.8400	CP;RTK;Rebar;0.58;Undisturbed;None;XS11 RM
EP96923	5574.530	1652615.9400	3186952.2200	CP;RTK;Plastic Cap on No. 5;1;Undisturbed;None;CP201
EP96012	5601.960	1649089.2200	3190783.3600	CP;RTK;Rebar;0.58;Undisturbed;None;XS6 RM
EP96013	5601.690	1649006.0200	3190735.6700	CP;RTK;Rebar;0.58;Undisturbed;None;XS6 RM
EP96027	5597.510	1649473.5200	3189926.7400	CP;RTK;Rebar;0.58;Undisturbed;None;XS7 RM
EP96028	5597.040	1649429.4500	3189879.8500	CP;RTK;Rebar;0.58;Undisturbed;None;XS7 RM
EP96761	5588.860	1649712.0900	3187349.5200	CP;RTK;Iron Pipe;1.5;Undisturbed;None;0.5FT ABOVE NG; PAINTED WHITE; USACE MARKER POST ADJACENT
TO48742	5599.020	1649468.8400	3190035.9600	CP
TO48743	5598.780	1649585.9900	3190038.6900	CP

Control Point Table

CP NO.	Elevation	Northing	Easting	DESC.
EP95894	5624.960	1646200.2200	3192593.4700	CP;OPUS;Aluminum Cap;2;Undisturbed;None
EP95919	5625.060	1646243.0400	3192564.7700	CP;RTK;Brass Cap;3.5;Undisturbed;None;ARMY CORPS ENG.; NO REF NO.
EP95943	5622.410	1646129.2400	3192605.3500	CP;RTK;Rebar;0.58;Undisturbed;None;XS2 RM
EP95944	5623.800	1646072.2200	3192570.2300	CP;RTK;Rebar;0.58;Undisturbed;None;XS2 RM
EP95945	5616.780	1646174.5300	3191580.7500	CP;RTK;Rebar;0.58;Undisturbed;None;XS4 RM
EP95946	5616.730	1646094.9100	3191550.2500	CP;RTK;Rebar;0.58;Undisturbed;None;XS4 RM
EP95992	5607.790	1647406.7000	3190884.4500	CP;RTK;Rebar;0.58;Undisturbed;None;XS5 RM
EP95993	5608.620	1647412.8000	3190810.3300	CP;RTK;Rebar;0.58;Undisturbed;None;XS5 RM
EP96043	5624.930	1646459.6900	3193091.4600	CP;RTK;Rebar;0.075;Undisturbed;None;XS1 RM
EP96044	5624.660	1646424.3600	3193145.3600	CP;RTK;Rebar;0.075;Undisturbed;None;XS1 RM
EP96045	5619.030	1646067.4900	3192359.0300	CP;RTK;Rebar;0.075;Undisturbed;None;XS3 RM
EP96046	5618.990	1645991.8600	3192341.7100	CP;RTK;Rebar;0.075;Undisturbed;None;XS3 RM

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CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

EXISTING CONDITIONS SITE PLAN

DATE 2/4/2022

DRAWING NO. EX-1

SHEET NO. 1 OF 6

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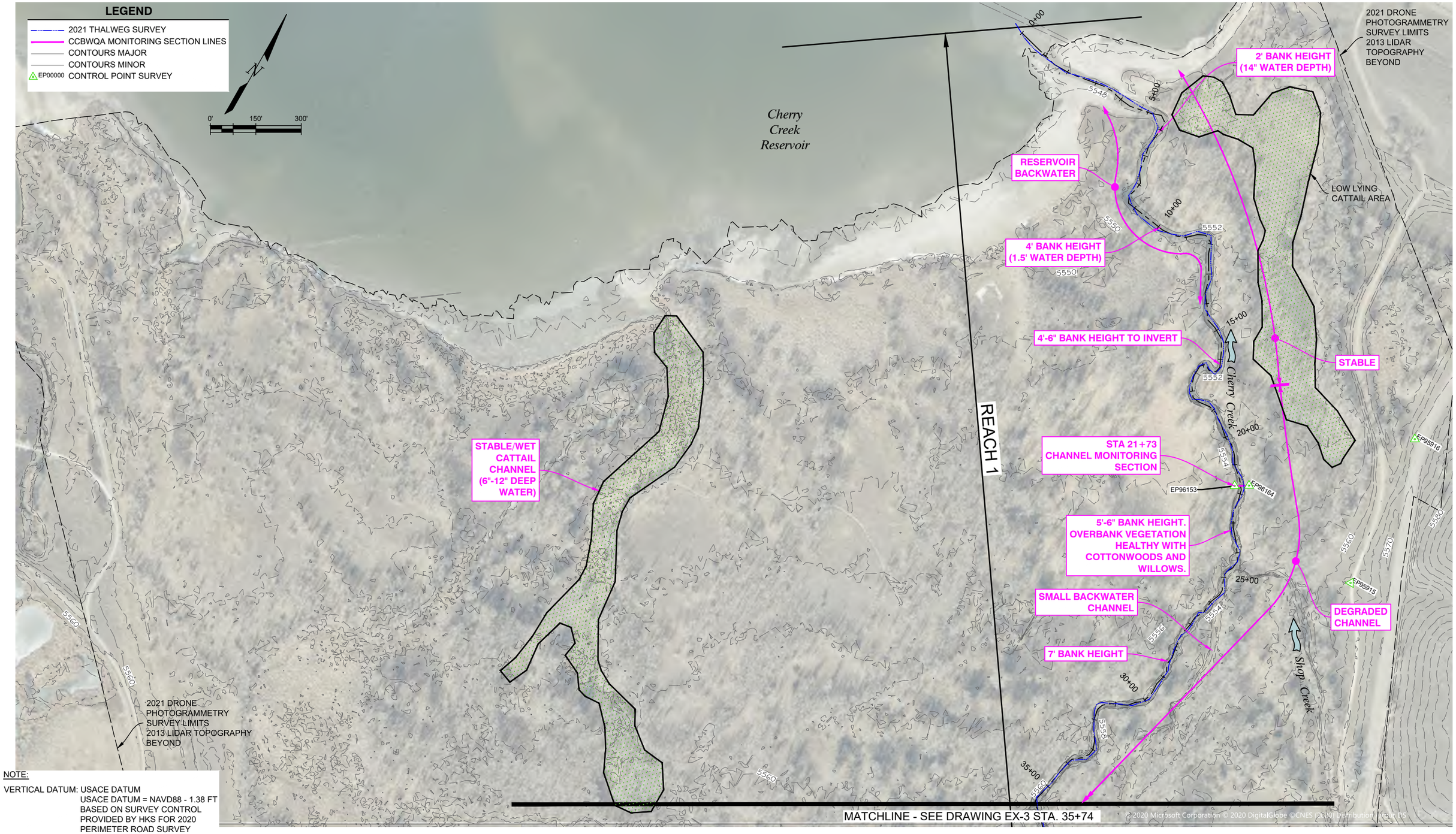
NAME: \\PERTH\PROJECTS\2020 PROJECTS\20-023.03 CHERRY CREEK STUDY - RES TO 12 MILE STUDY - CCBWQA\CAD\DRAWINGS\20-023.03_SITE EXHIBIT.DWG



NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL
PROVIDED BY HKS FOR 2020
PERIMETER ROAD SURVEY

MULLER ENGINEERING COMPANY
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

EXISTING CONDITIONS CHANNEL PLAN STA. 0+00 TO STA. 35+74

DATE 2/4/2022

DRAWING NO. EX-2

SHEET NO. 2 OF 6

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REACH 1

REACH 2

2021 DRONE PHOTOGRAMMETRY SURVEY LIMITS
2013 LIDAR TOPOGRAPHY BEYOND

0' 150' 300'

DEGRADED CHANNEL

STA 55+30 CHANNEL MONITORING SECTION

2.5' BANK HEIGHT WITH 1.25' WATER DEPTH

DEGRADED CHANNEL

3' BANK HEIGHT, SHALLOW CHANNEL

6' DEEP INCISED CHANNELS

NOTICEABLE BEAVER ACTIVITY AT CULVERTS

AGGRADED, WETLAND CHANNEL

EP96136
EP96135
EP96124
EP96123
EP96102
EP96101

35+00 40+00 45+00 50+00 55+00 60+00 65+00 70+00 75+00 80+00 85+00

SHEET PILE

40" AND 54" AURORA WATER LINES

DOWNED TREES, MOSTLY DUE TO BEAVERS

TREES FALLING INTO CHANNEL DUE TO EROSION

STA 48+33 CHANNEL MONITORING SECTION

DEEPLY INCISED CHANNEL. 8.5'-9' HEIGHT. TREES FALLING INTO CREEK, WITH WIDE SHALLOW ROOTS TREES.

STA 38+22 CHANNEL MONITORING SECTION

GRASS SWALE
5' BW
15' TW
1.5" DEEP

STA 57+48.26 CHANNEL MONITORING SECTION

CC-9

RESPEC DOING CULVERT SURVEY AND RATING CURVES. CULVERTS INSTALLED ABOUT 6 YEARS AGO (SEWER CMP 29" x 42" PIPES)

MW-9 EP96823

VALLEY FLOOR ALLUVIAL FAN. SEDIMENT DEPOSITS EVERYWHERE AND STANDING PONDS ON WEST SIDE

Cherry Creek

Lake View Road

Pipe Line Trail

MATCHLINE - SEE DRAWING EX-2 STA. 35+74

MATCHLINE - SEE DRAWING EX-4 STA. 81+26

5610 5600 5590 5580 5570 5560

LEGEND

- 2021 THALWEG SURVEY
- CCBWQA MONITORING SECTION LINES
- CONTOURS MAJOR
- CONTOURS MINOR
- EP00000 CONTROL POINT SURVEY

NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL
PROVIDED BY HKS FOR 2020
PERIMETER ROAD SURVEY

MULLER ENGINEERING COMPANY
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

EXISTING CONDITIONS
CHANNEL PLAN
STA. 35+74 TO STA. 81+26

DATE 2/4/2022
DRAWING NO. EX-3
SHEET NO. 3 OF 6

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REACH 2

REACH 3

2021 DRONE PHOTOGRAMMETRY SURVEY LIMITS
2013 LIDAR TOPOGRAPHY BEYOND

Cherry Creek Dog Off Leash Area

0' 150' 300'

MATCHLINE - SEE DRAWING EX-3 STA. 81+26

MATCHLINE - SEE DRAWING EX-5 STA. 138+98

Cherry Creek

BOULDERS ADDED IN 2012-2013. CREEK BREACHED IN 2015 TAKING ALL FLOW NORTH

LOG/DEBRIS DROP

STA 113+99 CHANNEL MONITORING SECTION

EDGE BOULDER. EROSION ON BACK SIDE

CHANNEL INVERT LOOKS STABLE THROUGH DOG PARK IMPROVEMENTS

STA 125+72 CHANNEL MONITORING SECTION

2'-3' BANK HEIGHT, WIDE CHANNEL WITH SAND BARS THAT ARE VEGETATED.

LESS INCISED QUASI-EQUILIBRIUM. 3' TO 3.5' BANK HEIGHT

WIDE CHANNEL WITH LARGE SAND BAR

SEDIMENT DEPOSITION AREA. FLOW SPIRALS IN ALL DIRECTIONS.

STA 94+06.05 CHANNEL MONITORING SECTION

STA 107+27.07 CHANNEL MONITORING SECTION

LARGE SAND DEPOSIT

VALLEY FLOOR ALLUVIAL FAN. SEDIMENT DEPOSITS EVERYWHERE AND STANDING PONDS ON WEST SIDE

CATTAILS AND SOME TREES

2.5' TALL LARGE BEAVER DAM

STANDING POOLS

ERODED BANK WITH SANDSTONE OUTCROP

SHALLOW MAIN CHANNEL, CATTAILS. 1' DEEP x 20' WIDE WITH STAGNANT, FLAT WATER

EP96027 EP96028 EP96012 EP96013 EP96761 TO48743 TO48742

85+00 90+00 95+00 100+00 105+00 110+00 115+00 120+00 125+00 130+00 135+00 140+00

5580 5590 5600 5610 5620 5630 5640 5550 5560

NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL
PROVIDED BY HKS FOR 2020
PERIMETER ROAD SURVEY

LEGEND

- 2021 THALWEG SURVEY
- CCBWQA MONITORING SECTION LINES
- CONTOURS MAJOR
- CONTOURS MINOR
- EP00000 CONTROL POINT SURVEY

MULLER ENGINEERING COMPANY
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

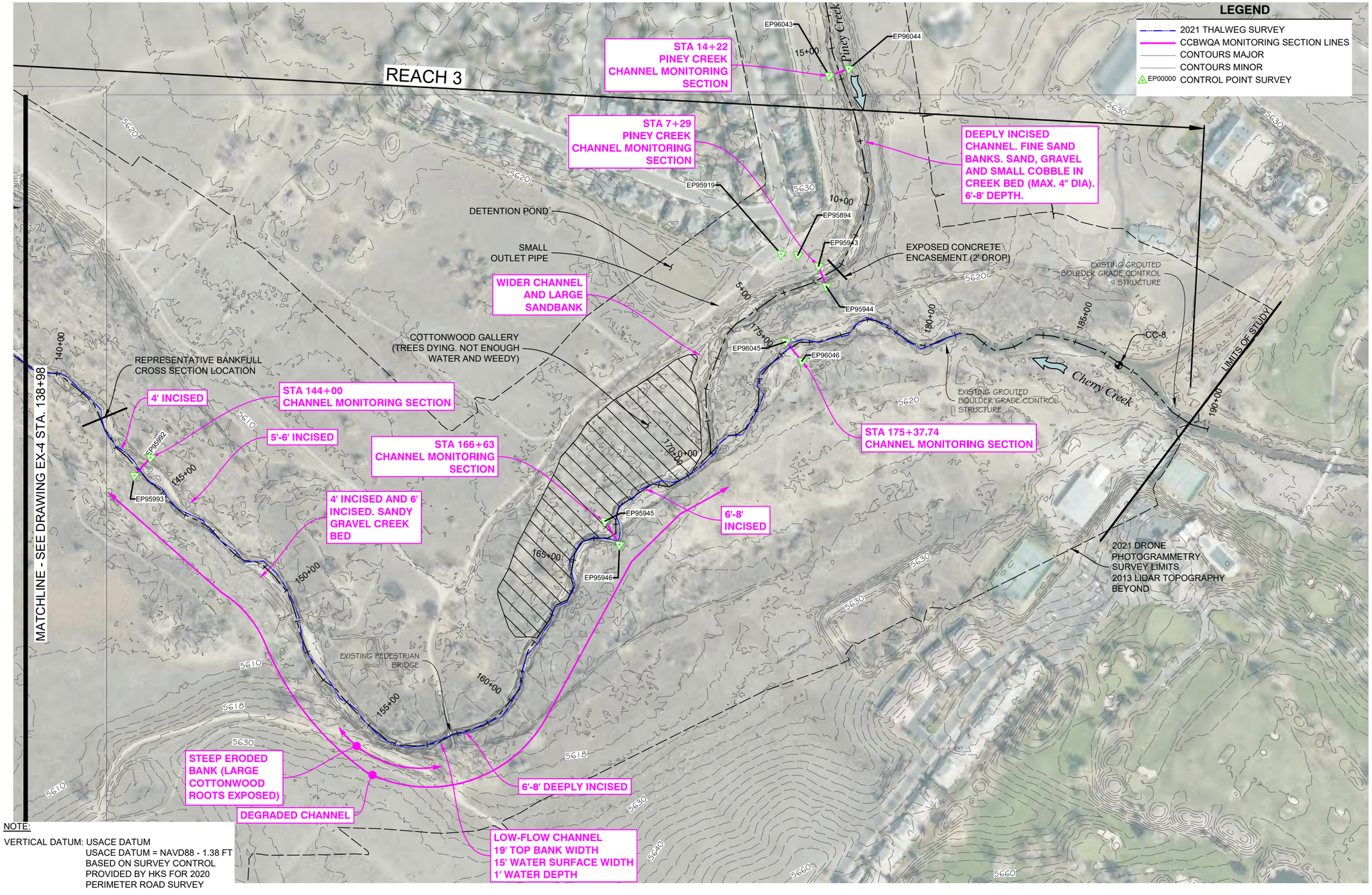
EXISTING CONDITIONS CHANNEL PLAN STA. 81+26 TO 138+98

DATE 2/4/2022

DRAWING NO. EX-4

SHEET NO. 4 OF 6

PLOTTED: 4/1/2022 2:47:36 PM
NAME: \\PERTH\PROJECTS\2020 PROJECTS\20-023.03 CHERRY CREEK STUDY - RES TO 12 MILE STUDY - CCBWQA\CAD\DRAWINGS\20-023.03_SITE EXHIBIT.DWG



NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL
PROVIDED BY HKS FOR 2020
PERIMETER ROAD SURVEY

MULLER ENGINEERING COMPANY
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

EXISTING CONDITIONS CHANNEL PLAN STA. 138+98 TO STA. 190+00

DATE 2/4/2022

DRAWING NO. EX-5

SHEET NO. 5 OF 6

PLOTTED: 4/12/2022 2:48:24 PM
NAME: \\PERTH\PROJECTS\2020 PROJECTS\20-023.03 CHERRY CREEK STUDY - RES TO 12 MILE STUDY - CCBWQA\CAD\DRAWINGS\20-023.03_SITE EXHIBIT.DWG

STEEP ERODED BANK (LARGE COTTONWOOD ROOTS EXPOSED)

LOW-FLOW CHANNEL
19' TOP BANK WIDTH
15' WATER SURFACE WIDTH
1' WATER DEPTH

DEGRADED CHANNEL

STA 166+63
CHANNEL MONITORING SECTION

6'-8' DEEPLY INCISED

REACH 4

COTTONWOOD GALLERY (TREES DYING. NOT ENOUGH WATER AND WEEDY)

WIDER CHANNEL AND LARGE SANDBANK

DETENTION POND

SMALL OUTLET PIPE

STA 7+29.21
PINEY CREEK
CHANNEL MONITORING SECTION

STA 14+22.16
PINEY CREEK
CHANNEL MONITORING SECTION

EXISTING PEDESTRIAN CROSSING

6'-8' INCISED

STA 175+37.74
CHANNEL MONITORING SECTION

EXPOSED CONCRETE ENCASEMENT (2' DROP)

2021 DRONE PHOTOGRAMMETRY SURVEY LIMITS
2013 LIDAR TOPOGRAPHY BEYOND

DEEPLY INCISED CHANNEL. FINE SAND BANKS. SAND, GRAVEL AND SMALL COBBLE IN CREEK BED (MAX. 4" DIA). 6'-8' DEPTH.

EP95946 EP95945 EP95919 EP96045 EP96046 EP95944 EP95894 EP95943 EP96043 EP96044

155+00 160+00 165+00 170+00 175+00 180+00 185+00 190+00 5+00 10+00 15+00 20+00 22+76

5620 5630 5640 5650 5660

Piney Creek
Cherry Creek
S. Parker Road

0' 150' 300'

NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL PROVIDED BY HKS FOR 2020 PERIMETER ROAD SURVEY

LEGEND

- 2021 THALWEG SURVEY
- CCBWQA MONITORING SECTION LINES
- CONTOURS MAJOR
- CONTOURS MINOR
- EP00000 CONTROL POINT SURVEY

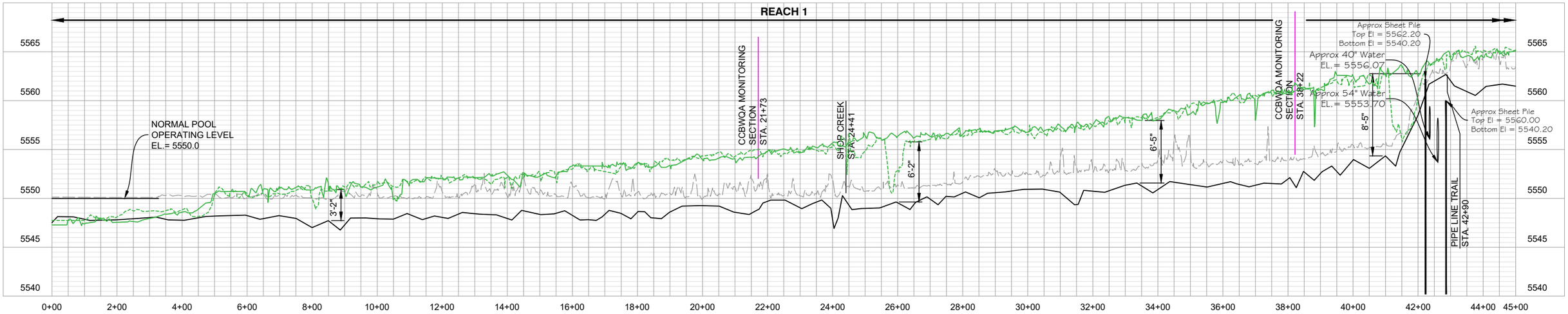
PLOTTED: 4/1/2022 2:49:38 PM
NAME: \\PERTH\PROJECTS\2020 PROJECTS\20-023.03 CHERRY CREEK STUDY - RES TO 12 MILE STUDY - CCBWQA\CAD\DRAWINGS\20-023.03_SITE EXHIBIT.DWG

MULLER ENGINEERING COMPANY
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

EXISTING CONDITIONS CHANNEL PLAN STA. 0+00 TO STA. 22+76

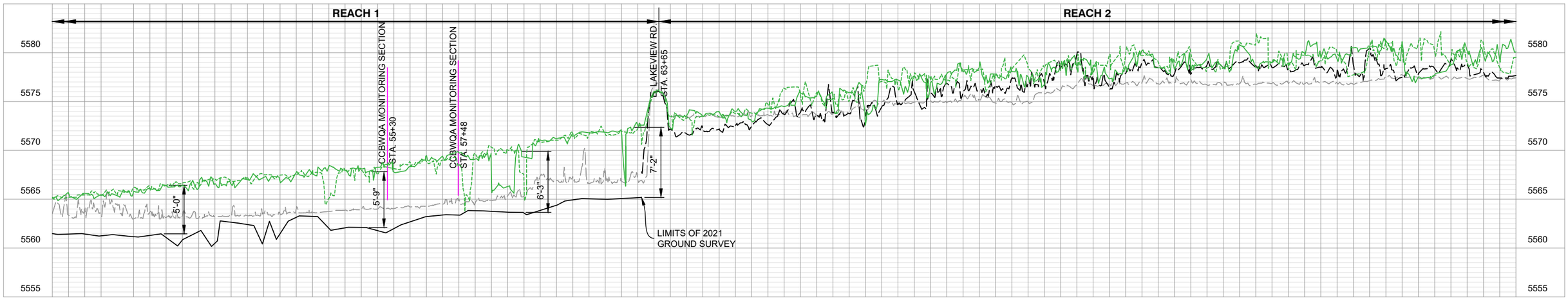
DATE 2/4/2022
DRAWING NO. EX-6
SHEET NO. 6 OF 6



CHERRY CREEK CHANNEL PROFILE

(STA. 0+00 TO STA. 45+00)

SCALE: 1"=150' (HORIZ.)
1"=5' (VERT.)



CHERRY CREEK CHANNEL PROFILE

(STA. 45+00 TO STA. 90+00)

SCALE: 1"=150' (HORIZ.)
1"=5' (VERT.)

NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL
PROVIDED BY HKS FOR 2020
PERIMETER ROAD SURVEY

LEGEND

- 2013 LIDAR CHANNEL THALWEG
- 2021 DRONE SURVEY CHANNEL THALWEG
- 2021 GROUND SURVEY CHANNEL THALWEG
- LEFT TOP BANK (2021 DRONE)
- RIGHT TOP BANK (2021 DRONE)

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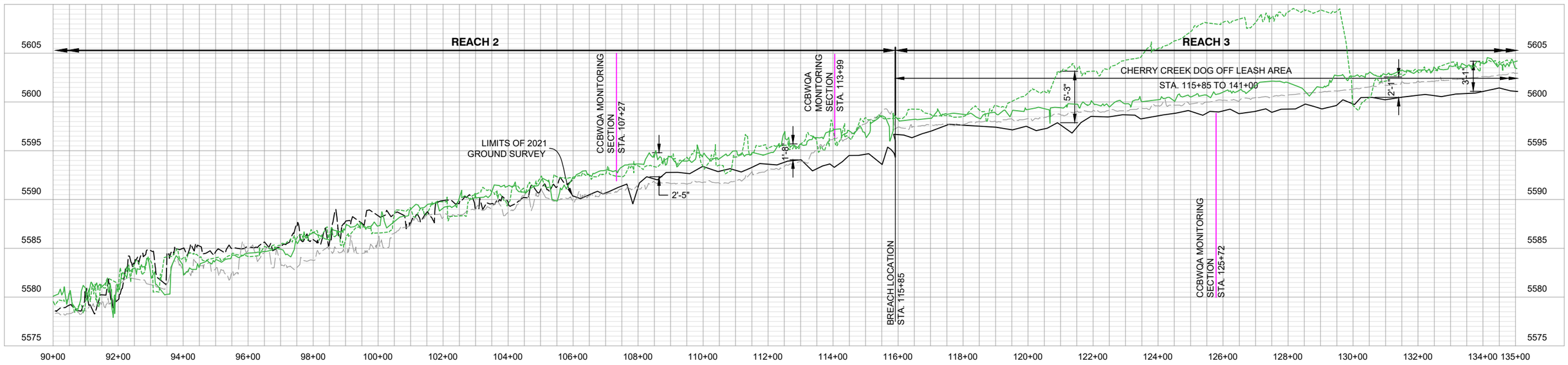
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

CHANNEL PROFILE

DATE 2/4/2022
DRAWING NO. PR-1
SHEET NO. 1 OF 3

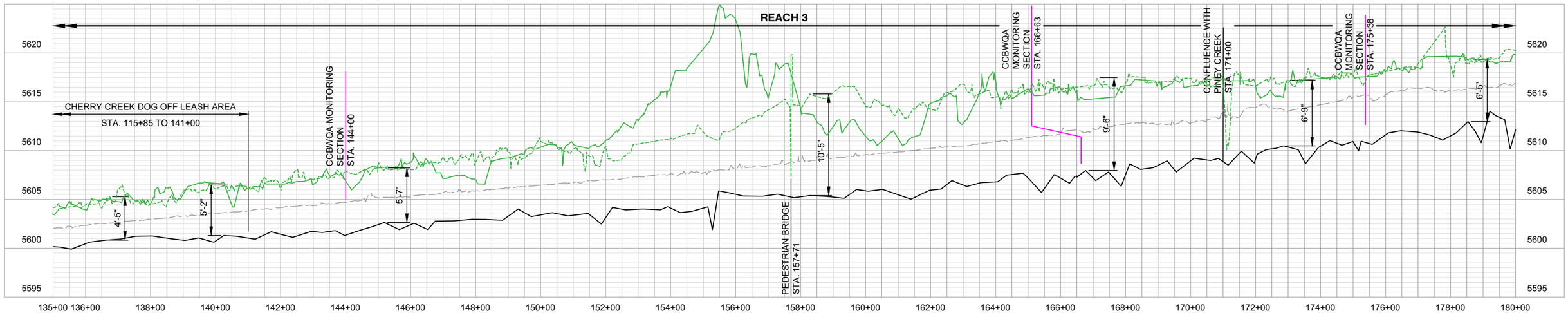
PLOTTED: 4/1/2022 2:42:38 PM
NAME: \\PERTH\PROJECTS\2020 PROJECTS\20-023.03 CHERRY CREEK STUDY - RES TO 12 MILE STUDY - CCBWQA\CAD\DRAWINGS\20-023.03_CHANNEL PROFILES.DWG



CHERRY CREEK CHANNEL PROFILE

(STA. 90+00 TO STA. 135+00)

SCALE: 1"=150' (HORIZ.)
1"=5' (VERT.)



CHERRY CREEK CHANNEL PROFILE

(STA. 135+00 TO STA. 180+00)

SCALE: 1"=150' (HORIZ.)
1"=5' (VERT.)

NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL
PROVIDED BY HKS FOR 2020
PERIMETER ROAD SURVEY

LEGEND

- 2013 LIDAR CHANNEL THALWEG
- 2021 DRONE SURVEY CHANNEL THALWEG
- 2021 GROUND SURVEY CHANNEL THALWEG
- LEFT TOP BANK (2021 DRONE)
- RIGHT TOP BANK (2021 DRONE)

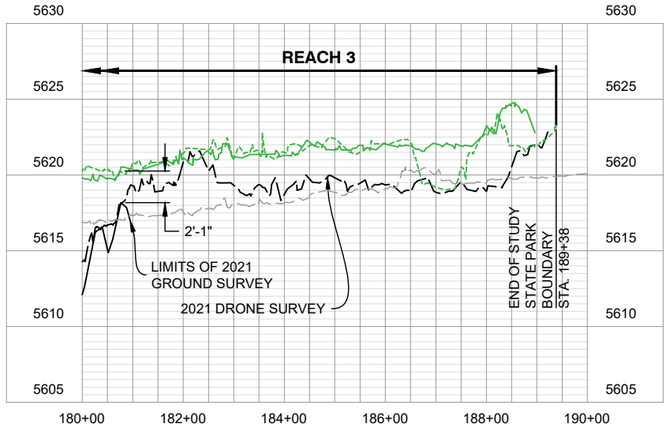
MULLER ENGINEERING COMPANY
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

CHANNEL PROFILE

DATE 2/4/2022
DRAWING NO. PR-2
SHEET NO. 2 OF 3

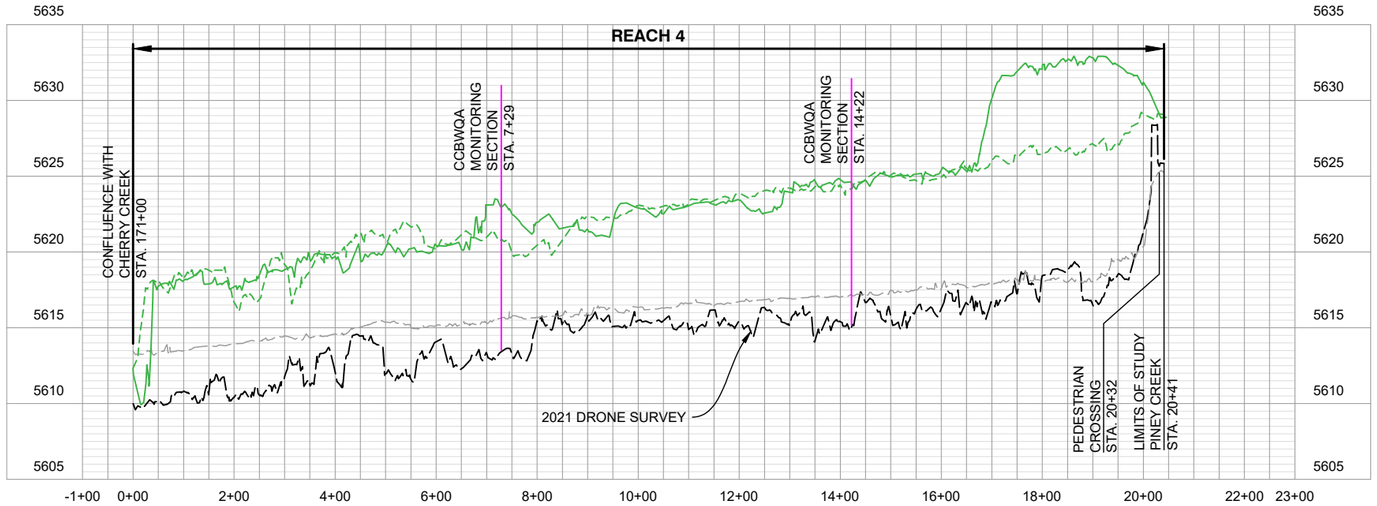
PLOTTED: 4/1/2022 2:42:41 PM
NAME: \\PERTH\PROJECTS\2020 PROJECTS\20-023.03 CHERRY CREEK STUDY - RES TO 12 MILE STUDY - CCBWQA\CAD\DRAWINGS\20-023.03_CHANNEL PROFILES.DWG



CHERRY CREEK CHANNEL PROFILE

(STA. 180+00 TO STA. 190+00)

SCALE: 1"=150' (HORIZ.)
1"=5' (VERT.)



PINEY CREEK CHANNEL PROFILE

(STA. -1+00 TO STA. 23+00)

SCALE: 1"=150' (HORIZ.)
1"=5' (VERT.)

NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL
PROVIDED BY HKS FOR 2020
PERIMETER ROAD SURVEY

LEGEND

- 2013 LIDAR CHANNEL THALWEG
- 2021 DRONE SURVEY CHANNEL THALWEG
- 2021 GROUND SURVEY CHANNEL THALWEG
- LEFT TOP BANK (2021 DRONE)
- RIGHT TOP BANK (2021 DRONE)

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CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

CHANNEL PROFILE

DATE 2/4/2022
DRAWING NO. PR-3
SHEET NO. 3 OF 3

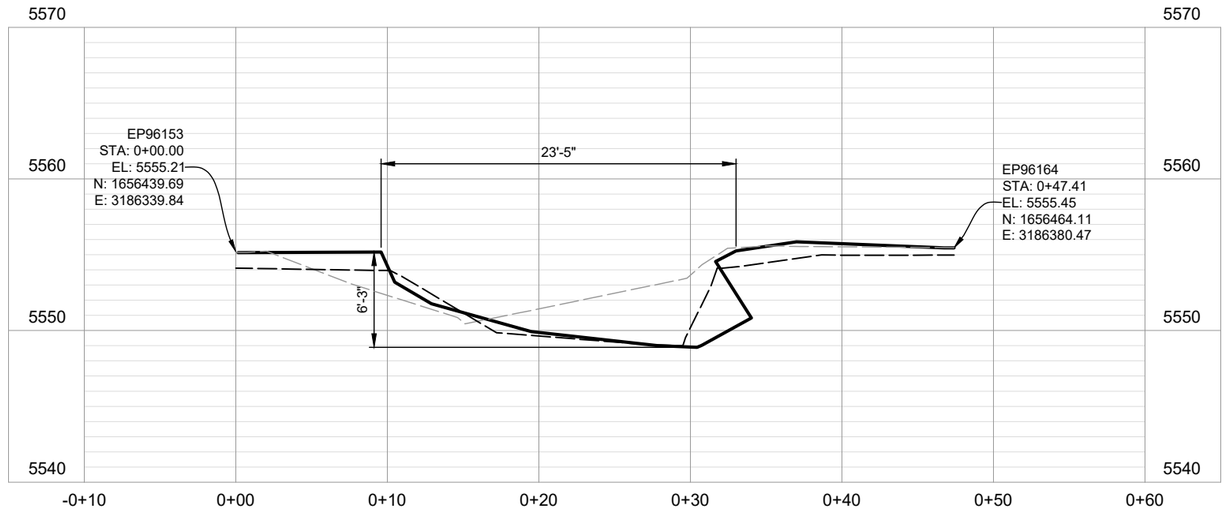
PLOTTED: 4/1/2022 2:43:04 PM
NAME: \\PERTH\PROJECTS\2020 PROJECTS\20-023.03 CHERRY CREEK STUDY - RES TO 12 MILE STUDY - CCBWQA\CAD\DRAWINGS\20-023.03_CHANNEL PROFILES.DWG

0' 100' 200' (HORIZ.)

0' 5' 10' (VERT.)

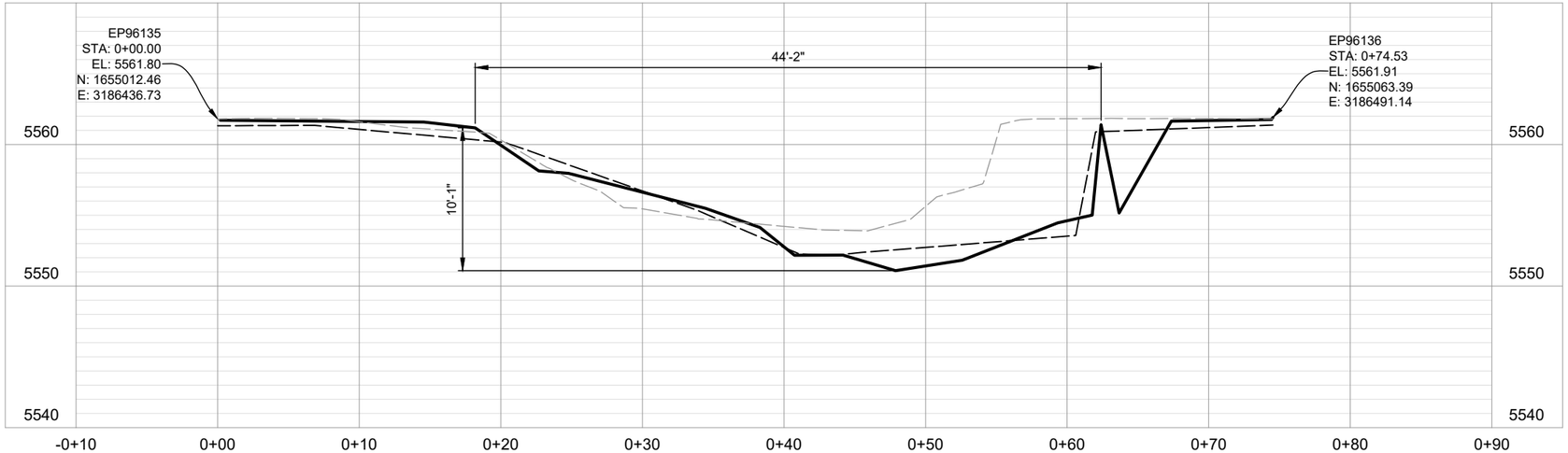
LEGEND - CHANNEL SECTIONS

- 2013 LIDAR
- 2021 DRONE SURVEY
- 2021 GROUND SURVEY



CHERRY CREEK CROSS SECTION (STA. 21+73)

(LOOKING DOWNSTREAM)



CHERRY CREEK CROSS SECTION (STA. 38+22)

(LOOKING DOWNSTREAM)

NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL
PROVIDED BY HKS FOR 2020
PERIMETER ROAD SURVEY

MULLER ENGINEERING COMPANY
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

MAIN CHANNEL CROSS SECTIONS

DATE 2/4/2022

DRAWING NO. XS-1

SHEET NO. 1 OF 6

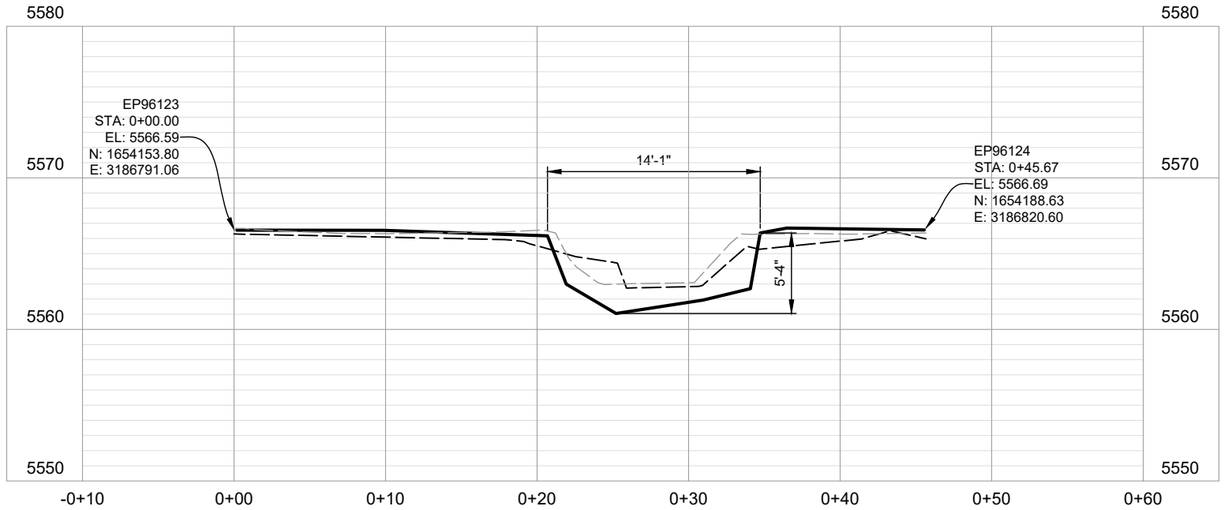
PLOTTED: 4/1/2022 2:43:19 PM
NAME: \\PERTH\PROJECTS\2020 PROJECTS\20-023.03 CHERRY CREEK STUDY - RES TO 12 MILE STUDY - CCBWOA\CAD\DRAWINGS\20-023.03_CHANNEL MONITORING SECTIONS.DWG

0' 100' 200' (HORIZ.)

0' 5' 10' (VERT.)

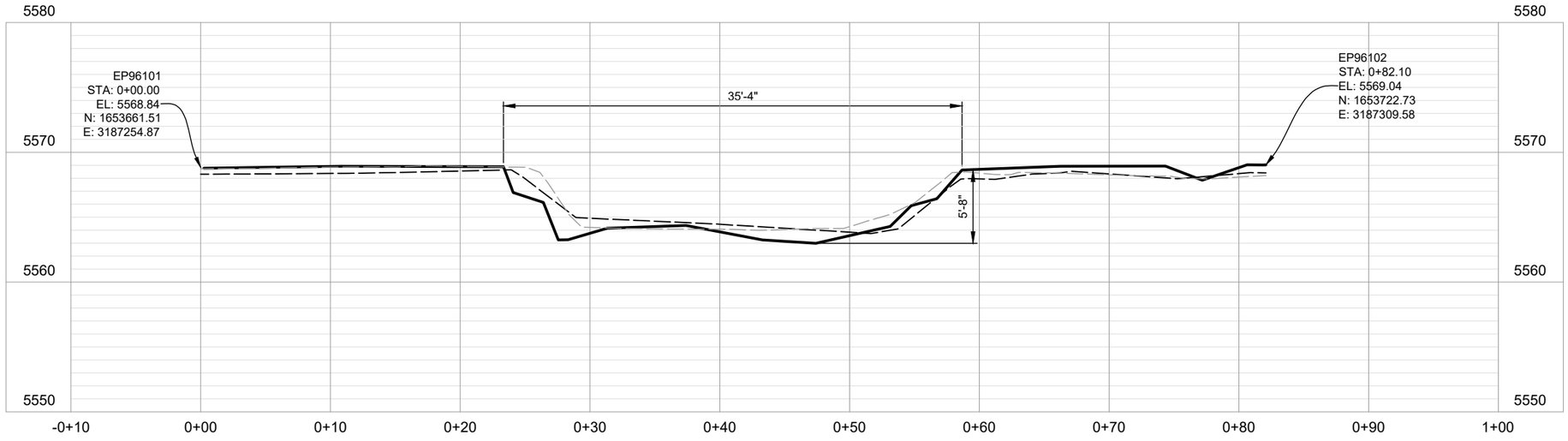
LEGEND - CHANNEL SECTIONS

- 2013 LIDAR
- 2021 DRONE SURVEY
- 2021 GROUND SURVEY



CHERRY CREEK CROSS SECTION (STA. 48+33)

(LOOKING DOWNSTREAM)



CHERRY CREEK CROSS SECTION (STA. 55+30)

(LOOKING DOWNSTREAM)

NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL
PROVIDED BY HKS FOR 2020
PERIMETER ROAD SURVEY

MULLER ENGINEERING COMPANY
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

MAIN CHANNEL CROSS SECTIONS

DATE 2/4/2022

DRAWING NO. XS-2

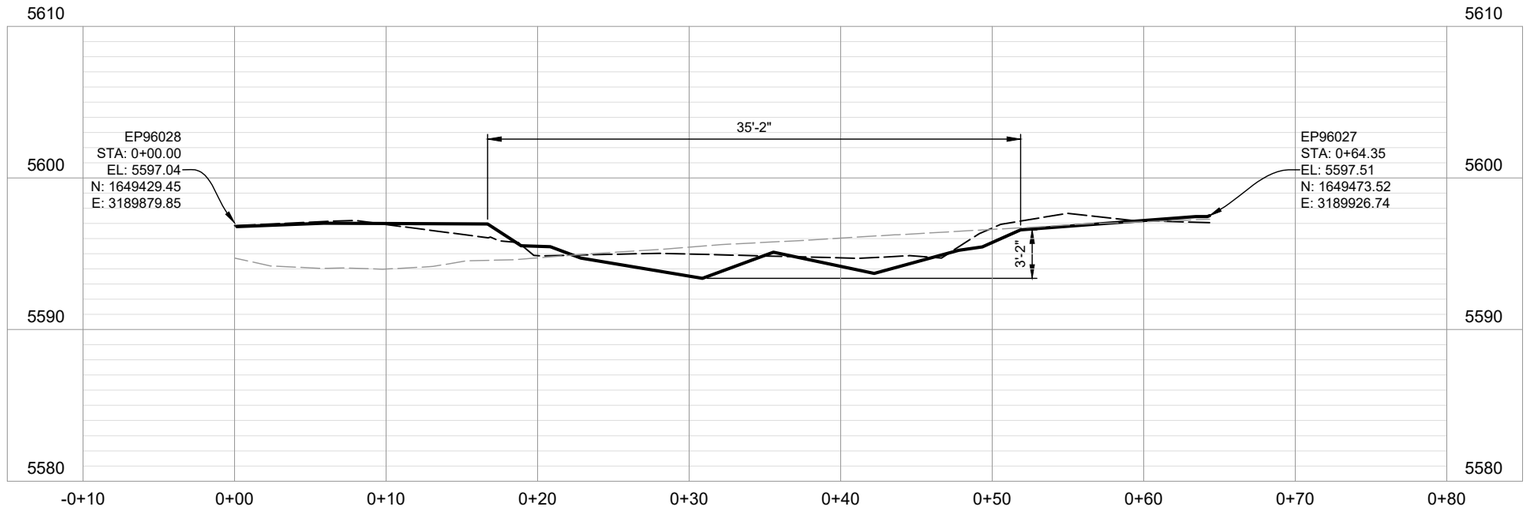
SHEET NO. 2 OF 6

0' 100' 200' (HORIZ.)

0' 5' 10' (VERT.)

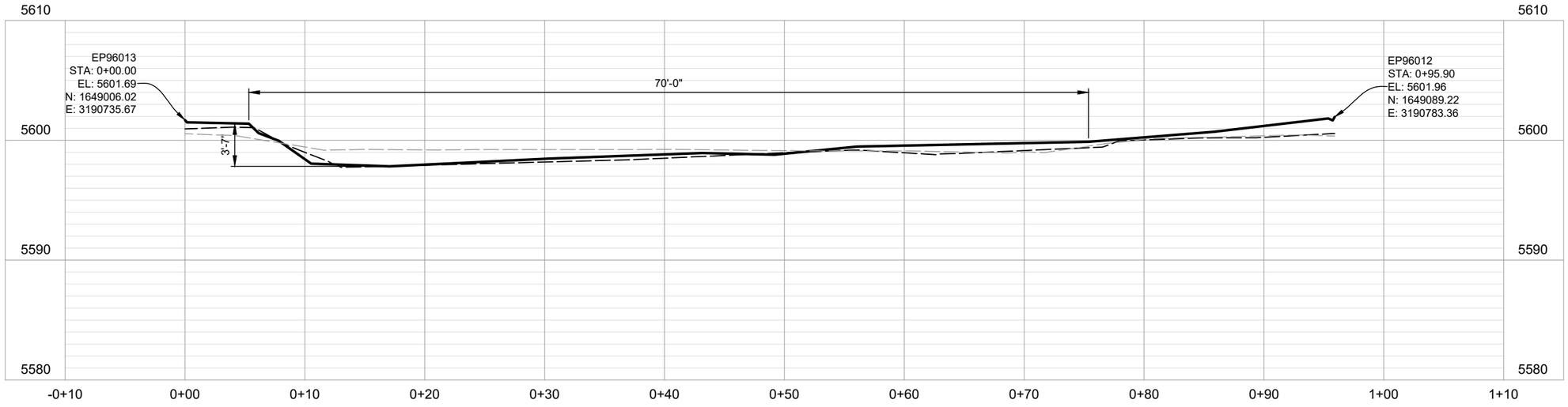
LEGEND - CHANNEL SECTIONS

- 2013 LIDAR
- 2021 DRONE SURVEY
- 2021 GROUND SURVEY



CHERRY CREEK CROSS SECTION (STA. 113+99)

(LOOKING DOWNSTREAM)



CHERRY CREEK CROSS SECTION (STA. 125+72)

(LOOKING DOWNSTREAM)

NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL
PROVIDED BY HKS FOR 2020
PERIMETER ROAD SURVEY

MULLER ENGINEERING COMPANY
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

MAIN CHANNEL CROSS SECTIONS

DATE 2/4/2022

DRAWING NO. XS-3

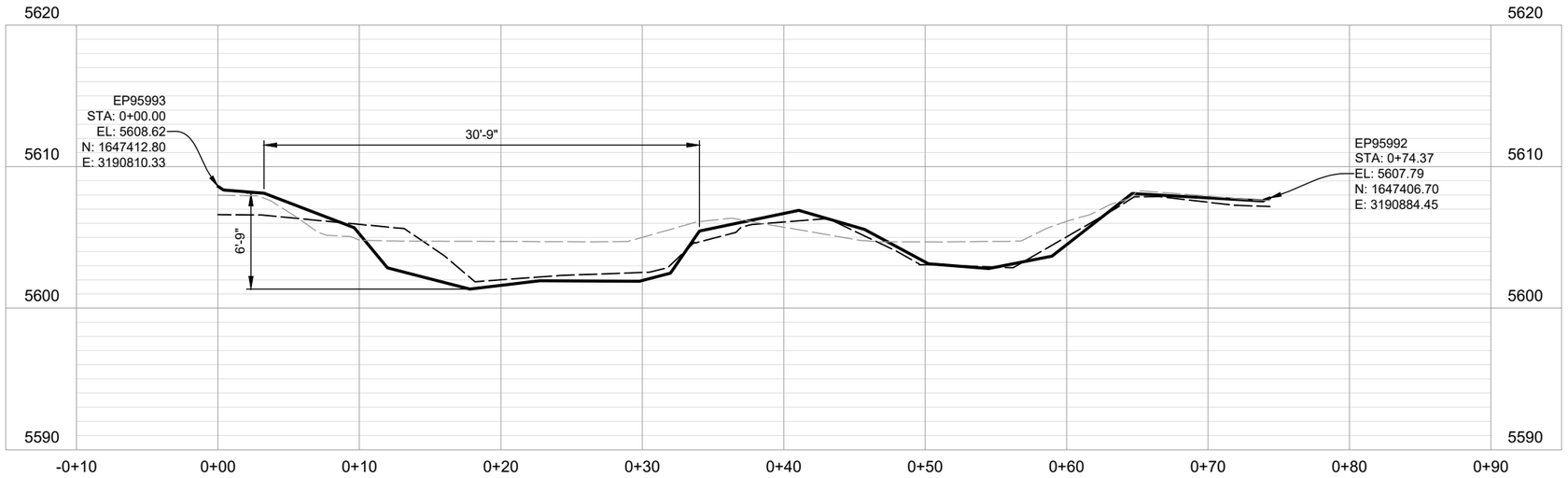
SHEET NO. 3 OF 6

0' 100' 200' (HORIZ.)

0' 5' 10' (VERT.)

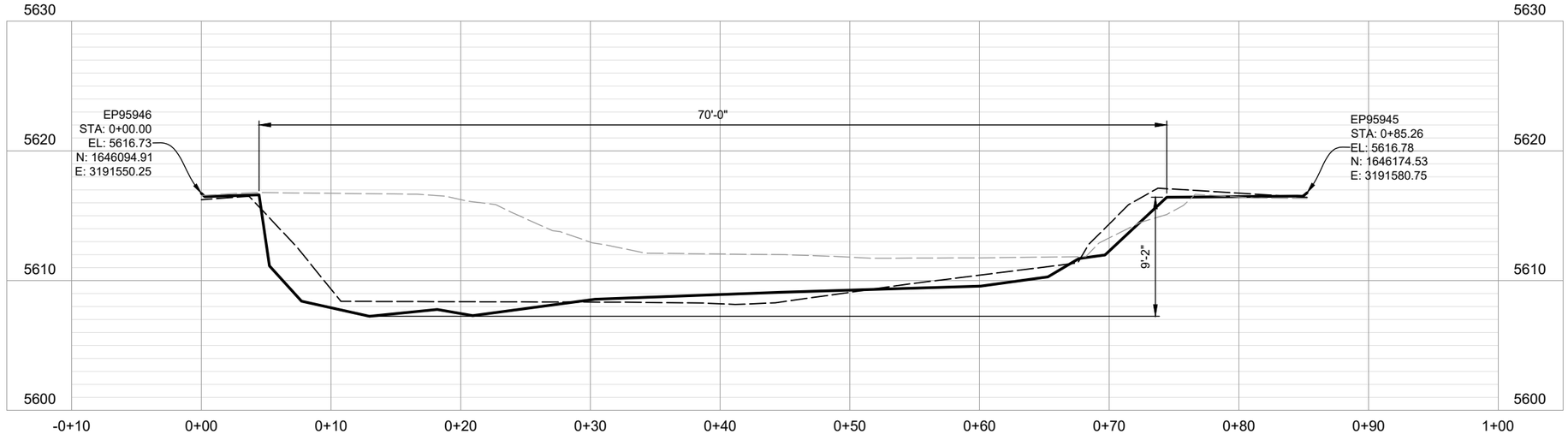
LEGEND - CHANNEL SECTIONS

- 2013 LIDAR
- 2021 DRONE SURVEY
- 2021 GROUND SURVEY



CHERRY CREEK CROSS SECTION (STA. 144+00)

(LOOKING DOWNSTREAM)



CHERRY CREEK CROSS SECTION (STA. 166+63)

(LOOKING DOWNSTREAM)

NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL
PROVIDED BY HKS FOR 2020
PERIMETER ROAD SURVEY

MULLER ENGINEERING COMPANY
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

MAIN CHANNEL CROSS SECTIONS

DATE 2/4/2022

DRAWING NO. XS-4

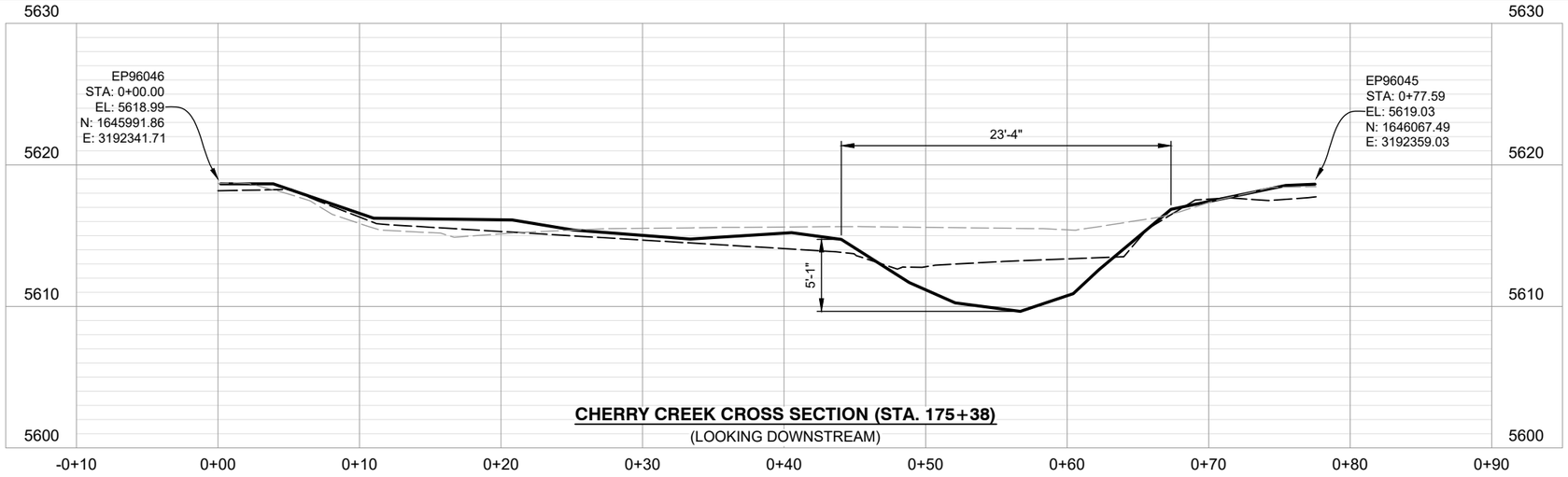
SHEET NO. 4 OF 6

0' 100' 200' (HORIZ.)

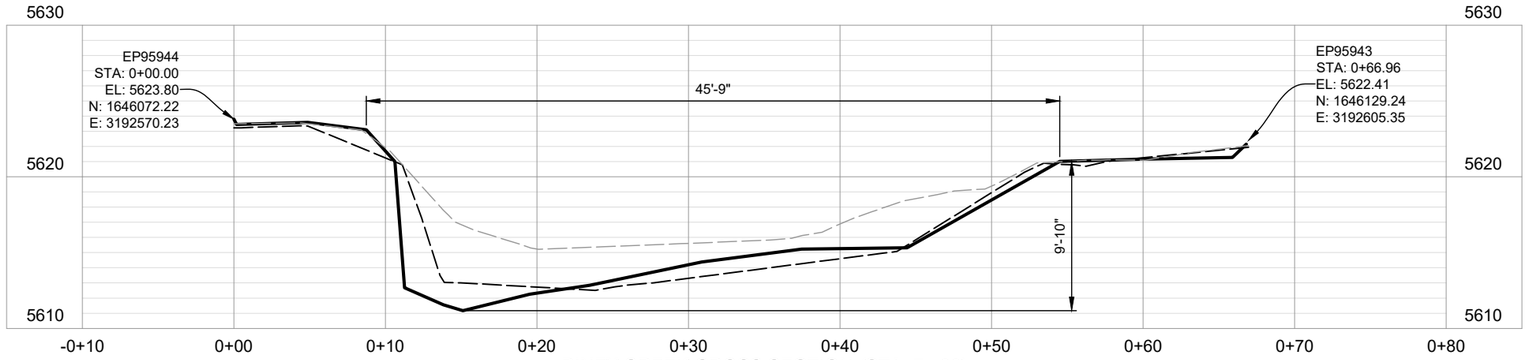
0' 5' 10' (VERT.)

LEGEND - CHANNEL SECTIONS

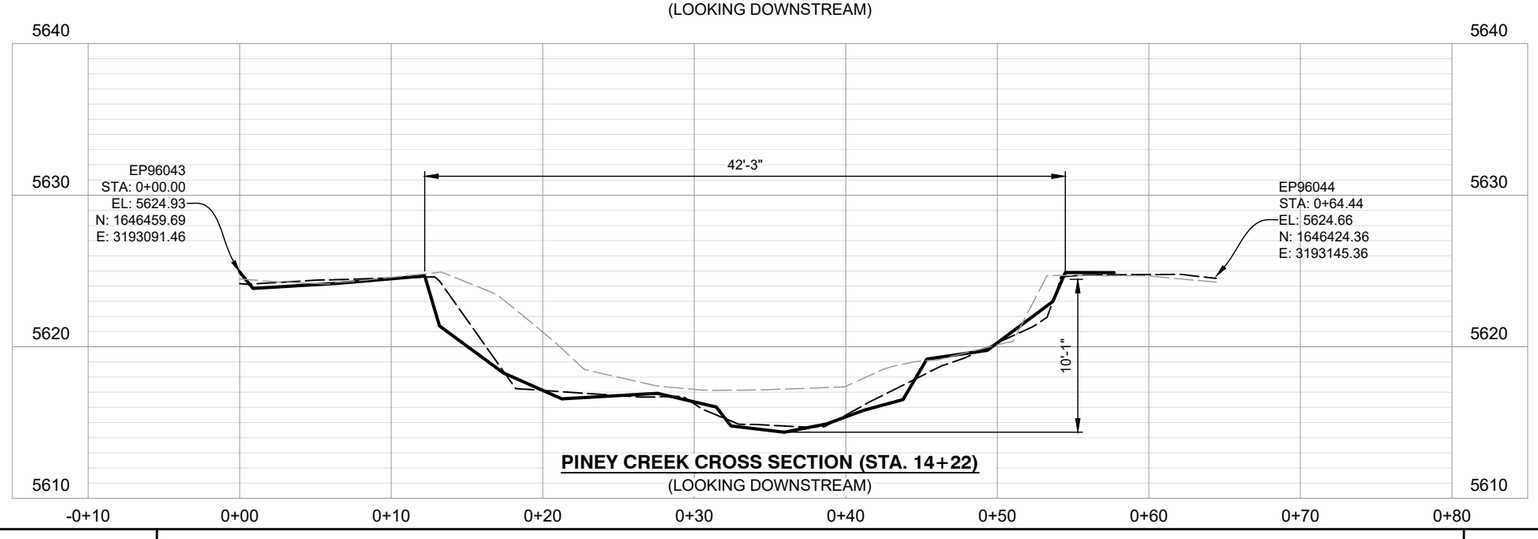
- 2013 LIDAR
- 2021 DRONE SURVEY
- 2021 GROUND SURVEY



CHERRY CREEK CROSS SECTION (STA. 175+38)
(LOOKING DOWNSTREAM)



PINEY CREEK CROSS SECTION (STA. 7+29)
(LOOKING DOWNSTREAM)



PINEY CREEK CROSS SECTION (STA. 14+22)
(LOOKING DOWNSTREAM)

NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL
PROVIDED BY HKS FOR 2020
PERIMETER ROAD SURVEY

MULLER ENGINEERING COMPANY
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

MAIN CHANNEL CROSS SECTIONS

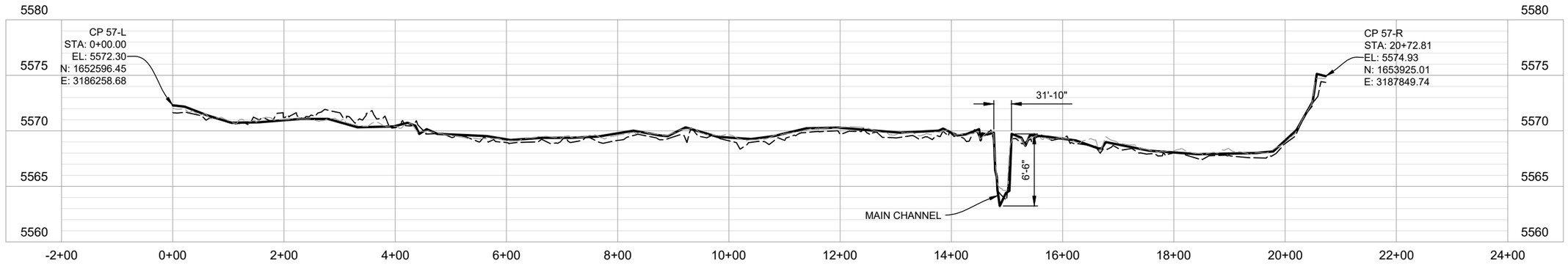
DATE: 2/4/2022
DRAWING NO.: XS-5
SHEET NO.: 5 OF 6

0' 100' 200' (HORIZ.)

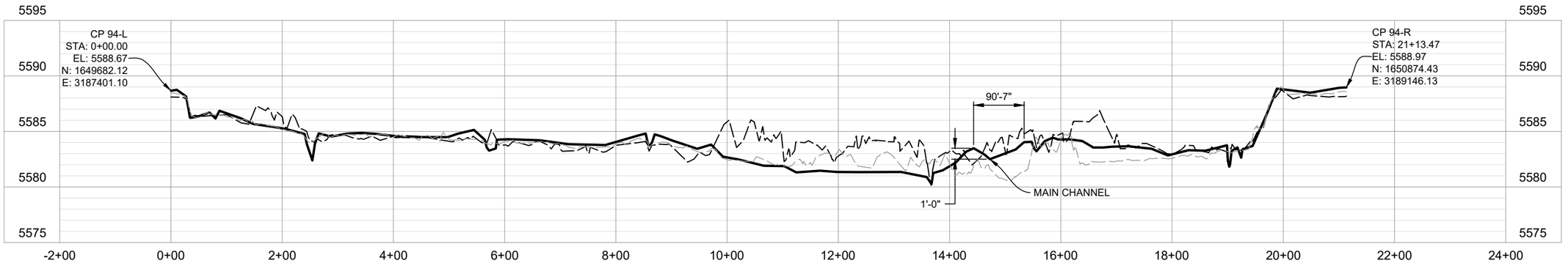
0' 5' 10' (VERT.)

LEGEND - CHANNEL SECTIONS

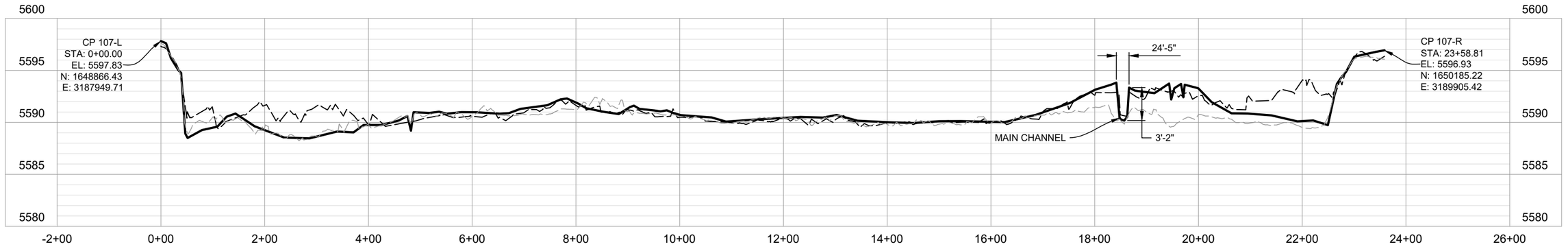
— — 2013 LIDAR
– – 2021 DRONE SURVEY
——— 2021 GROUND SURVEY



CHERRY CREEK CROSS SECTION (STA. 57+48)
(LOOKING DOWNSTREAM)



CHERRY CREEK CROSS SECTION (STA. 94+06)
(LOOKING DOWNSTREAM)



CHERRY CREEK CROSS SECTION (STA. 107+27)
(LOOKING DOWNSTREAM)

NOTE:

VERTICAL DATUM: USACE DATUM
USACE DATUM = NAVD88 - 1.38 FT
BASED ON SURVEY CONTROL
PROVIDED BY HKS FOR 2020
PERIMETER ROAD SURVEY

MULLER ENGINEERING COMPANY
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

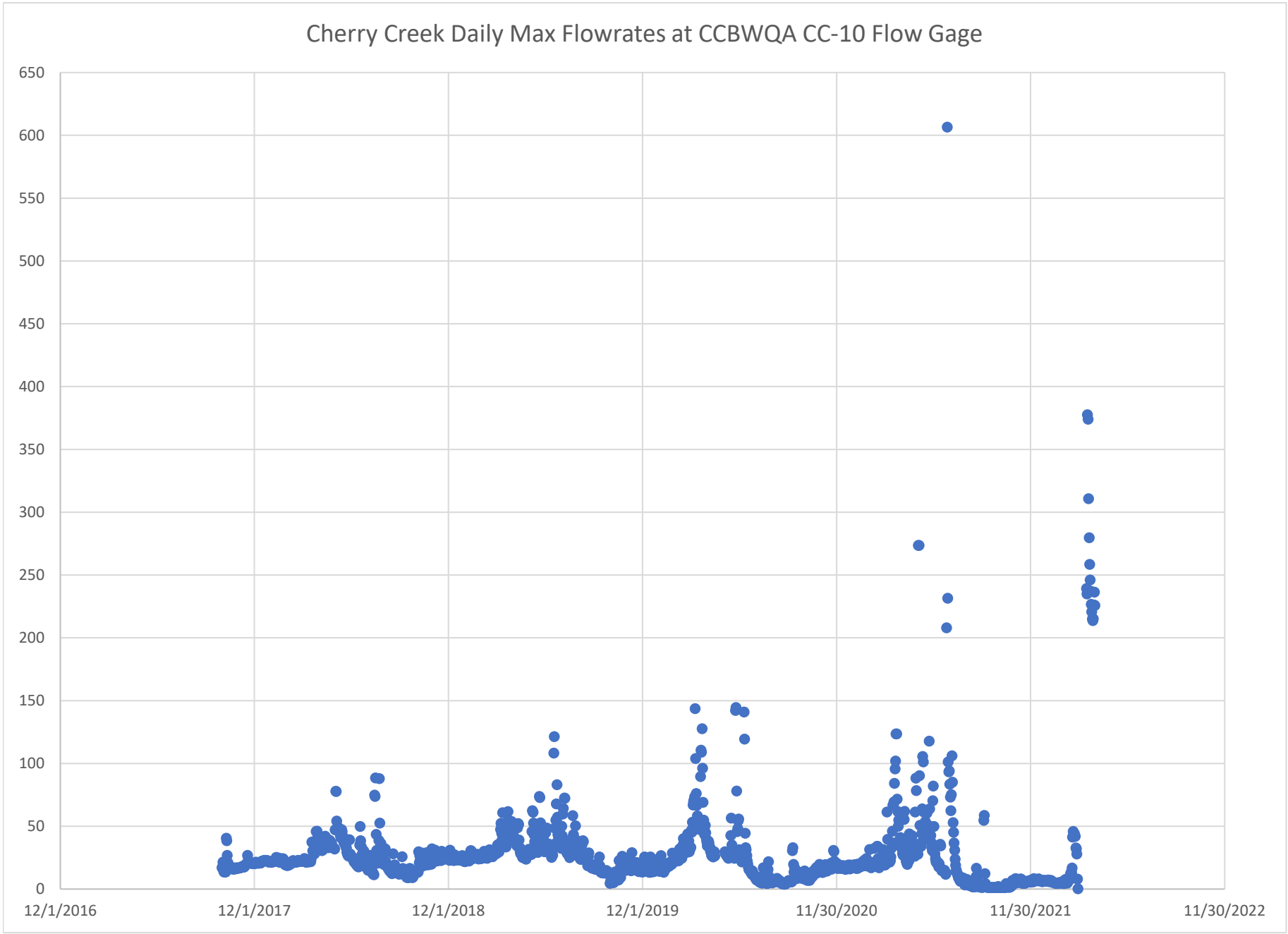
CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

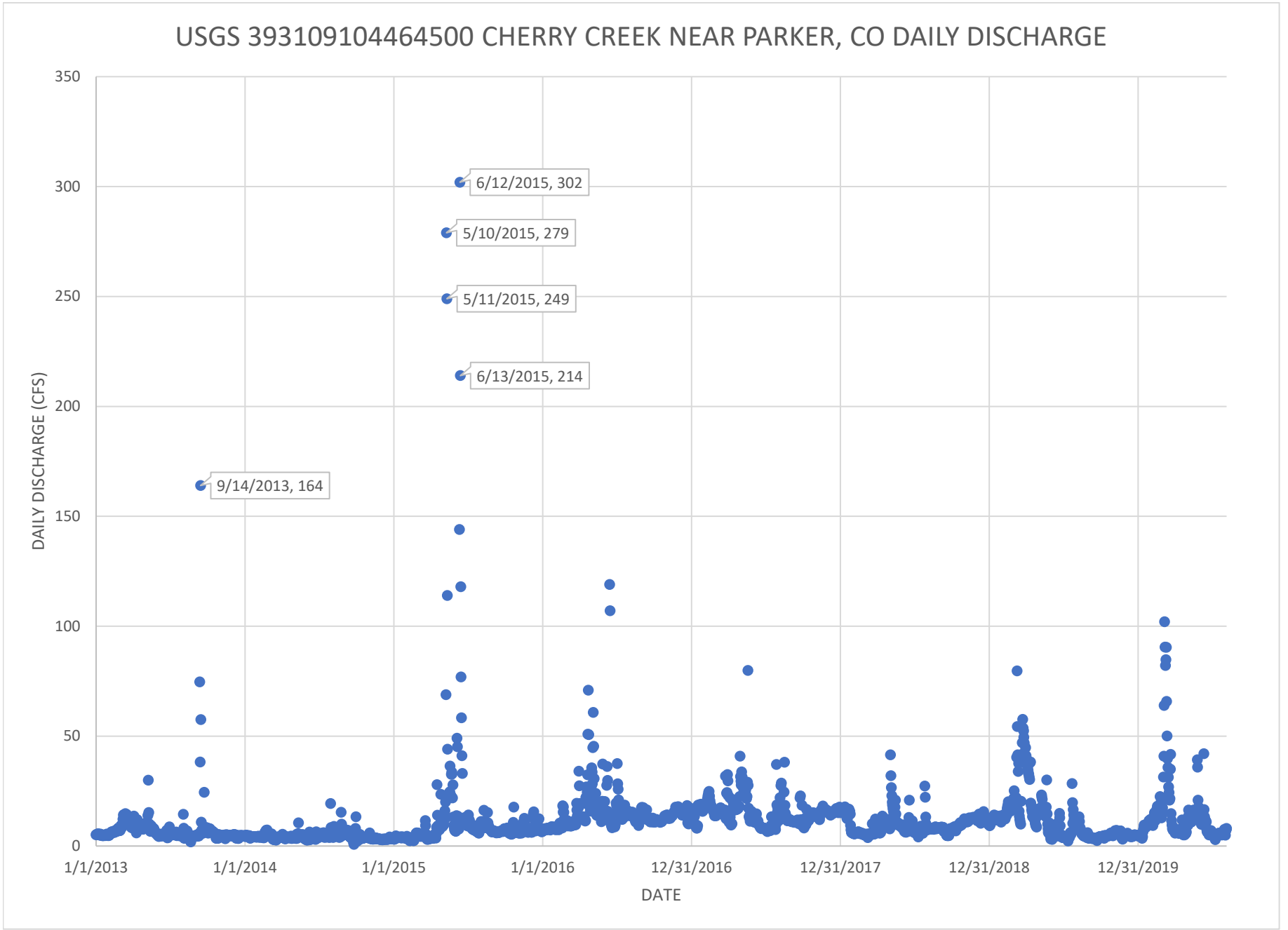
VALLEY WIDE CHANNEL CROSS SECTIONS

DATE 2/4/2022
DRAWING NO. XS-6
SHEET NO. 6 OF 6

Appendix C: Peak Streamflow

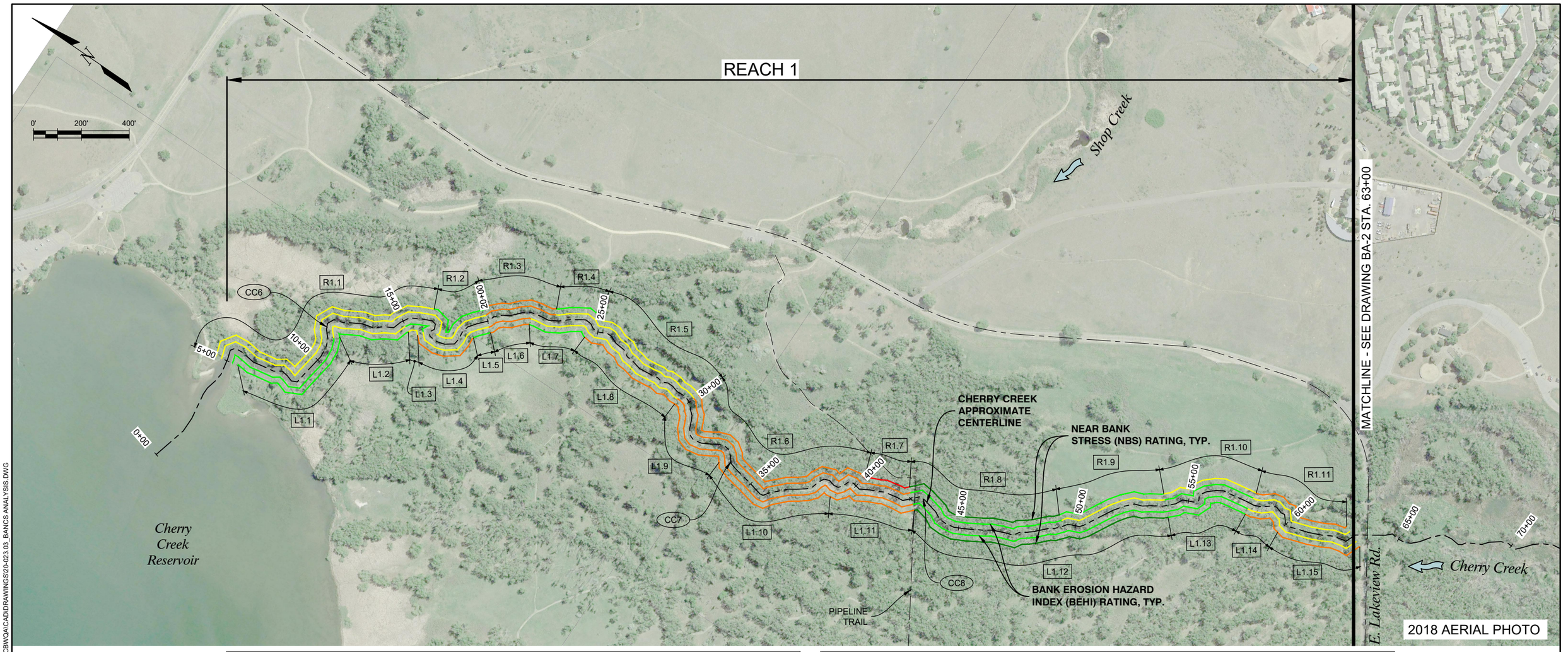
- CCBWQA CC-10 Stream Gage Data Plot
    - Parker Stream Gage Data Plot


Cherry Creek Daily Max Flowrates at CCBWQA CC-10 Flow Gage
650
600
550
500
450
400
350
300
250
200
150
100
50
0
12/1/2016
12/1/2017
12/1/2018
12/1/2019
11/30/2020
11/30/2021
11/30/2022


USGS 393109104464500 CHERRY CREEK NEAR PARKER, CO DAILY DISCHARGE
DAILY DISCHARGE (CFS)
350
300
250
200
150
100
50
0
6/12/2015, 302
5/10/2015, 279
5/11/2015, 249
6/13/2015, 214
9/14/2013, 164
1/1/2013
1/1/2014
1/1/2015
1/1/2016
12/31/2016
12/31/2017
12/31/2018
12/31/2019
DATE

Appendix D: BANCS Analysis

- BANCS Summary Plan Sheets
  - BEHI worksheets
  - NBS worksheets



LEGEND

Bank ID L1.1

Calibration Bank CC1

BEHI and NBS Ratings:

- Very Low
- Low
- Moderate
- High
- Very High
- Extreme

Summary of Bank Information: River Left

Reach	Bank ID	Bank Stationing		BEHI Rating	NBS Ratio	NBS Rating	Lateral Bank Erosion Rate (ft/year)	Length of Bank (ft)	Study Bank Height (ft)	Estimated Annual Soil Loss (ft^3/yr)	Estimated Annual Soil Loss (tons/yr)	Estimated Annual TP Load from Soil Loss (lb/year)
Reach 1	L1.1	5+00	11+50	Low	1.50	Low	0.025	650	4.5	72	3	2
	L1.2	11+50	15+00	Moderate	1.50	Low	0.119	350	4.5	187	7	4
	L1.3	15+00	16+50	Low	1.67	Moderate	0.028	150	5.0	21	1	0
	L1.4	16+50	19+00	Moderate	1.83	High	0.141	250	5.5	193	7	4
	L1.5	19+00	20+00	Moderate	1.33	Low	0.109	100	4.0	44	2	1
	L1.6	20+00	22+00	High	2.17	High	0.268	200	6.5	349	13	7
	L1.7	22+00	24+25	Moderate	1.50	Low	0.119	225	4.5	120	4	3
	L1.8	24+25	29+50	Moderate	2.00	High	0.153	525	6.0	482	18	10
	L1.9	29+50	33+75	High	2.00	High	0.250	425	6.0	639	24	14
	L1.10	33+75	39+00	High	2.25	High	0.278	525	6.8	985	36	21
	L1.11	39+00	42+50	High	2.33	High	0.288	350	7.0	705	26	15
	L1.12	42+50	54+00	Low	1.00	Very Low	0.017	1150	3.0	59	2	1
	L1.13	54+00	58+00	Low	1.50	Low	0.025	400	4.5	44	2	1
	L1.14	58+00	60+00	Moderate	2.00	High	0.153	200	6.0	183	7	4
	L1.15	60+00	63+00	Moderate	1.83	High	0.141	300	5.5	232	9	5
									Total	4314	160	92

Summary of Bank Information: River Right

Reach	Bank ID	Bank Stationing		BEHI Rating	NBS Ratio	NBS Rating	Lateral Bank Erosion Rate (ft/year)	Length of Bank (ft)	Study Bank Height (ft)	Estimated Annual Soil Loss (ft^3/yr)	Estimated Annual Soil Loss (tons/yr)	Estimated Annual TP Load from Soil Loss (lb/year)
Reach 1	R1.1	5+00	16+25	Moderate	1.67	Moderate	0.129	1125	5.0	726	27	15
	R1.2	16+25	20+00	Moderate	1.33	Low	0.109	375	4.0	164	6	3
	R1.3	20+00	23+00	High	2.17	High	0.268	300	6.5	523	19	11
	R1.4	23+00	24+50	Moderate	1.50	Low	0.119	150	4.5	80	3	2
	R1.5	24+50	30+00	Moderate	1.67	Moderate	0.129	550	5.0	355	13	8
	R1.6	30+00	40+00	High	2.00	High	0.250	1000	6.0	1503	56	32
	R1.7	40+00	42+50	High	2.83	Very High	0.354	250	8.5	753	28	16
	R1.8	42+50	49+50	Low	1.00	Very Low	0.017	700	3.0	36	1	1
	R1.9	49+50	54+00	Moderate	1.50	Low	0.119	450	4.5	240	9	5
	R1.10	54+00	58+00	Low	1.67	Moderate	0.028	486	5.0	68	3	1
	R1.11	58+00	63+00	Moderate	1.83	High	0.141	414	5.5	320	12	7
									Total	4768	177	101

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CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

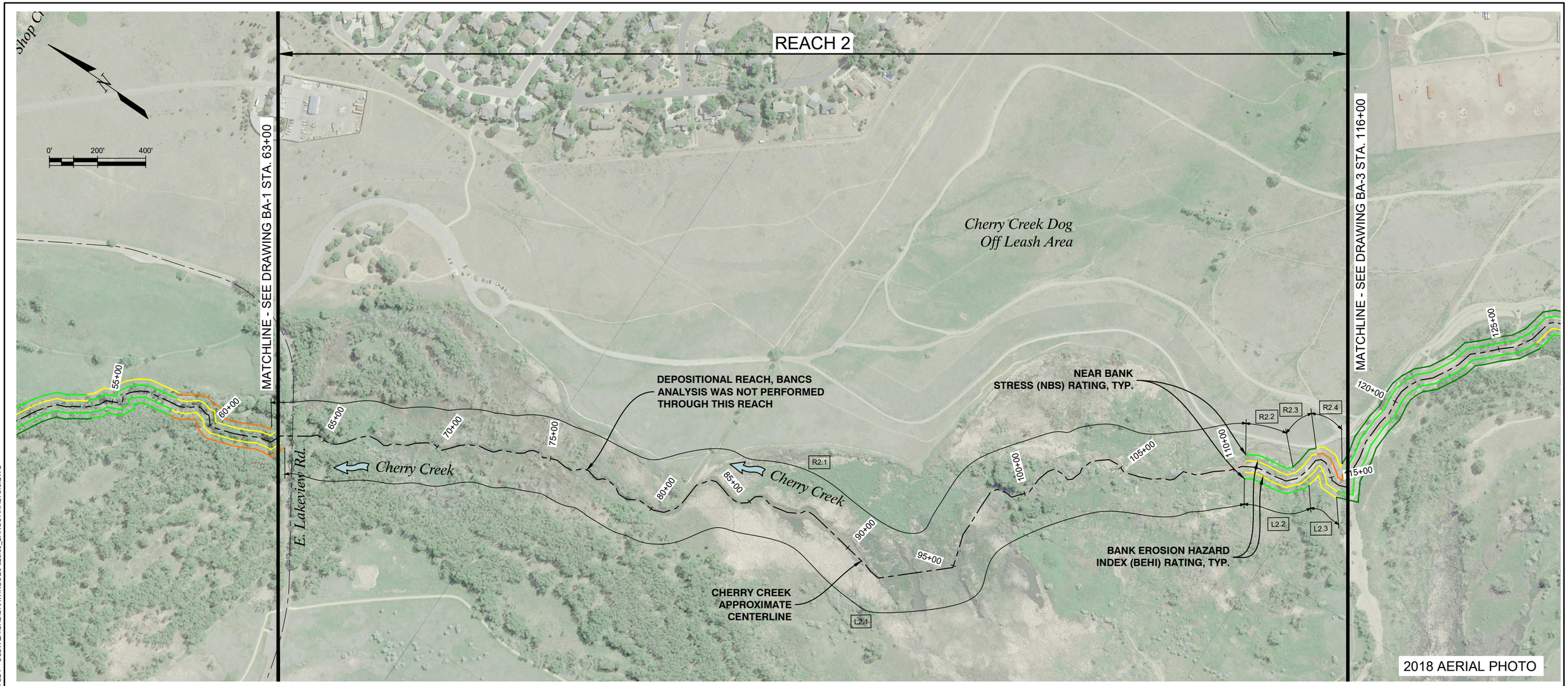
BANCS ANALYSIS REACH 1

DATE 2/4/2022

DRAWING NO. BA-1

SHEET NO. 1 OF 4

PLOTTED: 4/1/2022 3:46:20 PM
NAME: \\PERTH\PROJECTS\2020 PROJECTS\20-023.03 CHERRY CREEK STUDY - RES TO 12 MILE STUDY - CCBWQA\CAD\DRAWINGS\20-023.03_BANCS ANALYSIS.DWG



LEGEND

Bank ID — L1.1

Calibration Bank — CC1

BEHI and NBS Ratings:

- Very Low
- Low
- Moderate
- High
- Very High
- Extreme

Summary of Bank Information: River Left

Reach	Bank ID	Bank Stationing		BEHI Rating	NBS Ratio	NBS Rating	Lateral Bank Erosion Rate (ft/year)	Length of Bank (ft)	Study Bank Height (ft)	Estimated Annual Soil Loss (ft^3/yr)	Estimated Annual Soil Loss (tons/yr)	Estimated Annual TP Load from Soil Loss (lb/year)
Reach 2	L2.1	63+00	110+50	DEPOSITIONAL REACH - NOT RATED								
	L2.2	110+50	113+00	Moderate	1.33	Low	0.109	250	4.0	109	4	2
	L2.3	113+00	116+00	Moderate	1.67	Moderate	0.129	300	5.0	194	7	4
									Total	303	11	6

Summary of Bank Information: River Right

Reach	Bank ID	Bank Stationing		BEHI Rating	NBS Ratio	NBS Rating	Lateral Bank Erosion Rate (ft/year)	Length of Bank (ft)	Study Bank Height (ft)	Estimated Annual Soil Loss (ft^3/yr)	Estimated Annual Soil Loss (tons/yr)	Estimated Annual TP Load from Soil Loss (lb/year)
Reach 2	R2.1	63+00	110+50	DEPOSITIONAL REACH - NOT RATED								
	R2.2	110+50	113+00	Moderate	1.33	Low	0.109	250	4.0	109	4	2
	R2.3	113+00	114+00	Moderate	1.00	Very Low	0.092	100	3.0	28	1	1
	R2.4	114+00	116+00	High	1.67	Moderate	0.218	200	5.0	218	8	5
									Total	355	13	8

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CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

BANCS ANALYSIS REACH 2

DATE 2/4/2022

DRAWING NO. BA-2

SHEET NO. 2 OF 4

PLOTTED: 4/1/2022 3:46:22 PM
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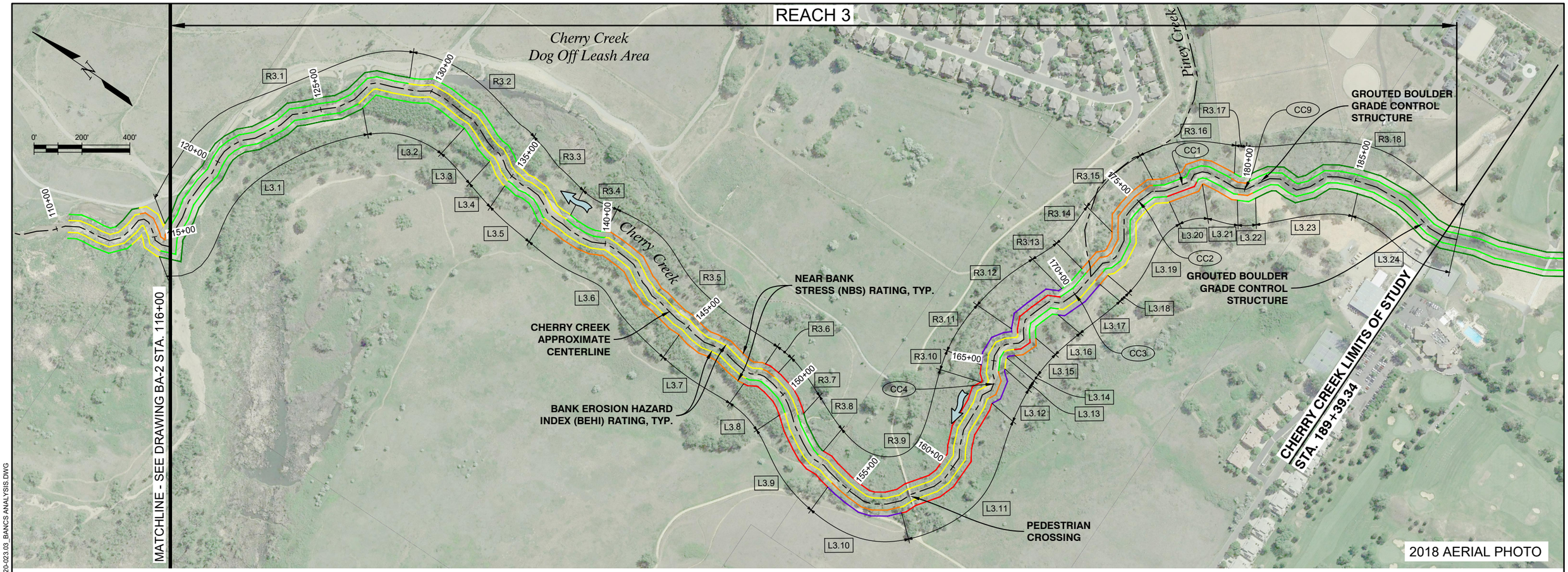

LEGEND

Bank ID — L1.1

Calibration Bank — CC1

BEHI and NBS Ratings:

- Very Low
- Low
- Moderate
- High
- Very High
- Extreme

Summary of Bank Information: River Left

Reach	Bank ID	Bank Stationing		BEHI Rating	NBS Ratio	NBS Rating	Lateral Bank Erosion Rate (ft/year)	Length of Bank (ft)	Study Bank Height (ft)	Estimated Annual Soil Loss (ft^3/yr)	Estimated Annual Soil Loss (tons/yr)	Estimated Annual TP Load from Soil Loss (lb/year)
Reach 3	L3.1	116+00	126+50	Low	1.00	Very Low	0.017	1050	3.0	54	2	1
	L3.2	126+50	132+00	Moderate	1.33	Low	0.109	550	4.0	240	9	5
	L3.3	132+00	134+00	Moderate	1.50	Low	0.119	200	4.5	107	4	2
	L3.4	134+00	135+00	Moderate	1.67	Moderate	0.129	100	5.0	65	2	1
	L3.5	135+00	137+25	Low	1.50	Low	0.025	225	4.5	25	1	1
	L3.6	137+25	145+00	Moderate	2.00	High	0.153	775	6.0	711	26	15
	L3.7	145+00	148+25	Moderate	2.33	High	0.181	325	7.0	412	15	9
	L3.8	148+25	150+75	Low	2.67	Very High	0.058	250	8.0	116	4	2
	L3.9	150+75	154+25	Moderate	2.67	Very High	0.214	350	8.0	600	22	13
	L3.10	154+25	157+25	High	5.00	Extreme	0.872	300	15.0	3924	145	83
	L3.11	157+25	163+50	Moderate	3.00	Very High	0.253	625	9.0	1426	53	30
	L3.12	163+50	164+50	High	3.17	Extreme	0.407	100	9.5	386	14	8
	L3.13	164+50	165+75	Low	1.67	Moderate	0.028	125	5.0	17	1	0
	L3.14	165+75	166+25	Moderate	3.17	Extreme	0.276	50	9.5	131	5	3
	L3.15	166+25	166+75	Very High	2.17	High	0.268	50	6.5	87	3	2
	L3.16	166+75	169+25	Low	1.50	Low	0.025	250	4.5	28	1	1
	L3.17	169+25	171+00	Moderate	3.17	Extreme	0.276	175	9.5	458	17	10
	L3.18	171+00	171+50	High	2.33	High	0.288	50	7.0	101	4	2
	L3.19	171+50	176+25	Low	1.67	Moderate	0.028	475	5.0	66	2	1
	L3.20	176+25	177+50	Very High	2.17	High	0.268	125	6.5	218	8	5
	L3.21	177+50	179+75	Low	1.83	High	0.032	225	5.5	39	1	1
	L3.22	179+75	180+25	High	1.33	Low	0.190	50	4.0	38	1	1
	L3.23	180+25	185+25	Low	0.67	Very Low	0.013	500	2.0	13	0	0
	L3.24	185+25	190+00	Low	0.50	Very Low	0.012	475	1.5	8	0	0
									Total	9271	343	197

Summary of Bank Information: River Right

Reach	Bank ID	Bank Stationing		BEHI Rating	NBS Ratio	NBS Rating	Lateral Bank Erosion Rate (ft/year)	Length of Bank (ft)	Study Bank Height (ft)	Estimated Annual Soil Loss (ft^3/yr)	Estimated Annual Soil Loss (tons/yr)	Estimated Annual TP Load from Soil Loss (lb/year)
Reach 3	R3.1	116+00	129+00	Low	1.00	Very Low	0.017	1300	3.0	67	2	1
	R3.2	129+00	135+00	Moderate	1.50	Low	0.119	600	4.5	321	12	7
	R3.3	135+00	138+00	Moderate	1.67	Moderate	0.129	300	5.0	194	7	4
	R3.4	138+00	140+00	Low	1.50	Low	0.025	200	4.5	22	1	0
	R3.5	140+00	148+75	Moderate	2.33	High	0.181	875	7.0	1108	41	24
	R3.6	148+75	149+25	High	2.67	Very High	0.330	50	8.0	132	5	3
	R3.7	149+25	151+00	Moderate	2.67	Very High	0.214	175	8.0	300	11	6
	R3.8	151+00	153+00	Low	1.00	Very Low	0.017	200	3.0	10	0	0
	R3.9	153+00	163+50	Moderate	3.00	Very High	0.253	1050	9.0	2395	89	51
	R3.10	163+50	164+25	Moderate	2.67	Very High	0.214	75	8.0	128	5	3
	R3.11	164+25	167+00	Moderate	3.17	Extreme	0.276	275	9.5	720	27	15
	R3.12	167+00	169+25	Very High	3.17	Extreme	0.407	225	9.5	870	32	18
	R3.13	169+25	171+00	Low	1.33	Low	0.022	175	4.0	15	1	0
	R3.14	171+00	173+50	High	2.33	High	0.288	250	7.0	503	19	11
	R3.15	173+50	175+75	High	2.33	High	0.288	225	7.0	453	17	10
	R3.16	175+75	179+25	Low	1.83	High	0.032	350	5.5	61	2	1
	R3.17	179+25	180+25	High	1.33	Low	0.190	100	4.0	76	3	2
	R3.18	180+25	190+00	Low	0.50	Very Low	0.012	975	1.5	17	1	0
									Total	7393	274	157

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CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

BANCS ANALYSIS REACH 3

DATE 2/4/2022

DRAWING NO. BA-3

SHEET NO. 3 OF 4

PLOTTED: 4/1/2022 3:46:25 PM
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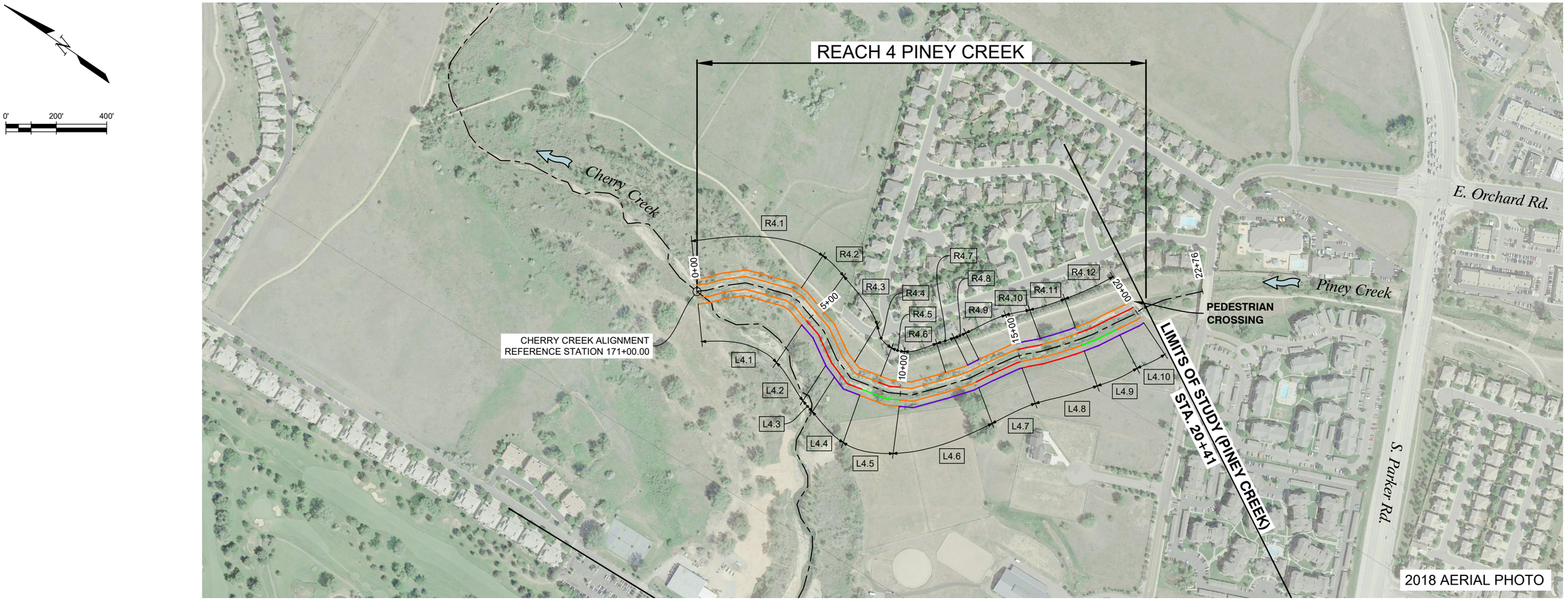


LEGEND

Bank ID L1.1

Calibration Bank CC1

BEHI and NBS Ratings:

- Very Low
- Low
- Moderate
- High
- Very High
- Extreme

Summary of Bank Information: River Left

Reach	Bank ID	Bank Stationing		BEHI Rating	NBS Ratio	NBS Rating	Lateral Bank Erosion Rate (ft/year)	Length of Bank (ft)	Study Bank Height (ft)	Estimated Annual Soil Loss (ft^3/yr)	Estimated Annual Soil Loss (tons/yr)	Estimated Annual TP Load from Soil Loss (lb/year)
Reach 4	L4.1	0+00	5+00	High	2.33	High	0.288	500	7.0	1007	37	21
	L4.2	5+00	7+00	Very High	3.17	Extreme	0.407	200	9.5	773	29	16
	L4.3	7+00	7+50	Very High	4.33	Extreme	0.661	50	13.0	430	16	9
	L4.4	7+50	8+50	Very High	3.17	Extreme	0.407	100	9.5	386	14	8
	L4.5	8+50	10+00	Low	2.33	High	0.046	150	7.0	48	2	1
	L4.6	10+00	13+00	High	3.17	Extreme	0.407	300	9.5	1159	43	25
	L4.7	13+00	15+00	Very High	3.33	Extreme	0.436	200	10.0	872	32	19
	L4.8	15+00	17+50	High	2.67	Very High	0.330	250	8.0	661	24	14
	L4.9	17+50	19+00	Low	4.00	Extreme	0.155	150	12.0	279	10	6
	L4.10	19+00	20+00	High	4.00	Extreme	0.575	100	12.0	690	26	15
									Total	6305	234	134

Summary of Bank Information: River Right

Reach	Bank ID	Bank Stationing		BEHI Rating	NBS Ratio	NBS Rating	Lateral Bank Erosion Rate (ft/year)	Length of Bank (ft)	Study Bank Height (ft)	Estimated Annual Soil Loss (ft^3/yr)	Estimated Annual Soil Loss (tons/yr)	Estimated Annual TP Load from Soil Loss (lb/year)
Reach 4	R4.1	0+00	4+00	High	2.00	High	0.250	400	6.0	601	22	13
	R4.2	4+00	5+00	High	2.33	High	0.288	100	7.0	201	7	4
	R4.3	5+00	7+50	High	2.00	High	0.250	250	6.0	376	14	8
	R4.4	7+50	9+00	High	2.33	High	0.288	150	7.0	302	11	6
	R4.5	9+00	10+00	Very High	2.33	High	0.288	100	7.0	201	7	4
	R4.6	10+00	12+00	High	2.33	High	0.288	200	7.0	403	15	9
	R4.7	12+00	13+00	High	2.00	High	0.250	100	6.0	150	6	3
	R4.8	13+00	13+50	High	3.17	Extreme	0.407	50	9.5	193	7	4
	R4.9	13+50	15+00	High	2.00	High	0.250	150	6.0	225	8	5
	R4.10	15+00	16+00	Very High	3.67	Extreme	0.501	100	11.0	551	20	12
	R4.11	16+00	17+50	High	3.17	Extreme	0.407	150	9.5	580	21	12
	R4.12	17+50	20+00	Very High	2.33	High	0.288	250	7.0	503	19	11
									Total	4287	159	91

MULLER ENGINEERING COMPANY
777 S. WADSWORTH BLVD. 4-100 LAKEWOOD, COLORADO 80226

CHERRY CREEK RESERVOIR TO 12 MILE CHANNEL MONITORING

BANCS ANALYSIS REACH 4

DATE 2/4/2022

DRAWING NO. BA-4

SHEET NO. 4 OF 4

PLOTTED: 4/1/2022 3:46:27 PM
NAME: \\PERTH\PROJECTS\2020 PROJECTS\20-023.03 CHERRY CREEK STUDY - RES TO 12 MILE STUDY - CCBWQA\CAD\DRAWINGS\20-023.03_BANCS ANALYSIS.DWG

Cherry Creek Reservoir to State Park Boundary Channel Monitoring Reference Banks: BEHI Rating Calculations

Reach	Name	Station	Bank Side	Study Bank Height (ft)	Bankfull Height (ft)	Root Depth (ft)	Root Density (%)	Bank Angle (degree)	Surface Protection (%)	Study Bank to Bankfull Height (C)	Root Depth to Study Bank Height (E)	Weighted Root Density (G)	Bank Angle (H)	Surface Protection (I)	(C) BEHI SCORE	(E) BEHI SCORE	(G) BEHI SCORE	(H) BEHI SCORE	(I) BEHI SCORE	Bank Material Adjustment	Total Score	Rating
Reach 1	CC6	11+50	Right	5	3	2.5	75	90	50	1.67	0.5	37.5	90	50	**7**	**3.75**	**5.25**	**7.5**	**4.5**	0	**28**	Moderate
	CC7	33+75	Left	7	3	2	75	90	20	2.33	0.29	21.43	90	20	**8.5**	**6.5**	**2.5**	**8**	**7**	0	**32.5**	High
	CC8	43+00	Left/Right	3.3	3	2	75	90	90	1.10	0.61	45.45	90	90	**1.5**	**3.5**	**2.5**	**8**	**1**	0	**16.5**	Low
	CC9	180+00	Left/Right	4	3	1	25	90	20	1.33	0.25	6.25	90	20	**4**	**6.5**	**9**	**8**	**7**	0	**34.5**	High
Reach 3	CC1	177+00	Left	6.5	3	1	50	90	20	2.17	0.15	7.69	90	20	**10**	**7.5**	**4.5**	**8**	**7**	5	**42**	Very High
	CC2	175+00	Right	7	3	1	75	45	50	2.33	0.14	10.71	45	50	**8.5**	**7.5**	**2.5**	**3**	**4.5**	5	**31**	High
	CC3	170+00	Left	9.5	3	2.5	75	51	90	3.17	0.26	19.74	51	90	**9.5**	**6.5**	**2.5**	**3.5**	**1**	0	**23**	Moderate
	CC4	164+00	Right	8	3	2	75	35	50	2.67	0.25	18.75	35	50	**9**	**6.5**	**2.5**	**3**	**4.5**	5	**30.5**	High
Reach 4	PC1	18+75	Right	7	3	1	50	90	20	2.33	0.14	7.14	90	20	**8.5**	**7.5**	**4.5**	**8**	**7**	5	**40.5**	Very High
	PC2	16+75	Right	9.5	3	1	75	45	75	3.17	0.11	7.89	45	75	**10**	**8.5**	**2.5**	**3**	**2.5**	5	**31.5**	High
	PC3	14+25	Right	6	3	1	75	90	20	2.00	0.17	12.50	90	20	**8**	**7.5**	**2.5**	**8**	**7**	5	**38**	High
	PC4	11+00	Right	7	3	1	75	30	50	2.33	0.14	10.71	35	50	**8.5**	**8**	**8.5**	**2.5**	**4.5**	0	**32**	High

Cherry Creek Reservoir to State Park Boundary Channel Monitoring Near-Bank Stress (NBS) Estimation : Method 5

Left Bank

Reach	Bank ID	Starting Station	Ending Station	Near-Bank Max Depth (ft)	Mean Depth (ft)	Ratio	Near-Bank Stress
Reach 1	L1.1	10+00	11+50	4.5	3	1.5	Low
	L1.2	11+50	15+00	4.5	3	1.5	Low
	L1.3	15+00	16+50	5	3	1.67	Moderate
	L1.4	16+50	19+00	5.5	3	1.83	High
	L1.5	19+00	20+00	4	3	1.33	Low
	L1.6	20+00	22+00	6.5	3	2.17	High
	L1.7	22+00	24+25	4.5	3	1.5	Low
	L1.8	24+25	29+50	6	3	2	High
	L1.9	29+50	33+75	6	3	2	High
	L1.10	33+75	39+00	6.75	3	2.25	High
	L1.11	39+00	42+50	7	3	2.33	High
	L1.12	42+50	54+00	3	3	1.00	Very Low
	L1.13	54+00	58+00	4.5	3	1.5	Low
	L1.14	58+00	60+00	6	3	2	High
	L1.15	60+00	63+00	5.5	3	1.83	High

Right Bank

Reach	Bank ID	Starting Station	Ending Station	Near-Bank Max Depth (ft)	Mean Depth (ft)	Ratio	Near-Bank Stress
Reach 1	R1.1	11+25	16+25	5	3	1.67	Moderate
	R1.2	16+25	20+00	4	3	1.33	Low
	R1.3	20+00	23+00	6.5	3	2.17	High
	R1.4	23+00	24+50	4.5	3	1.50	Low
	R1.5	24+50	30+00	5	3	1.67	Moderate
	R1.6	30+00	40+00	6	3	2.00	High
	R1.7	40+00	42+50	8.5	3	2.83	Very High
	R1.8	42+50	49+50	3	3	1	Very Low
	R1.9	49+50	54+00	4.5	3	1.5	Low
	R1.10	54+00	58+00	5	3	1.67	Moderate
	R1.11	58+00	63+00	5.5	3	1.83	High

Reach	Bank ID	Starting Station	Ending Station	Near-Bank Max Depth (ft)	Mean Depth (ft)	Ratio	Near-Bank Stress
Reach 2	L2.1	63+00	110+50	N/A	--	--	--
	L2.2	110+50	113+00	4	3	1.33	Low
	L2.3	113+00	115+50	5	3	1.67	Moderate

Reach	Bank ID	Starting Station	Ending Station	Near-Bank Max Depth (ft)	Mean Depth (ft)	Ratio	Near-Bank Stress
Reach 2	R2.1	63+00	110+50	N/A	--	--	--
	R2.2	110+50	113+00	4	3	1.33	Low
	R2.3	113+00	114+00	3	3	1.00	Very Low
	R2.4	114+00	116+00	5	3	1.67	Moderate

Cherry Creek Reservoir to State Park Boundary Channel Monitoring Near-Bank Stress (NBS) Estimation : Method 5

Left Bank

Reach	Bank ID	Starting Station	Ending Station	Near-Bank Max Depth (ft)	Mean Depth (ft)	Ratio	Near-Bank Stress
Reach 3	L3.1	115+50	126+50	3	3	1.00	Very Low
	L3.2	126+50	132+00	4	3	1.33	Low
	L3.3	132+00	134+00	4.5	3	1.50	Low
	L3.4	134+00	135+00	5	3	1.67	Moderate
	L3.5	135+00	137+25	4.5	3	1.50	Low
	L3.6	137+25	145+00	6	3	2.00	High
	L3.7	145+00	148+25	7	3	2.33	High
	L3.8	148+25	150+75	8	3	2.67	Very High
	L3.9	150+75	154+25	8	3	2.67	Very High
	L3.10	154+25	157+25	15	3	5.00	Extreme
	L3.11	157+25	163+50	9	3	3.00	Very High
	L3.12	163+50	164+50	9.5	3	3.17	Extreme
	L3.13	164+50	165+75	5	3	1.67	Moderate
	L3.14	165+75	166+25	9.5	3	3.17	Extreme
	L3.15	166+25	166+75	6.5	3	2.17	High
	L3.16	166+75	169+25	4.5	3	1.50	Low
	L3.17	169+25	171+00	9.5	3	3.17	Extreme
	L3.18	171+00	171+50	7	3	2.33	High
	L3.19	171+50	176+25	5	3	1.67	Moderate
	L3.20	176+25	177+50	6.5	3	2.17	High
	L3.21	177+50	179+75	5.5	3	1.83	High
	L3.22	179+75	180+25	4	3	1.33	Low
	L3.23	180+25	185+25	2	3	0.67	Very Low
	L3.24	185+25	190+00	1.5	3	0.50	Very Low

Right Bank

Reach	Bank ID	Starting Station	Ending Station	Near-Bank Max Depth (ft)	Mean Depth (ft)	Ratio	Near-Bank Stress
Reach 3	R3.1	116+00	129+00	3	3	1.00	Very Low
	R3.2	129+00	135+00	4.5	3	1.50	Low
	R3.3	135+00	138+00	5	3	1.67	Moderate
	R3.4	138+00	140+00	4.5	3	1.50	Low
	R3.5	140+00	148+75	7	3	2.33	High
	R3.6	148+75	149+25	8	3	2.67	Very High
	R3.7	149+25	151+00	8	3	2.67	Very High
	R3.8	151+00	153+00	3	3	1.00	Very Low
	R3.9	153+00	163+50	9	3	3.00	Very High
	R3.10	163+50	164+25	8	3	2.67	Very High
	R3.11	164+25	167+00	9.5	3	3.17	Extreme
	R3.12	167+00	169+25	9.5	3	3.17	Extreme
	R3.13	169+25	171+00	4	3	1.33	Low
	R3.14	171+00	173+50	7	3	2.33	High
	R3.15	173+50	175+75	7	3	2.33	High
	R3.16	175+75	179+25	5.5	3	1.83	High
	R3.17	179+25	180+25	4	3	1.33	Low
	R3.18	180+25	190+00	1.5	3	0.50	Very Low

Cherry Creek Reservoir to State Park Boundary Channel Monitoring Near-Bank Stress (NBS) Estimation : Method 5

Left Bank

Reach	Bank ID	Starting Station	Ending Station	Near-Bank Max Depth (ft)	Mean Depth (ft)	Ratio	Near-Bank Stress
Reach 4	L4.1	0+00	5+00	7	3	2.33	High
	L4.2	5+00	7+00	9.5	3	3.17	Extreme
	L4.3	7+00	7+50	13	3	4.33	Extreme
	L4.4	7+50	8+50	9.5	3	3.17	Extreme
	L4.5	8+50	10+00	7	3	2.33	High
	L4.6	10+00	13+00	9.5	3	3.17	Extreme
	L4.7	13+00	15+00	10	3	3.33	Extreme
	L4.8	15+00	17+50	8	3	2.67	Very High
	L4.9	17+50	19+00	12	3	4.00	Extreme
	L4.10	19+00	20+00	12	3	4.00	Extreme

Right Bank

Reach	Bank ID	Starting Station	Ending Station	Near-Bank Max Depth (ft)	Mean Depth (ft)	Ratio	Near-Bank Stress
Reach 4	R4.1	0+00	4+00	6	3	2.00	High
	R4.2	4+00	5+00	7	3	2.33	High
	R4.3	5+00	7+50	6	3	2.00	High
	R4.4	7+50	9+00	7	3	2.33	High
	R4.5	9+00	10+00	7	3	2.33	High
	R4.6	10+00	12+00	7	3	2.33	High
	R4.7	12+00	13+00	6	3	2.00	High
	R4.8	13+00	13+50	9.5	3	3.17	Extreme
	R4.9	13+50	15+00	6	3	2.00	High
	R4.10	15+00	16+00	11	3	3.67	Extreme
	R4.11	16+00	17+50	9.5	3	3.17	Extreme
	R4.12	17+50	20+00	7	3	2.33	High

Worksheet 3-11. Form to calculate an overall Bank Erosion Hazard Index (BEHI) rating. Use **Figure 3-7** to determine individual BEHI scores.

Bank Erosion Hazard Index (BEHI)

Stream: **Teton Creek** Location: **Idaho (the state)**

Station: Observers: **Team 1**

Date: **7/25/2019** Stream Type: **C4** Landscape Type: **U-LA_LD**

BEHI Score (Fig. 3-7)

Study Bank Height to Bankfull Height (C)

Study Bank Height (ft) =	(A)	Bankfull Height (ft) =	(B)	(A) / (B) =	(C)	

Root Depth to Study Bank Height (E)

Root Depth (ft) =	(D)	Study Bank Height (ft) =	(A)	(D) / (A) =	(E)	

Weighted Root Density (G)

Root Density as % =	(F)	(F) × (E) =	(G)	

Bank Angle (H)

Bank Angle as *Degrees* =	(H)	

Surface Protection (I)

Surface Protection as % =	(I)	

Bank Material Adjustment:

Bedrock (Overall *Very Low* BEHI)

Boulders (Overall *Low* BEHI)

Cobble (Subtract 10 points if uniform medium to large cobble)

Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)

Sand (Add 10 points)

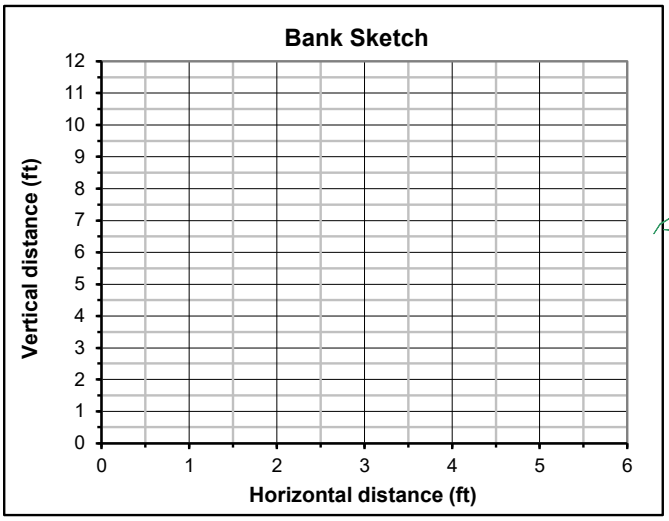
Silt/Clay (Add 10 points if uniform silt; No adjustment if silt with a mixture of clay; Subtract 10 points if silt/clay mixture with high % of clay; Subtract 20 points if clay)

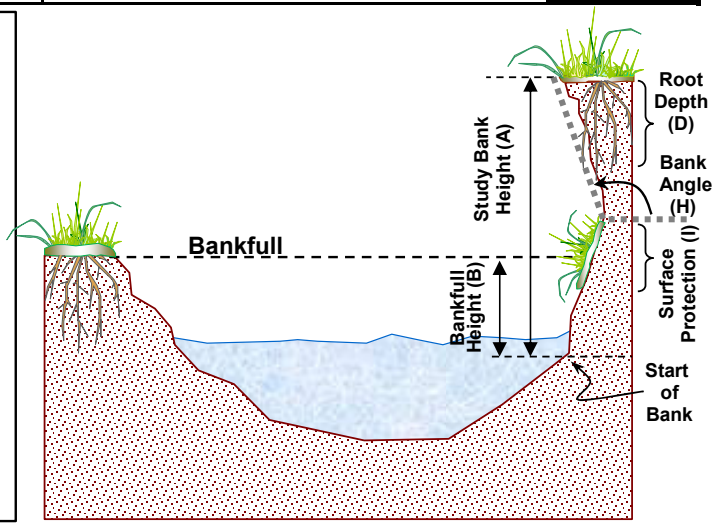
Bank Material Adjustment

Stratification Adjustment

Add 5–10 points, depending on position of unstable layers in relation to bankfull stage

Very Low	*Low*	*Moderate*	*High*	*Very High*	*Extreme*	**Adjective Rating** and **Total Score**
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	





Worksheet 3-11. Form to calculate an overall Bank Erosion Hazard Index (BEHI) rating. Use **Figure 3-7** to determine individual BEHI scores.

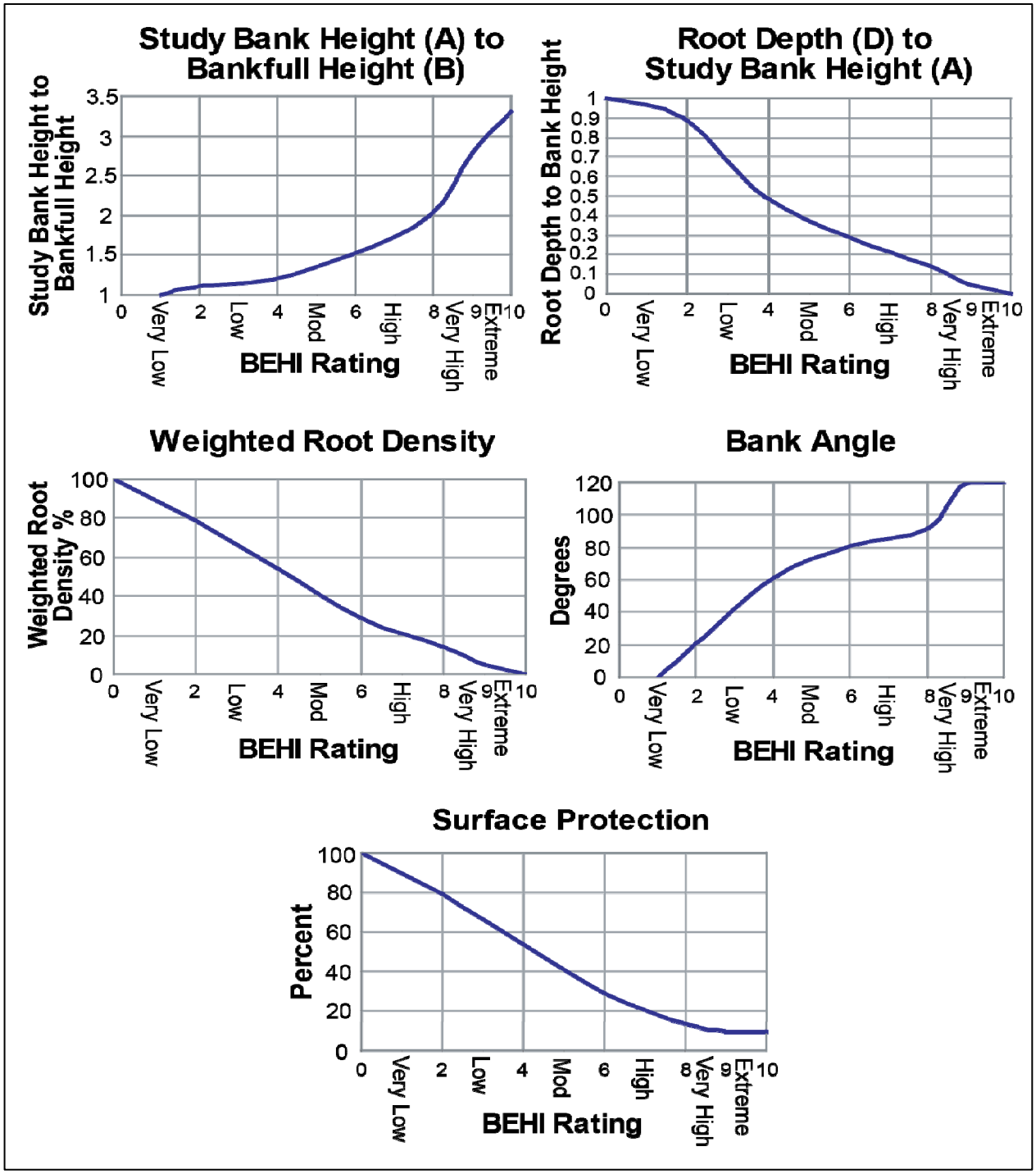


Figure 3-7. Streambank erodibility criteria showing conversion of measured ratios and bank variables to a BEHI rating (Rosgen, 1996, 2001b, 2006b). Use **Worksheet 3-11** to determine BEHI score.

Worksheet 3-12. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate an erosion rate.

Methods for Estimating Near-Bank Stress (NBS)		
(1) Channel pattern, transverse bar, or central bar creating NBS	Level I	Reconaissance
(2) Radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General Prediction
(3) Pool slope to average water surface slope (S_p / S)	Level II	General Prediction
(4) Pool slope to riffle slope (S_p / S_{rif})	Level II	General Prediction
(5) Near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed Prediction
(6) Near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed Prediction
(7) Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I — **(1)**

Transverse or central bars - short or discontinuous……..…… ……..…**NBS = *High* / *Very High***
Extensive deposition (continuous, cross-channel)……..……..……..…**NBS = *Extreme***
Chute cutoffs, down-valley meander migration, converging flow……..…**NBS = *Extreme***

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	**Near-Bank Stress (NBS)**

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	**Near-Bank Stress (NBS)**

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	**Near-Bank Stress (NBS)**

Dominant Near-Bank Stress

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	**Near-Bank Stress (NBS)**

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	*Ratio* τ_{nb} / τ_{bkf}	**Near-Bank Stress (NBS)**

Level IV — **(7)**

Velocity Gradient (ft / sec / ft)	**Near-Bank Stress (NBS)**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) Ratings	Method Number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) Rating