

Memorandum - Draft

Project: Kiowa Creek Open Space

To: Arapahoe County Open Spaces

From: Muller Engineering Company
Gene Ryken, PE

Date: November 21, 2023

Subject: Creek Crossing Options

Introduction

This memorandum includes design information pertaining to planned creek crossings within the Kiowa Creek Open Space project. The Kiowa Creek Open Space property is located north of East County Road 6 (6th Avenue) and between North Kiowa-Bennett Road and North County Road 133 along Kiowa Creek.

Hydrology

Approximately 3,300 linear feet of Kiowa Creek is located within the Kiowa Creek Open Space. The creek flows from south to north through the property at an average channel slope of roughly 0.5%. According to the Kiowa Creek Master Drainage Plan (MDP) performed by Bohannan Huston (September, 2017), “the potential for flooding within and along Kiowa Creek is great.” The 2017 master drainage plan also includes hydrologic analysis of the creek with design peak flows for existing and future fully developed conditions of the Kiowa Creek watershed. Peak flow rates from the master drainage plan are listed in the tables which follow. These existing and future peak flows from the MDP coincide with the effective FEMA model developed by Bohannan Huston in 2017. Columns with an asterisk (*) represent storm event frequencies that were not listed in the MDP report, but were derived from the effective HEC-RAS model.

Location, DP#	Existing Peak Flows (cfs)						
	2-year	5-year*	10-year	25-year*	50-year	100-year	500-year
I-70, K_1.839	26	989	2,075	5,000	7,304	12,525	20,793
6 th Ave, K_2.63	26	989	2,096	5,000	7,314	12,533	20,826

Table 1. Existing Peak Flows from Master Drainage Plan, Bohannan Huston (September, 2017)

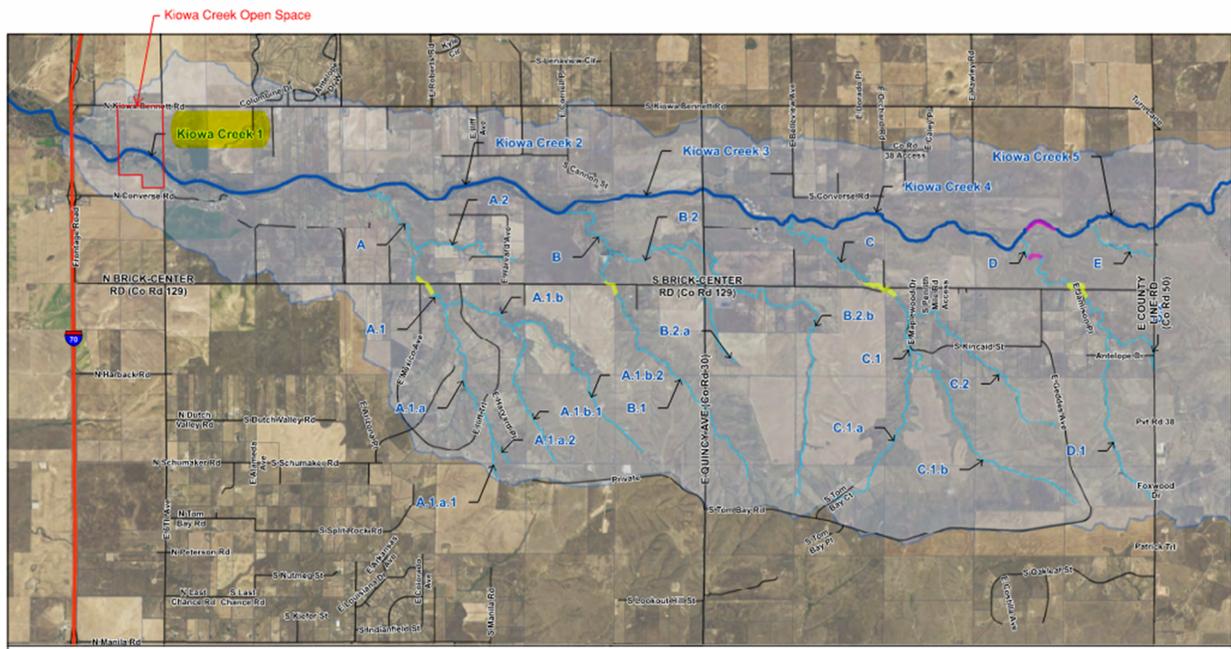
Location, DP#	Future Peak Flows (cfs)						
	2-year	5-year*	10-year	25-year*	50-year	100-year	500-year
I-70, K_1.839	1,405	2,563	3,394	11,614	15,210	21,188	31,199
6 th Ave, K_2.63	1,404	2,563	3,403	11,614	15,226	21,246	31,236

Table 2. Future Peak Flows from Master Drainage Plan, Bohannon Huston (September, 2017)

To provide a sense of scale, the existing 10-year peak flow of 2,096 cfs at the south edge of the open space property is larger than the 10-year peak flow rate of 1,608 cfs at the Cherry Creek Corridor Improvements recently constructed between East Iliff Avenue and South Quebec Street, in which Arapahoe County was a project partner. Once the Kiowa Creek watershed is developed, the 10-year future peak flow is expected to be near 3,403 cfs, approximately twice the 10-year flow rate of Cherry Creek at the Iliff Avenue to Quebec Street improvements. An even larger difference is the 100-year peak flow rate. The future peak flow rate for Kiowa Creek is 21,246 cfs which is roughly four times the 5,000 cfs 100-year peak flow rate of Cherry Creek at East Iliff Avenue.

Existing Creek Conditions

The Kiowa Creek watershed is approximately 247 square miles and is largely undeveloped. Kiowa Creek Open Space is located within the lower portion of the watershed (see image).



Kiowa Creek appears to be transitioning between ephemeral and perennial flow conditions and as the watershed continues to develop, it is expected that a reliable and constant perennial baseflow will become present. Through the project reach, an active or low-flow channel is visible however channel conditions vary through the Open Space, especially the top width which varies from 10 feet to nearly 100 feet. The floodplain can generally be described as being broad and containing flat side slopes. Much of Kiowa Creek, including through the Open Space, appears to have a channel slope of nearly 0.5% and the bed material is dominated by sand which can be highly susceptible to erosion. As the watershed develops, it is expected that a stable channel slope will be closer to the 0.05% to 0.2% range.

A geomorphic study/assessment of Kiowa Creek was not performed for this project, but information contained in the MDP and Muller's visual observation of the site and review of studies available provide a better understanding of creek conditions and can be summarized as follows:

- Kiowa Creek through the Open Space parcel is expected to evolve, especially as development within the watershed occurs. Channel degradation and lateral movement of the channel, including aggradation, and bank erosion should be expected to occur.
- Kiowa Creek conditions through the Open Space are and will continue to be influenced by upstream and downstream conditions. For example, if channel degradation and headcutting occurs downstream, and is unmanaged and allowed to propagate upstream into the Open Space, significant downcutting of Kiowa Creek could occur. Alternatively, active erosion upstream of the Open Space could transport large volumes of sediment into the Open Space corridor where significant deposition could occur. Both conditions can damage infrastructure and open space improvements.
- Geomorphic conditions could vary significantly over time and will be difficult to predict and/or manage. Rainfall and the pace and magnitude of watershed development have the potential to significantly alter geomorphic conditions.
- Flooding is expected to occur frequently within the floodplain, and flood damage of park infrastructure and the open space should be anticipated. Routine maintenance, especially within the floodplain should be planned for.

Kiowa Creek Open Space Improvement Summary

One goal of the Open Space project is to provide pedestrian, bicycle, equestrian, and maintenance vehicle access across Kiowa Creek. Planned improvements do not contain significant grading or hydraulic improvements to the existing Kiowa Creek channel corridor and considering the watershed characteristics this seems appropriate. The Arapahoe County Stormwater Management Manual (section 11.5) states pedestrian crossings, where practical, shall be designed to span the 100-year floodplain. When not practical, the minimum design conveyance shall be the 10-year storm event. The hydraulics, broad and shallow floodplain, and anticipated stream evolution process make it impractical to meet either requirement therefore the project team requested the Technical Review Committee (TRC) of Arapahoe County to consider a design variance, which was granted provided the design team perform a hydraulic analysis using the county-provided HEC-RAS model and evaluate the safety, performance, and anticipated maintenance of each crossing.

Two creek crossings are proposed with the Kiowa Creek Open Space project. One crossing is located within the northern third of the property and is roughly 350 feet south of the north property line. This crossing has been named “North Crossing” and is primarily designed to be used as a mixed-used pedestrian trail, though an option for vehicle use is still being considered. The second crossing is approximately 750 feet north of the southern boundary of the Open Space property and is named, “South Crossing”. This crossing is only planned to provide pedestrian access. Further design discussion for each crossing follows. A Creek Crossing exhibit is also included at the end of this memo.

North Crossing

At the location of the North Crossing the low-flow channel portion of the creek has an approximate 25-foot width. In this location, the low-flow channel has relatively defined banks which range in height between roughly one to two feet, but it should be noted that due to the sandy conditions of the creek corridor, the depth and width of the low-flow channel can fluctuate rapidly. Immediately above the low-flow channel is a broad and relatively flat terrace which conveys flows up the 50-year flow. This floodplain terrace is nearly 500 feet wide at the location of the proposed North Crossing and has outer bank heights of about 4 feet. The 100-year flow exceeds this flood terrace and produces additional shallow flooding primarily above and along the east (right) bank.

Due to the existing floodplain cross-section geometry it is not practical to construct a crossing which fully spans the 100-year or 10-year floodplain. In addition, due to the short bank height of the low-flow channel and potential for lateral migration of the low-flow channel within the larger 450-foot wide flood terrace, it is also not advised or practical to construct a crossing which only spans the low-flow channel. Considering the floodplain geometry, flows, and potential for natural channel evolution, a low-height boardwalk type crossing which spans the entire 450-foot flood terrace is recommended. The boardwalk would have a maximum deck to ground height of 42 inches which could avoid the use of railing which would simplify maintenance and reduce the potential for structure damage during flood events. This design matches other low-flow type crossings in the region, which usually include extra width for a rumble strip if railing is not used. An assumed deck width of 12-feet was made for the purposes of the cost estimates included in this memorandum. Options due exist for rub rails, partially railed sections, etc. which can be further evaluated by the project team. Ultimately, final approval will need to be given by the county for any crossing solution that is chosen.

Recommended North Crossing Design: Boardwalk which spans the 450-foot flood terrace.

A low-height boardwalk structure is recommended for the following reasons:

- It is lower cost than other concrete/steel alternatives.
- It can be constructed without a railing and low within the floodplain which will allow larger flows to overtop the structure with minimal impact.
- It will better accommodate changes associated with the natural channel evolution process and hydrologic changes.

The boardwalk can be constructed using different materials but for cost estimating purposes we've assumed the structure and decking will be treated lumber. The structure will be supported by a deep foundation (piers, piles). The deep foundation is necessary to provide structural integrity during flood events and will accommodate minor channel changes due to degradation and aggradation. For cost estimate the depth of foundations was assumed to be 15 feet, however final depth is subject to change based on the geotechnical investigation. After flood events, regular maintenance will be required to remove debris material from the foundation and boardwalk structure to prevent further erosion and structural damage. In addition, if scour begins to occur around the foundation, the county will have to perform repairs to avoid damage to the structure.

An estimate cost is also provided below for a boardwalk type crossing that accommodates vehicle loading. In this scenario, it is assumed county staff will use the bridge to make routine crossings with maintenance vehicles. This structure would look similar to a boardwalk structure designed for pedestrian loading only, however future design consideration will need to be given to horizontal and vertical alignment. The deep foundation for a vehicle-loaded structure would remain almost identical to a pedestrian-loaded structure. The estimated increase in cost is largely due to the additional timber framing required for the structure.

Estimated Cost (12-foot wide, pedestrian loading only) = \$1,017,900.00 (\$180/SF)

Estimated Cost (12-foot wide, pedestrian/vehicle loading) = \$1,225,900.00 (\$217/SF)

South Crossing (Optional)

The design team understands that a second crossing may not be realistic given costs, but included the following information to assist the county in long-term planning for the open space. The South Crossing low-flow channel is narrower and shallower compared to the North Crossing section. At the South Crossing location, the low-flow channel portion of Kiowa creek has an approximate 5-foot width and 1-foot depth. At 250 feet wide, the floodplain terrace immediately above the low-flow channel is about half the width of the terrace at the North Crossing section with two different bank heights. The western bank height is approximately 3 feet tall, while the eastern bank is taller at about 7 feet high. The smaller sized low-flow channel has resulted in a braided channel system at the southern area of the creek. During storm events larger than the 2-year event, stormwater overtops the shallow low-flow channel and utilizes the full width of the 250-foot-wide floodplain terrace. In combination with the sandy bed material this causes erratic sediment movement and a fluctuating creek bed. With similar, volatile conditions as the North Crossing area, a low-height boardwalk type crossing which spans the 250-foot flood terrace and is supported by a similar deep foundation discussed with the North Crossing is recommended. The South Crossing boardwalk would also have a maximum deck height of 42 inches to reduce the risk of damage and minimize debris catchment.

Recommended South Crossing Design: Boardwalk which spans the 250-foot flood terrace.

The offset in bank heights creates the need for regrading along the east bank of the creek's floodplain terrace. By regrading the east bank of the creek, a proposed crossing can meet ADA requirements and avoid a steep slope that would be required to climb the 4 feet of difference between the western and eastern bank. Proposed grading would lower the elevation of the

eastern bank at the location of the crossing by roughly four and a half feet to allow for a constant slope from the boardwalk.

Larger flow events have defined the low-flow channel along the right bank of the existing floodplain corridor. This has created a condition that if the existing low-flow channel were to downcut and become deeper, the proposed structure may be at risk of damage or of increasing the drop off height from the deck. To protect the South Crossing at the proposed location, Muller recommends installing natural channel stabilization infrastructure to manage erosion currently occurring along the east bank and direct the low-flow channel towards the center of the larger creek corridor. This would be vegetative, non-structural techniques that mimic existing vegetation that currently shapes the creek.

Estimated Cost (12-foot wide, pedestrian loading only) = \$827,450.00 (\$215/SF)

At-Grade Crossings

An at-grade option exists for proposed creek crossings, but we advise this be considered only for equestrian and second tier pedestrian crossings. An unimproved creek crossing would generally maintain existing conditions of the creek to allow for pedestrian crossing on-foot, and equestrian crossing for visitors on horseback. An at-grade crossing could also be achieved with minor improvements by installing granular material below the creek surface and burying with 0 to 6 inches of native soil. At-grade crossings introduce a higher variability to safety conditions than boardwalk crossings because conditions are subject to constant change.

There are many factors to consider for the ability of visitors to safely use at-grade crossings and the potential that natural conditions will allow for long-term use. Safe use of an at-grade crossing depends on surface conditions like soil saturation and creek flows. At-grade structures are likely to be more useful during winter months when upstream runoff is minimal and seasonal creek flows aren't as high as in the summer and early fall months. Higher flow rates like the ones witnessed by county and design staff in the summer of 2023 could deter crossing use for long periods of time throughout the year typically considered recreational seasons for expected visitors. Also, as discussed in the Hydrology section of this memo, peak flows for Kiowa Creek are expected to increase drastically in the future as development takes place within the tributary basin. This will increase the probability of soil saturation and crossing inundation for larger flows. Another factor to consider for at-grade crossings is sediment transport of the creek. The Kiowa Creek corridor will continue to undergo fairly major channel evolution, causing aggradation and degradation at various points along the creek. This unpredictable movement of sandy bed material may make it difficult or even impossible for county staff to maintain usable conditions of the crossings. With these considerations, an at-grade crossing carries more risk for failure than a boardwalk crossing. However, the low cost and risk tolerance may be suitable for second tier creek crossings.

Memorandum - Draft
November 21, 2023

Kiowa Creek Open Space
Creek Crossing Options

Please feel free to contact us with any questions regarding this memo.

Sincerely,
MULLER ENGINEERING COMPANY, INC.

Gene Ryken, PE (#57459)
Project Engineer

MULLER Engineering Company

7245 W. Alaska Dr. Suite 300
Lakewood CO 80226
303-988-4939

Cc: Paul Thomas, Stream Landscape Architecture and Planning
Nick Piche, Stream Landscape Architecture and Planning
Shaelyn Vering, Stream Landscape Architecture and Planning

Enclosures: Kiowa Creek Crossing Engineer's Cost Estimate, 30% Design
Kiowa Creek Crossing Plan & Profile Exhibit
Kiowa Creek Floodplain Exhibit

**ENGINEER'S CONSTRUCTION COST ESTIMATE - NOVEMBER 2023
KIOWA CREEK OPEN SPACE**

	SUBTOTAL
NORTH CROSSING STRUCTURE - FULL SPAN BOARDWALK WITH PEDESTRIAN LOADING ONLY	\$ 1,017,900.00
NORTH CROSSING STRUCTURE - FULL SPAN BOARDWALK WITH VEHICLE LOADING	\$ 1,225,900.00
SOUTH CROSSING STRUCTURE - LONG SPAN BOARDWALK WITH PEDESTRIAN LOADING ONLY	\$ 827,450.00

Cost Estimate Assumptions	
	Boardwalk Crossing estimates are assumed treated timber on helical pier foundation elevated approximately 3'-6" above creek bed.

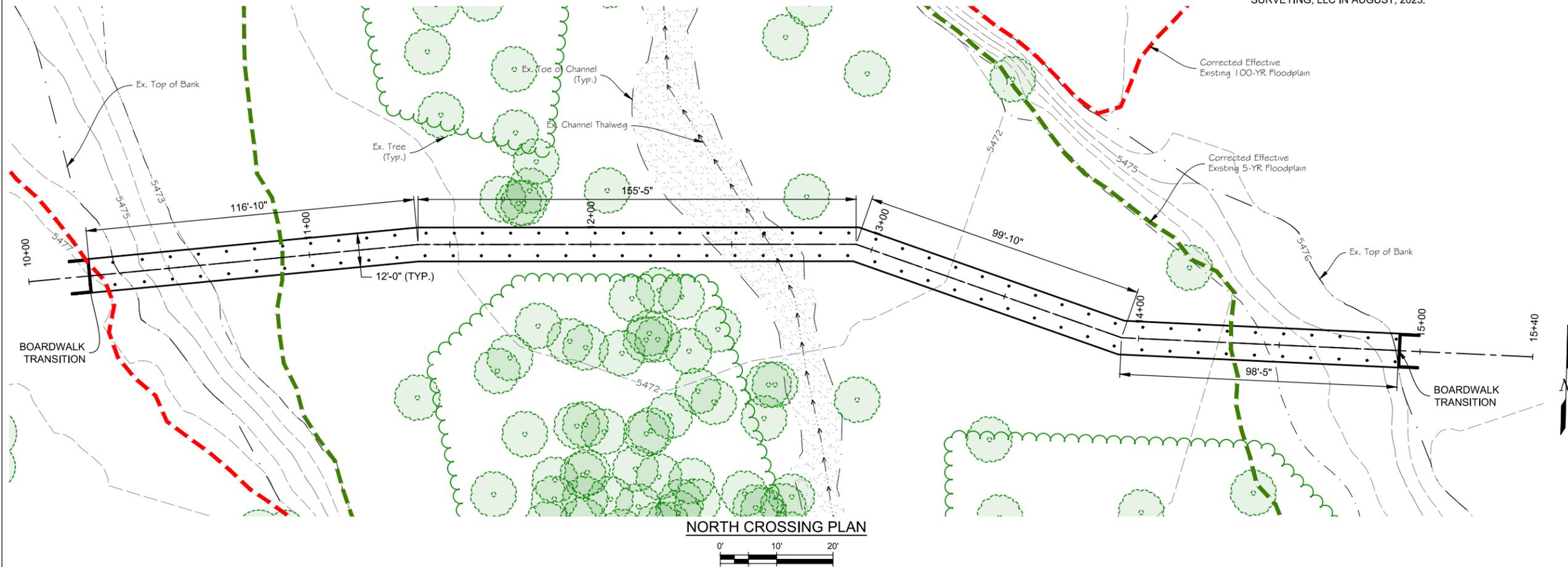
NORTH CROSSING STRUCTURE - FULL SPAN BOARDWALK WITH PEDESTRIAN LOADING ONLY						
BID ITEM NO.	BID ITEM	QTY	PAY UNIT	UNIT PRICE	TOTAL COST OF BID ITEM	NOTES
1	Mobilization	1	LS	\$ 50,000.00	\$ 50,000.00	
2	Surveying	1	LS	\$ 15,000.00	\$ 15,000.00	
3	Water Control/Dewatering	1	LS	\$ 20,000.00	\$ 20,000.00	
4	Excavation	250	CY	\$ 50.00	\$ 12,500.00	
5	Aggregate Base Course, Class 6	10	CY	\$ 150.00	\$ 1,500.00	
6	Treated Timber	42	MFBM	\$ 6,000.00	\$ 252,000.00	
7	Helical Piers	2880	LF	\$ 150.00	\$ 432,000.00	
					SUBTOTAL= \$ 783,000.00	
					CONTINGENCY (30%) \$ 234,900.00	
					OPTION #1 NORTH CROSSING SUBTOTAL= \$ 1,017,900.00	
					COST PER SQUARE FOOT= \$ 180.48 /SF, (12-foot width x 470-foot length)	

NORTH CROSSING STRUCTURE - FULL SPAN BOARDWALK WITH VEHICLE LOADING						
BID ITEM NO.	BID ITEM	QTY	PAY UNIT	UNIT PRICE	TOTAL COST OF BID ITEM	NOTES
1	Additional Treated Timber	20	MFBM	\$ 8,000.00	\$ 160,000.00	
2	Additional Helical Piers	0	LF	\$ 150.00	\$ -	
					SUBTOTAL= \$ 160,000.00	
					CONTINGENCY (30%)= \$ 48,000.00	
					OPTION #1 (PED. LOADING) SUBTOTAL= \$ 1,017,900.00	
					OPTION #1A NORTH CROSSING (VEHICLE LOADING) SUBTOTAL= \$ 1,225,900.00	
					COST PER SQUARE FOOT= \$ 217.36 /SF, (12-foot width x 470-foot length)	

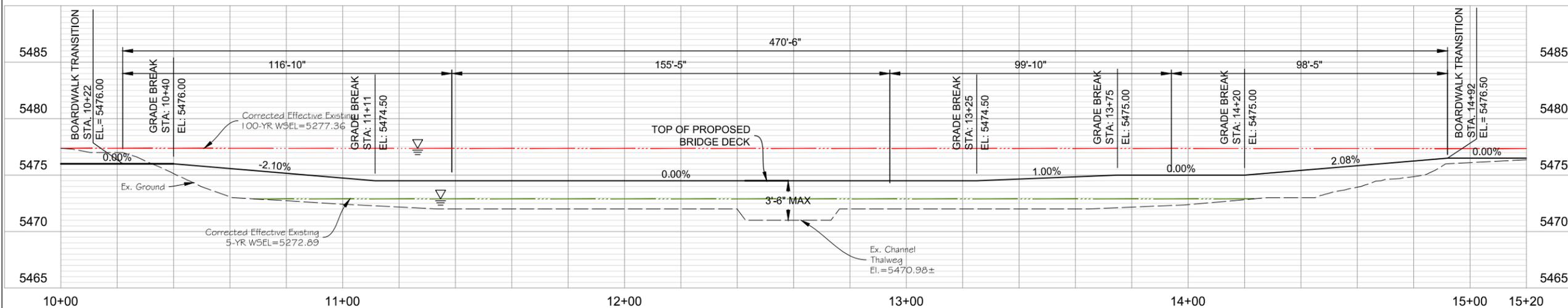
SOUTH CROSSING STRUCTURE - LONG SPAN BOARDWALK WITH PEDESTRIAN LOADING ONLY						
BID ITEM NO.	BID ITEM	QTY	PAY UNIT	UNIT PRICE	TOTAL COST OF BID ITEM	NOTES
1	Mobilization	1	LS	\$ 40,000.00	\$ 40,000.00	
2	Surveying	1	LS	\$ 10,000.00	\$ 10,000.00	
3	Water Control/Dewatering	1	LS	\$ 20,000.00	\$ 20,000.00	
4	Excavation	3000	CY	\$ 30.00	\$ 90,000.00	
5	Aggregate Base Course, Class 6	10	CY	\$ 150.00	\$ 1,500.00	
6	Treated Timber	28	MFBM	\$ 6,000.00	\$ 168,000.00	
7	Helical Piers	1980	LF	\$ 150.00	\$ 297,000.00	
8	Bush Layering, Willow Stakes (24" O.C.)	2000	EA	\$ 5.00	\$ 10,000.00	
					SUBTOTAL= \$ 636,500.00	
					CONTINGENCY (30%) \$ 190,950.00	
					OPTION #1 SOUTH CROSSING SUBTOTAL= \$ 827,450.00	
					COST PER SQUARE FOOT= \$ 215.48 /SF, (12-foot width x 320-foot length)	

KIOWA CREEK OPEN SPACE
ARAPAHOE COUNTY
ARAPAHOE COUNTY OPEN SPACES
COUNTY ROAD 137
BENNETT, CO 80102

NOTES:
1. LISTED EXISTING SURFACE ELEVATIONS WERE OBTAINED FROM SURVEY DATA COLLECTED BY HCL ENGINEERING & SURVEYING, LLC IN AUGUST, 2023.



NORTH CROSSING PLAN
0' 10' 20'



PROFILE
SCALE: 1" = 20' (HORIZ.)
1" = 5' (VERT.)

REVISIONS:

#	DATE	DESCRIPTION

DATE: NOVEMBER, 2023
DRAWN BY: RTS
REVIEWED BY: GTR

PROGRESS SET - NOT FOR CONSTRUCTION
These documents are incomplete, are released for interim review only, and are not intended for regulatory approval, bidding, permit, or construction purposes.

ISSUE:

60% DESIGN

SHEET TITLE:
CREEK CROSSING PLAN AND PROFILE (NORTH)

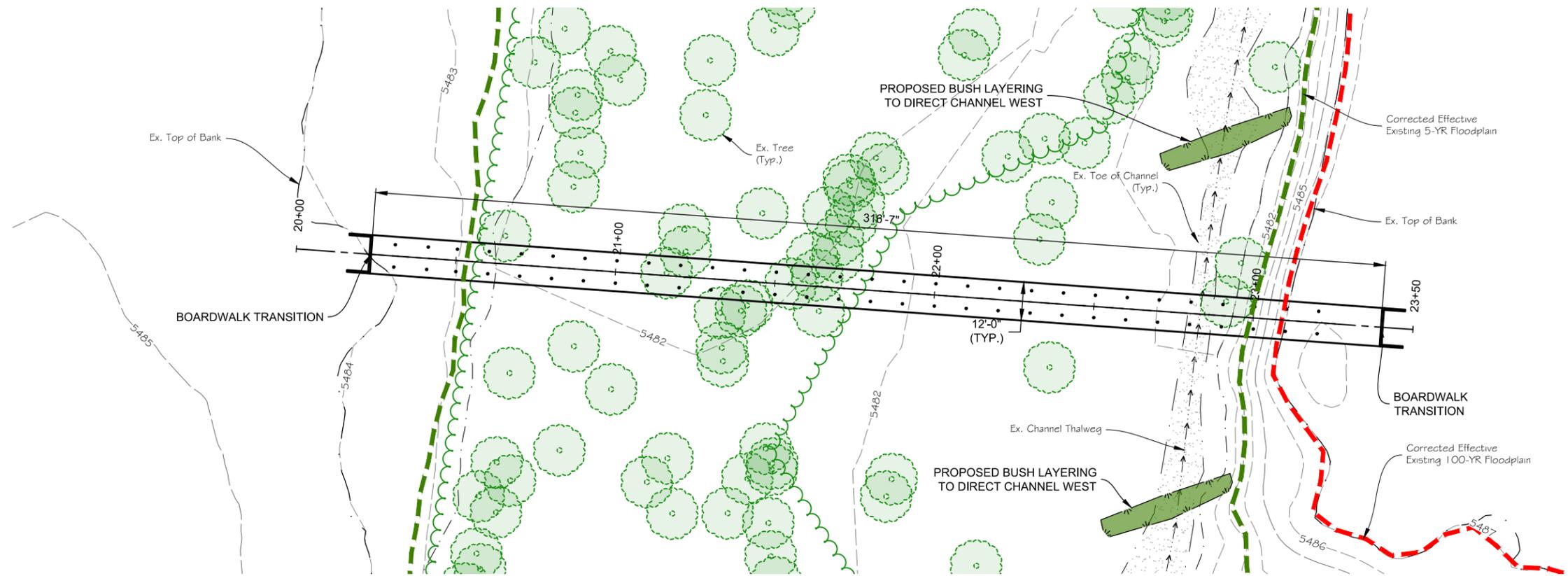
SHEET NUMBER:

DRAWING SCALE:

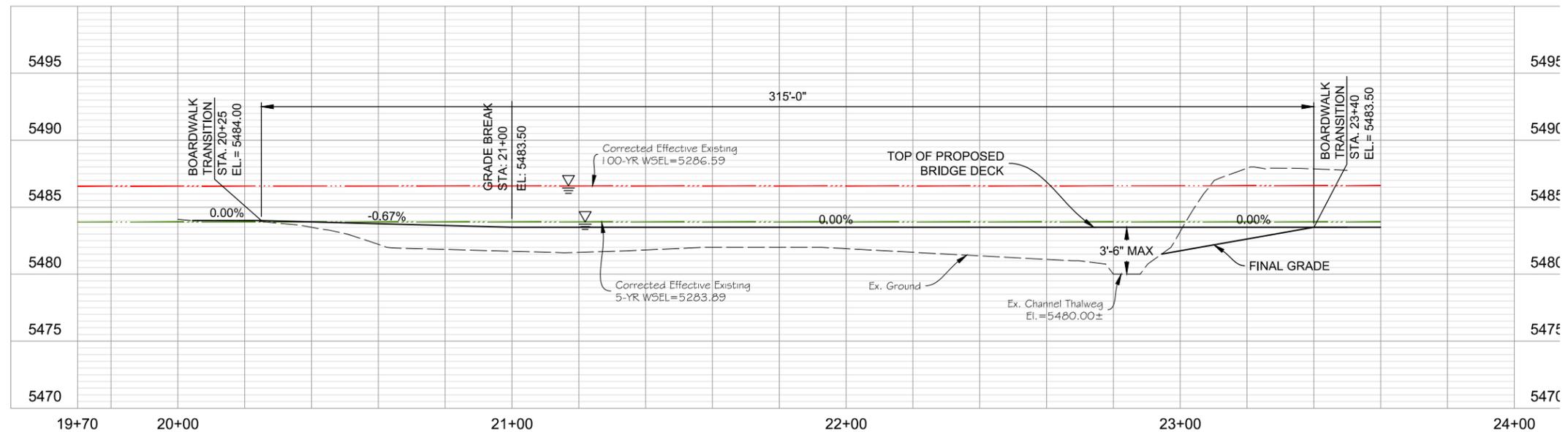
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FILE NAME: P:\2023 Projects\23-004.01 Kiowa Creek North Open Space - Arapahoe County\CAD\Drawings\23-004.01_CROSSINGS P&P.dwg
PCP FILE: STREAM\Mullers_PCP
PLOT DATE: November 27, 2023
THIS DRAWING IS CURRENT AS OF PLOT DATE AND MAY BE SUBJECT TO CHANGE.

KIOWA CREEK OPEN SPACE
ARAPAHOE COUNTY
ARAPAHOE COUNTY OPEN SPACES
COUNTY ROAD 137
BENNETT, CO 80102



SOUTH CROSSING PLAN



PROFILE
SCALE: 1" = 20' (HORIZ.)
1" = 5' (VERT.)

REVISIONS:

#	DATE	DESCRIPTION

DATE: NOVEMBER, 2023
DRAWN BY: RTS
REVIEWED BY: GTR

PROGRESS SET - NOT FOR CONSTRUCTION
These documents are incomplete, are released for interim review only, and are not intended for regulatory approval, bidding, permit, or construction purposes.

ISSUE:

60% DESIGN

SHEET TITLE:
CREEK CROSSING
PLAN AND PROFILE
(SOUTH)

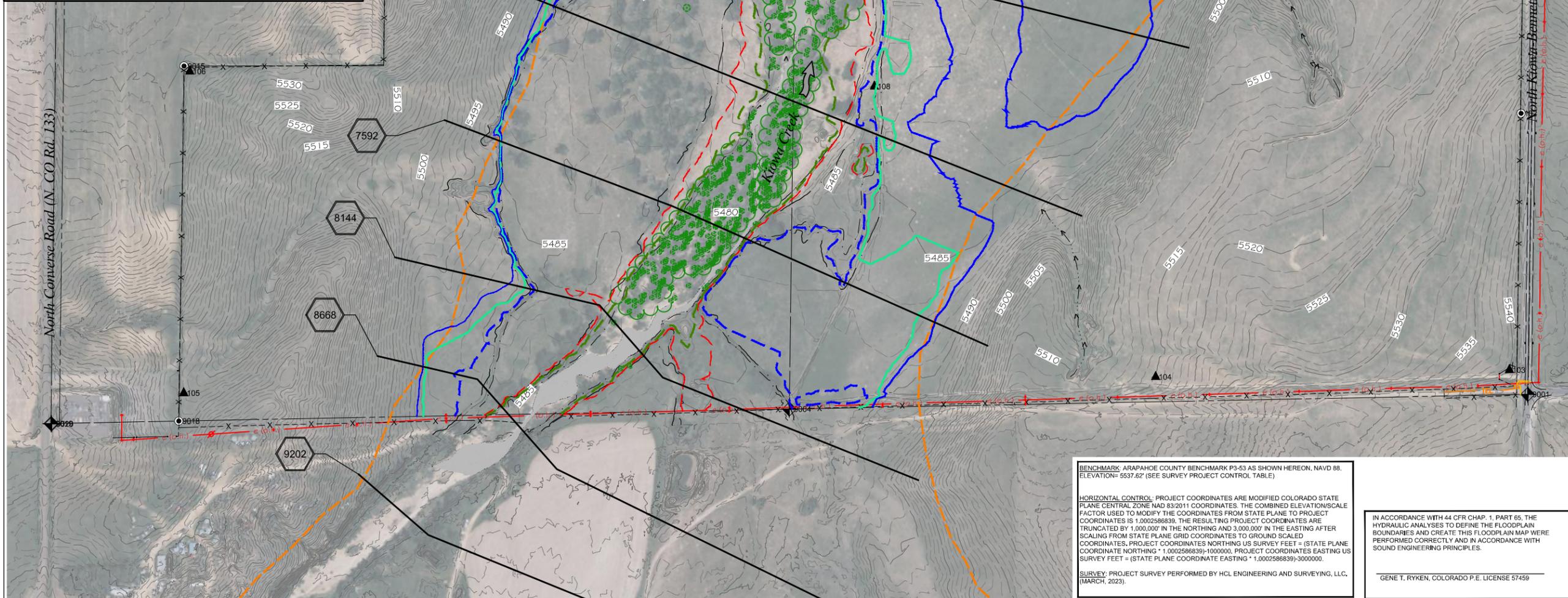
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DRAWING SCALE:

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PCP FILE: STREAM\Mullers_PCP
PLOT DATE: November 27, 2023
THIS DRAWING IS CURRENT AS OF PLOT DATE AND MAY BE SUBJECT TO CHANGE.

LEGEND

- CD CROSS SECTION LOCATION (FEMA REGULATORY SECTION)
- CB CROSS SECTION LOCATION (ADDED BY MULLER ENGINEERING)
- EFFECTIVE 100-YR FEMA FLOODPLAIN (FIRM NO. 08005C0260K, - DEC. 17, 2010)
- CORRECTED EFFECTIVE 5-YR FLOODPLAIN, $Q_5=989$ CFS MULLER ENGINEERING (OCTOBER, 2323)
- CORRECTED EFFECTIVE 10-YR FLOODPLAIN, $Q_{10}=2,211$ CFS MULLER ENGINEERING (OCTOBER, 2323)
- CORRECTED EFFECTIVE 100-YR, $Q_{100}=12,576$ CFS FLOODPLAIN MULLER ENGINEERING (OCTOBER, 2023)
- FUTURE 100-YR FLOODPLAIN, $Q_{100}=21,728$ CFS MULLER ENGINEERING (OCTOBER, 2023)
- FUTURE 500-YR FLOODPLAIN, $Q_{500}=31,320$ CFS MULLER ENGINEERING (OCTOBER, 2023)
- EXISTING CONTOURS
- PROPOSED CONTOUR



stream
landscape architecture + planning
A LIMITED LIABILITY COMPANY
899 LOGAN STREET, STE. 500
DENVER, CO 80203
720.663.7352

MULLER
ENGINEERING COMPANY
7245 W. ALASKA DR., SUITE 300 LAKEWOOD, COLORADO 80226

KIOWA CREEK OPEN SPACE
ARAPAHOE COUNTY
ARAPAHOE COUNTY OPEN SPACES
COUNTY ROAD 137
BENNETT, CO 80102

REVISIONS:

#	DATE	DESCRIPTION

DATE: NOVEMBER 29, 2023
DRAWN BY: RGH
REVIEWED BY: GTR

**PROGRESS SET:
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These documents are incomplete, are released for interim review only, and are not intended for regulatory approval, bidding, permit, or construction purposes.

ISSUE:
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SHEET TITLE:
FLOODPLAIN WORKMAP
SHEET NUMBER:
1

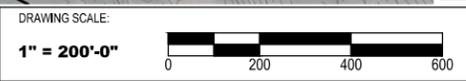
BENCHMARK: ARAPAHOE COUNTY BENCHMARK P3-53 AS SHOWN HEREON, NAVD 88, ELEVATION= 5537.52' (SEE SURVEY PROJECT CONTROL TABLE)

HORIZONTAL CONTROL: PROJECT COORDINATES ARE MODIFIED COLORADO STATE PLANE CENTRAL ZONE NAD 83/2011 COORDINATES. THE COMBINED ELEVATION/SCALE FACTOR USED TO MODIFY THE COORDINATES FROM STATE PLANE TO PROJECT COORDINATES IS 1.0002586839. THE RESULTING PROJECT COORDINATES ARE TRUNCATED BY 1,000,000' IN THE NORTHING AND 3,000,000' IN THE EASTING AFTER SCALING FROM STATE PLANE GRID COORDINATES TO GROUND SCALED COORDINATES. PROJECT COORDINATES NORTHING US SURVEY FEET = (STATE PLANE COORDINATE NORTHING * 1.0002586839)-1000000. PROJECT COORDINATES EASTING US SURVEY FEET = (STATE PLANE COORDINATE EASTING * 1.0002586839)-3000000.

SURVEY: PROJECT SURVEY PERFORMED BY HCL ENGINEERING AND SURVEYING, LLC, (MARCH, 2023).

IN ACCORDANCE WITH 44 CFR CHAP. 1, PART 65, THE HYDRAULIC ANALYSES TO DEFINE THE FLOODPLAIN BOUNDARIES AND CREATE THIS FLOODPLAIN MAP WERE PERFORMED CORRECTLY AND IN ACCORDANCE WITH SOUND ENGINEERING PRINCIPLES.

GENE T. RYKEN, COLORADO P.E. LICENSE 57459



FILE MANAGEMENT:
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PCP FILE: STREAM\Muller\PCP
PLOT DATE: November 29, 2023
THIS DRAWING IS CURRENT AS OF PLOT DATE AND MAY BE SUBJECT TO CHANGE.