Geotechnical Baseline Report

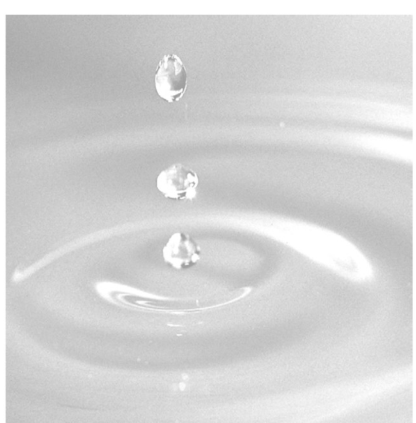
Thornton Segment F.2 – Issue For Bid

Larimer County, Colorado

Submitted to:
HDR Engineering, Inc.
1670 Broadway, Suite 3400
Denver, CO 80202

Submitted by:
GEI Consultants, Inc.
724 Whalers Way, H100
Fort Collins, CO 80525
970.373.3195

August, 2026
Project No. 2505320



Dylan Fawaz, P.E.
Project Manager

Nate Soule, P.E., P.G.
Senior Engineer

Table of Contents

List of Tables

List of Figures

Appendices

Report Organization

The Geotechnical Baseline Report (GBR) is organized as follows:

Section 1: Introduction

Describes the project background and discusses the purpose and intended usage of the GBR.

Section 2: Geology and Subsurface Conditions

Provides background on the site geology and describes the investigations undertaken to evaluate ground conditions along the alignment. Provides general baselines for the geologic units to be encountered including geologic and geotechnical characteristics and tunneling behavior. Baselines are provided for groundwater as well.

Section 3: Tunnels

Describes the subsurface conditions anticipated at each tunnel and provides specific baselines for the materials' geotechnical values and behavior in an excavation. Additional tunnel specific baselines are provided for groundwater and dewatering. Construction considerations specific to each tunnel are discussed in this section.

Section 4: General Construction Considerations

Discusses general shaft excavation and support, instrumentation and monitoring, and environmental considerations specific to tunneling, as well as general considerations for the tunnel methods appropriate for each tunnel. Additional considerations are given for general problems which may arise during shaft or tunnel construction, which the contractor should account for in their bid, designs, and performance.

Sections 5 and 6: Limitations and References

Describes limitations of the GBR and provides references for citations within the report.

1. Introduction

1.1. Project Description

The Thornton Water Project Pipeline is a multi-segment pipeline intended to provide water conveyance for the City of Thornton (City), of which Segment F.2 is to be collocated with the NTTO Segment of the North East Alignment of the NISP Pipeline. Segment F.2 of the project involves design and construction of approximately 4.39 miles of new water pipeline. New pipeline installation will be performed using open-cut and tunneling methods. Two tunnels are anticipated to be constructed using tunneling techniques with a 42-inch diameter steel pipe carrier pipe installed within a 54-inch diameter steel casing.

Tunnel construction has been chosen at specific locations due to the presence of roadways, utility corridors, and other features that will not allow conventional open cut construction.

1.2. Project Tunnels

Table 1-1 below provides approximate length and tunnel characteristics associated with each tunnel on the project. Actual lengths and depths of the tunnels are shown in the Contract Drawings. All casing pipe diameters provided in this report are for the nominal pipe diameter measurement.

Table 1-1. Project Tunnel Summary

Tunnel	Length (LF)	Cover Depth (FT)	Slope
I-25	295	13-18	0.44%
CR 52	81	19-24	0.51%

Overall tunnel excavation techniques considered viable for tunneling on the project include use of guided auger bore, tunnel boring machine (TBM), and microtunnel boring machine (MTBM). Initial support will consist of jacked steel casing. Specific tunnel techniques suited for each tunnel are described in their respective section within this report. Within the limits set by the Project Specifications and as discussed in this GBR, the Contractor is responsible for selecting the appropriate excavation and ground support methods for the work.

A minimum of two shafts will be required for each crossing. The optimal layout of the shafts will be at the Contractor's discretion; however, for the purposes of generating a baseline, it is assumed that the launch shaft (used to launch tunneling equipment) will be on the downhill side of each crossing and the receiving shaft (used to recover tunneling equipment) will be on the uphill side unless otherwise noted. The anticipated site layout including borings, tunnel alignment and assumed shafts are shown in Figures 1.1 and 1.2 for the I-25 and CR52 crossings, respectively.

1.3. Description and Purpose of the GBR

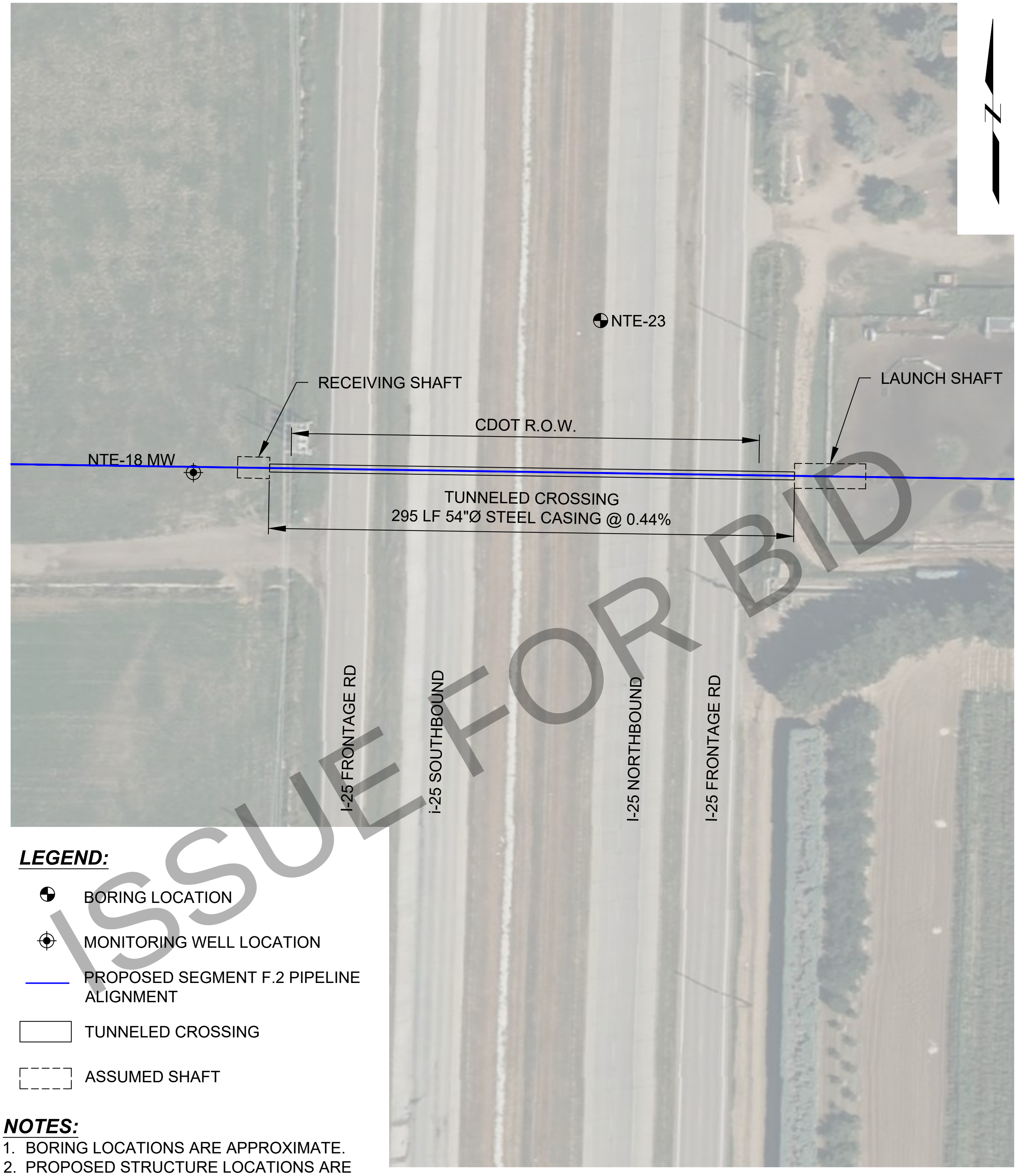
The main purpose of this GBR is to establish contractual baselines for anticipated ground conditions and behavior that will be encountered during shaft and tunnel construction (see Specifications for Contract

Document precedence and GBR use). Subsurface conditions observed through geotechnical field explorations and through laboratory analyses of collected samples are presented in the Geotechnical Data Report (GDR) (GEI, 2026). GBR preparation was performed in general accordance with an ASCE document entitled: “Geotechnical Baseline Reports, Suggested Guidelines,” dated 2022.

The baselines established in this GBR for the anticipated subsurface conditions are recommended to be used as the basis for developing bids and to help the Contractor evaluate means and methods. The baselines will be used for evaluating potential differing site conditions (DSC) during construction. This GBR also summarizes geotechnical and construction considerations that form the basis of the project design and Contract Documents. The GBR is prepared in tandem with the applicable Contract Documents, particularly Specification 31 71 00 Tunnel Excavation and Initial Support. In the event of a conflict, the Contract Drawings and Specifications take contractual precedence over the GBR, and the GBR takes precedence over the GDR.

The baselines for anticipated subsurface conditions presented in this GBR reflect the design team’s judgment of anticipated subsurface conditions and ground behavior based on assumed construction means and methods expected to be employed in the work. The baselines were established by considering available geologic and geotechnical data, together with previous construction experience in similar subsurface conditions. Development of the project design required interpretation, extrapolation, and interpolation between data obtained for the project including aerial imagery, geotechnical test boreholes (i.e. borings), groundwater monitoring, and laboratory tests. While the actual conditions encountered during construction of any given tunnel are expected to be within the range of conditions baselined herein, the locations where specific subsurface conditions are encountered may vary from those described in this GBR. The contractors should familiarize themselves with the DSC process to judge whether variances justify pursuit of a DSC claim.

Figure 1.1 Site Map (I-25 Crossing)



LEGEND:

- BORING LOCATION
- MONITORING WELL LOCATION
- PROPOSED SEGMENT F.2 PIPELINE ALIGNMENT
- TUNNELED CROSSING
- ASSUMED SHAFT

NOTES:

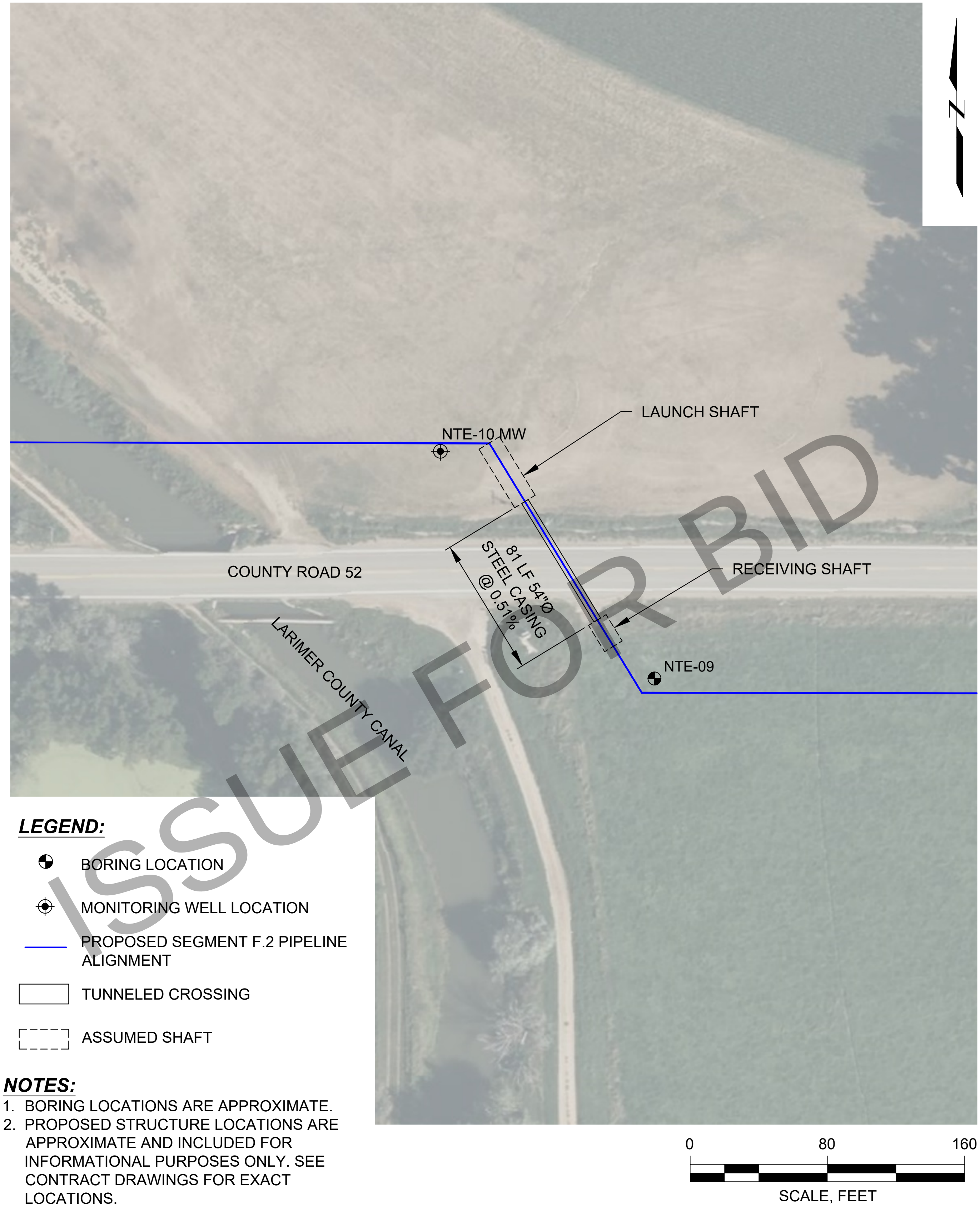
1. BORING LOCATIONS ARE APPROXIMATE.
2. PROPOSED STRUCTURE LOCATIONS ARE APPROXIMATE AND INCLUDED FOR INFORMATIONAL PURPOSES ONLY. SEE CONTRACT DRAWINGS FOR EXACT LOCATIONS.

0 80 160
SCALE, FEET

Thornton Raw Waterline Segment F.2	GEI Consultants	SITE MAP I-25 CROSSING SEGMENT F.2
HDR Engineering, Inc. Denver, Colorado	Project 2505320	August 2026 Fig. 1.1

FAWAZ, DYLAN B:\Working\HDR\2505320 Thornton Segment F\06_DESIGN\Drawings\Segment_F.2_Site_Map.dwg - 8/01/2026

Figure 1.2 Site Map (CR 52 Crossing)



LEGEND:

- BORING LOCATION
- MONITORING WELL LOCATION
- PROPOSED SEGMENT F.2 PIPELINE ALIGNMENT
- TUNNELED CROSSING
- ASSUMED SHAFT

NOTES:

1. BORING LOCATIONS ARE APPROXIMATE.
2. PROPOSED STRUCTURE LOCATIONS ARE APPROXIMATE AND INCLUDED FOR INFORMATIONAL PURPOSES ONLY. SEE CONTRACT DRAWINGS FOR EXACT LOCATIONS.

Thornton Raw Waterline Segment F.2	GEI Consultants	SITE MAP CR 52 CROSSING SEGMENT F.2
HDR Engineering, Inc. Denver, Colorado	Project 2505320	August 2026 Fig. 1.2

FAWAZ, DYLAN B:\Working\HDR\2505320 Thornton Segment F\06_DESIGN\Drawings\Segment_F.2_Site_Map.dwg - 8/01/2026

2. Geology and Subsurface Conditions

2.1. Regional Geology

The geologic conditions in the area are characterized by surficial materials consisting of eolian deposits including loess, Piney Creek Alluvium, and Broadway Alluvium. These soils overlie sandstone, shale, and claystone bedrock of the Pierre Shale. The project site is located within the Colorado Piedmont section of the Great Plains Physiographic Province. The piedmont, being an erosional inlier, consists of arid plains that are lower than the foothills to the west and slightly lower than the Great Plains to the east. During periods of uplift of the Rocky Mountains, younger sedimentary rock units were eroded and transported by streams and rivers to the piedmont. As rivers have historically meandered, alluvium was deposited in a broad swath across the plain, with wind sorting and re-distributing these materials as eolian deposits including loess. Tributary creeks and streams drain towards the rivers and re-distribute both eolian and alluvial deposits.

Groundwater in the region is heavily influenced by the Rocky Mountains to the west and the local rivers, creeks, and drainages. Groundwater generally flows west to east from the foothills with more localized flow towards and along waterbodies. Northern Colorado has semi-confined, unconfined, and perched aquifers within surficial sediments and confined and semi-confined aquifers in bedrock. The historically meandering and braided easterly-flowing rivers have significant influence on the local groundwater levels and hydrogeology.

More specifically, geologic mapping of the Boulder-Fort Collins-Greeley area (Colton, 1978) indicates the site is underlain primarily by upper Holocene-aged eolian clay, silt, and sand with some local channel deposits consisting of upper Holocene-aged Piney Creek alluvium. The eolian deposits are described as light-brown, reddish-brown, and olive-gray clay, silt (loess), and fine sand. Eolian deposits in the vicinity of the Project site likely consist primarily of loess with a thickness of between 3 and 15 feet. The Piney Creek alluvium is described as dark gray sandy to gravelly alluvium that underlies terraces whose surfaces are 10 to 20 feet above the nearby flood plain. The thickness of the alluvium is described as 0 to 20 feet.

Bedrock in the vicinity of the project site is mapped as the Upper Transition Member of Cretaceous-aged Pierre Shale consisting of friable sandstone and soft shaly sandstone containing thin-bedded sandy shale and calcareous sandstone concretions. The thickness of the unit is approximately 2,000 feet.

Specific to the Project site, the unconfined aquifer groundwater levels are generally higher in the immediate vicinity of waterbodies such as rivers, creeks, and irrigation ditches and decreases with distance away from waterbodies.

2.2. Subsurface Investigations

2.2.1. Field Investigations

GEI performed geotechnical subsurface investigations for the project tunnels between January and July of 2025. Field investigations consisted of geotechnical borehole drilling (“borings”). In general, borings were performed at either end of each tunnel alignment as near to the anticipated shaft locations as access allowed. In general, GEI collected Modified California and split spoon samples. Exploration data from these investigations are presented in the GDR. Many of the geologic terminology used in this GBR are further described and summarized in the GDR.

A geotechnical laboratory testing program was performed on selected samples and the results assisted in classification and assessment of applicable engineering properties for encountered subsurface materials. GEI designed the laboratory testing program. Details of the procedures used for conducting the field work and laboratory testing, and the factual results of the subsurface investigations and laboratory testing performed for this project are summarized in the GDR. Summaries of geotechnical data encountered during the investigation or provided by laboratory testing are embedded within this report. All bedrock testing was performed on Modified California samples rather than rock core; as such, baselined bedrock strength values may be higher than results presented in the laboratory testing results.

2.2.2. Literature Review

In addition to the field investigation, GEI performed a review of available literature, including historic aerial photography for each tunnel location and subsurface data from the United States Geological Survey (USGS), and other public entities. Specific documents reviewed for pertinent data include:

- GEI reviewed historical aerial imagery through Google Earth and Historic Aerials (historicaerials.com). Images dating from the 1960s through present were reviewed for each tunnel crossing. GEI identified no relevant feature changes that would affect tunnel construction.

- GEI reviewed the USGS Geologic Maps available for the tunnel crossings to identify the mapped deposits and bedrock formations. This aided in identifying the geologic processes that shaped the present-day subsurface conditions for each tunnel.

Relevant observations or construction considerations are noted in the GBR text for each tunnel where findings were applicable, and baselines were developed accordingly.

2.2.3. Relevant Historic Tunnel Projects

Data, observations, and design elements from nearby completed tunneling projects aided in developing this GBR. GEI relied on experience designing tunnels crossing I-25 and roadways near the I-25 corridor of northern Colorado in similar geologic conditions to supplement the geotechnical data, geologic behavior, and develop the baselines included herein. Of immediate relevance are the Greeley Waterline I-25 Widening and NEWT III Pipeline I-25 Tunnel projects that were designed and constructed in 2018 and 2023, respectively. The separate I-25 crossings for the relevant projects were of similar lengths, diameters, subsurface conditions, tunneling techniques, third parties, and design constraints. Specifically, both of the relevant projects were completed using microtunnel tunneling techniques through a non-cohesive material below groundwater. Both projects were completed successfully and with no impact to the I-25 pavement surface or right-of-way. Relevant observations or construction considerations are noted in the GBR text where findings were applicable, and baselines were developed accordingly.

2.3. Geologic Units

GEI's geotechnical test borehole reports, observations and literature review were used to create the geologic profiles associated with each tunnel. Geologic units that will be encountered in tunnel and shaft excavation include cohesive soils, non-cohesive soils, and bedrock. The sections below discuss the geologic and geotechnical characteristics of these materials. Index properties, material sizes, and volumetric percentages of material, including features specific to each crossing are described in each tunnel's respective section of the GBR. Specific modifications to the general baselines presented in Section 2.3 may be included in each individual tunnel section if it modifies the baselines presented within this section. Baselines for ground behavior included in this report are derived based on Tunnelman's classification system, which is included for reference in Appendix A at the end of this report.

2.3.1. Cohesive Soil

Cohesive soil to be encountered in shaft and tunnel excavations consists of lean clay (CL), lean clay with sand (CL), sandy lean clay (CL), and clayey sand (SC). Cohesive soil generally consists of native materials and imported fill with greater than 30% fines (clay and silt passing a No. 200 sieve) and exhibits a cohesive (plastic) behavior as determined by either laboratory Atterberg limits testing or visual-manual field observation, with the former procedure taking precedence over the latter. Cohesive soil will be encountered above and below groundwater. The table below provides the baseline conditions of cohesive soil.

Table 2-1. Baseline Conditions of Cohesive Soil

Tunnelman's Classification		Grain Size Distribution (% Composition)	Stickiness (% of Excavation)			Soil Abrasivity	Blow Counts (Blow/Foot; ASTM D3550)
Above Groundwater	Below Groundwater		High	Medium	Low		
Slow Raveling	Squeezing	Gravel Avg: 2 (Range: 0-10) Sand Avg: 40 (Range: 10-60) Fines Avg: 58 (Range: 40-90)	70	15	15	Low	Avg: 9 Range: 0-21

Cohesive soil has a low to high potential (as defined by Hollman and Thewes, 2012) to create problems with adhesion and/or clogging equipment with the in-situ moisture content. Precipitation, nuisance water, or added moisture from construction (e.g. lubrication fluids) have the potential to create higher stickiness conditions. Hollman and Thewes suggest that the stickiness of fines, if present, can be determined based on the consistency index and plasticity index of the clay. The consistency index is a function of the natural moisture content, the liquid limit, and the plasticity index. A graphical plot of clogging potential from Hollman and Thewes (2012) is shown in Figure 2.1.

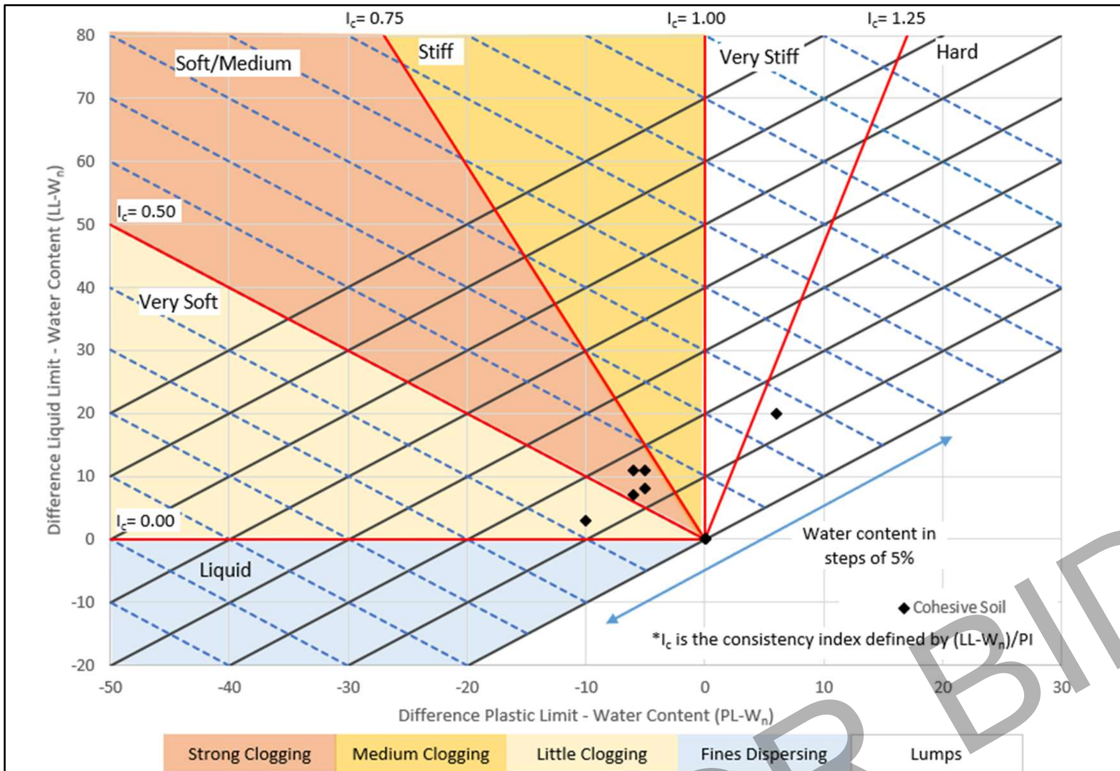


Figure 2.1 Cohesive Soil Clogging Potential Chart (Hollman and Thewes, 2012)

Cohesive soil has a low potential for excessive steel wear. Soil abrasivity is known to affect the wear and replacement rate of steel excavating components. Soil abrasivity is a function of the nature of the soil (e.g. mineralogy, quartz content, abrasiveness, rounding, compaction, and grain size distribution), soil moisture content, soil conditioning during excavation, and rate of excavation (Jakobsen, et al, 2013). Soil abrasivity was estimated based on mineral percentages of quartz-rich sand.

For bidding and baseline purposes, cobbles, boulders, or other obstructions, including natural or artificial singular features greater than three inches will not be encountered.

2.3.2. Non-Cohesive Soil

Non-cohesive soil to be encountered in shaft and tunnel excavations consists of clayey sand with gravel (SC), poorly-graded sand (SP), poorly-graded sand with clay and gravel (SP-SC), and well-graded sand with clay and gravel (SW-SC). Non-cohesive soil generally consists of native materials with less than 30% fines (clay and silt passing a No. 200 sieve) and exhibits a non-cohesive (non-plastic) behavior as determined by either laboratory Atterberg limits testing or visual-manual field observation, with the former procedure taking precedence over the latter. Non-cohesive soil will be encountered above and below groundwater. The table below provides the baseline conditions of the non-cohesive soil.

Table 2-2. Baseline Conditions of Non-Cohesive Soil

Tunnelman's Classification		Grain Size Distribution (% Composition)	Stickiness (% of Excavation)			Soil Abrasivity	Blow Counts (Blow/Foot; ASTM D3550)
Above Groundwater	**Below Groundwater**		**High**	**Medium**	**Low**		
Fast Raveling	Flowing	Gravel Avg: 22 (Range: 10-40) Sand Avg: 69 (Range: 45-80) Fines Avg: 9 (Range: 5-23)	0	0	100	High	Avg: 24 Range: 2-49

Non-cohesive soil has a low potential to create problems with adhesion and/or clogging equipment with the in-situ moisture content and a high potential for excessive steel wear based on estimations of mineral percentages of quartz-rich sand.

Cobbles in non-cohesive soil are anticipated based on the GDR and regional geology at the project location. For bidding and baseline purposes, the Contractor shall assume:

- A maximum cobble volume ratio of 10%;
- 90% of cobbles will have a maximum dimension of 6 inches, and 10% will have a maximum dimension between 6 inches and 12 inches;
- Cobbles will have a maximum unconfined compressive strength (UCS) of 15,000 psi and maximum Cerchar Abrasivity Index (CAI) of 4.0;
- Cobbles will be sub-angular to sub-rounded;
- Cobbles will be isolated throughout non-cohesive soil.

For bidding and baseline purposes, boulders, or other obstructions, including natural or artificial singular features greater than 12 inches will not be encountered.

2.3.3. Bedrock

Bedrock to be encountered in shaft and tunnel excavations consists of interbedded sandstone, and clayey sandstone. Bedrock is undifferentiated in this GBR due to similarity in Baseline Conditions affecting construction. The bedrock at depths relevant to the excavations is classified as extremely weak rock to weak rock for ISRM field strength estimate procedures (ISRM, 2007) above and below groundwater. Unconfined Compressive Strength (UCS) laboratory tests were performed on intact samples that resulted in values between 11 psi and 128 psi, however stronger localized clasts and beds are possible given regional project experience and will be encountered as baselined below. These stronger bedrock zones have additional cementation that significantly increases both bedrock hardness and strength. Additionally, the International Society for Rock Mechanics provides a guideline for compressive strength ranges based on the relative strength of bedrock as determined in the field and assisted in compressive strength baseline determination (ISRM, 2007).

These values are higher than as tested based on geotechnical drilling performance and GEI's experience with bedrock in the project vicinity. The table below provides the baseline conditions of bedrock.

Table 2-3. General Baseline Conditions of Bedrock

Tunnelman's Classification	Stickiness (% of Excavation)			Abrasivity	UCS (% of Excavation: psi)
Above and Below Groundwater	High	Medium	Low		
Firm[1]	0	25	75	Moderate	95%: 150 maximum 5%: 2,000 maximum

Notes:
1. Though bedrock is a rock unit, classification in accordance with Tunnelman's Ground Classification for Soils is more representative of ground behavior.

Bedrock in the region is known to exhibit swelling characteristics with moisture variations; however, swelling rock is not anticipated during tunnel excavation. Bedrock has a low potential to create problems with adhesion and/or clogging equipment with the in-situ moisture content. A graphical plot of clogging potential from Hollman and Thewes (2012) is shown in Figure 2.2.

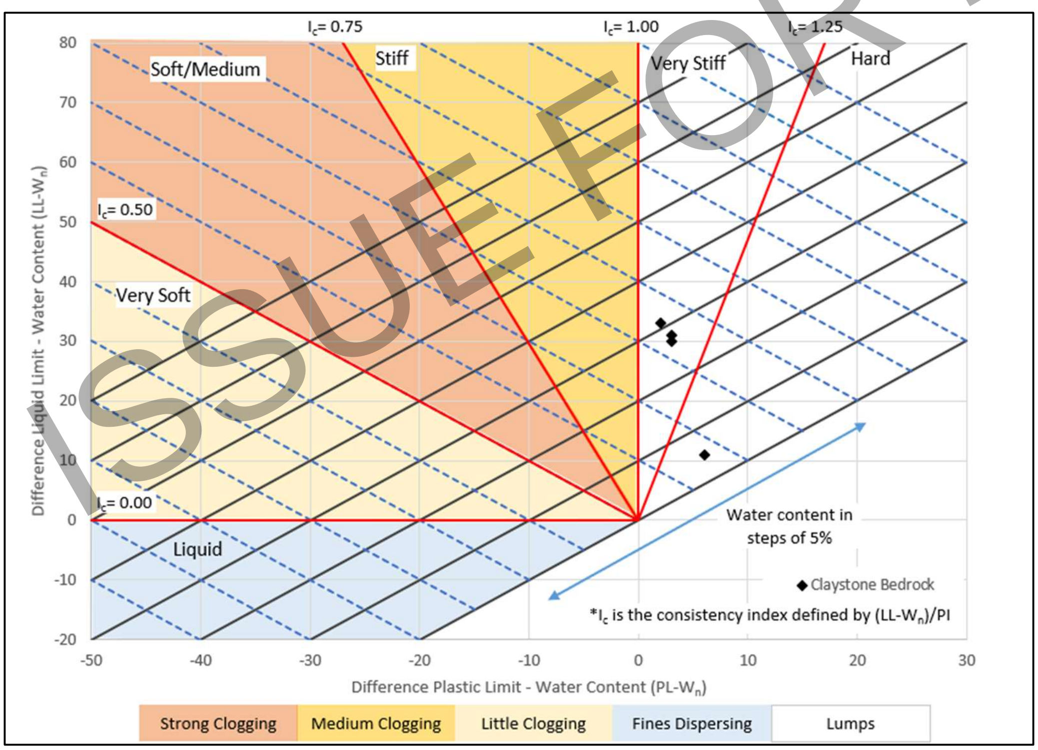


Figure 2.2: Bedrock Clogging Potential Chart (Hollman and Thewes, 2012)

2.4. Groundwater

Groundwater was encountered throughout the project geotechnical investigation. The baseline groundwater elevations for each tunnel are shown in each respective section.

The Contractor should anticipate that local variations in hydraulic conductivity and aquifer characteristics will be encountered. Fluctuations in groundwater levels may occur due to variations in seasonal fluctuations, stormwater runoff, rainfall, temperature, site development, and other factors not evident at the time these measurements were made. With respect to construction dewatering design, the cohesive soil is problematic in that frequent layers of lower hydraulic conductivity material with a high percentage of fines can hinder dewatering. In addition, shallow bedrock specifically at the CR 52 crossing location will hinder groundwater drawdown. Excavations with significant proportions of cohesive material or bedrock should anticipate lower inflow rates and dewatering design should be for planned accordingly. Tunnel and shaft-specific requirements for dewatering and groundwater management are discussed in each respective tunnel-specific section herein.

The hydraulic conductivity of the geologic units varies with fines content, void ratio and particle size. The Contractor should be aware that horizontal hydraulic conductivity in these deposits is significantly greater (from 5x to 10x) than vertical hydraulic conductivity. For baseline purposes, the hydraulic conductivity of the materials found onsite is as follows in the table below:

Table 2-4. Baseline Hydraulic Conductivity of Materials

Geologic Unit	Horizontal Hydraulic Conductivity (cm/s)	
	Baseline	Range
Cohesive Soil	$1x10^{-4}$	$1x10^{-6}$ to $1x10^{-3}$
Non-cohesive Soil	$1x10^{-1}$	$1x10^{-3}$ to $1x10^{-1}$
Bedrock	$1x10^{-5}$	$1x10^{-6}$ to $1x10^{-3}$

3. Tunnels

Per specification 31 71 00, the allowable tunneling techniques and initial support methods for the tunnels associated with the project are provided in the table below.

Table 3-1. Tunnel Summary

Tunnel	Length (LF)	Initial Support Minimum Diameter (inch)	Allowable Tunneling Techniques			Allowable Initial Support
			TBM	MTBM	Guided Auger Boring	Casing Pipe
I-25	295	54		X		X
CR 52	81	54	X	X	X	X

3.1. Interstate 25 (I-25) Crossing

This tunnel crosses beneath Interstate 25 and local utilities. The total tunnel length is 295 feet at a slope of 0.44% down from West to East. A 42-inch-diameter steel carrier pipe will be installed within a 54-inch-minimum-diameter steel casing pipe. The launch shaft is planned on the east side of I-25 within a fenced commercial lot without existing structures, and the receiving shaft is planned on the west side of I-25 within an agricultural lot without existing structures. The baseline geologic profile is shown in Figure 3.1.

3.1.1. Subsurface Characteristics and Ground Behavior

The soil characteristics and ground conditions described in this section constitute the baseline geotechnical conditions to be anticipated during construction of the shafts and tunnel. Geologic baselines include percent by volume of material anticipated to be encountered, groundwater elevation, and potential for obstructions. Baseline values and discussion pertinent to the geologic conditions from which the baselines are derived are provided below.

3.1.2. Geologic Units (Tunnel Specific)

Borings NTE-17-MW, NTE-18-MW and NTE-23 were used to create the Baseline Geologic Profile shown in Figure 3.1, however boring NTE-17-MW was completed approximately 350 feet to the east of the proposed launch shaft location due to restricted site access at the time of the investigation, and is not shown on the figures. Geologic units that will be encountered in tunnel and shaft excavations consist of cohesive soil and non-cohesive soil. The sections below discuss the geologic and geotechnical characteristics of these units.

3.1.2.1. Cohesive Soil

Cohesive soil will be encountered within the shaft excavations and tunnel excavation at the I-25 crossing. At the I-25 crossing, Cohesive soil consists of lean clay with varying amounts of sand (CL) and clayey sand (SC). Cohesive soil will be encountered above groundwater.

3.1.2.2. Non-Cohesive Soil

Non-cohesive soil will be encountered in both shaft and tunnel excavations at the I-25 crossing. Non-cohesive soil to be encountered in the shafts and tunnel excavations consists of poorly graded sand with varying amounts of clay (SP-SC, SW-SC, SP), and clayey sand with gravel (SC). Non-cohesive soil will be encountered above and below groundwater.

3.1.3. Groundwater

Groundwater was encountered during drilling of all three borings. Monitoring wells were installed at both borings NTE-17-MW and NTE-18-MW and depth to water was periodically measured thereafter. Shaft and tunnel construction will encounter groundwater. The baseline groundwater elevation is shown in Figure 3.1.

The local aquifer at the site is unconfined within surficial deposits. Unconfined aquifers are highly influenced by storm water runoff and infiltration, storm events, and drought conditions; however, this is accounted for in the baseline groundwater elevation. Section 2.4 discusses the baseline hydraulic conductivities of materials found onsite.

3.1.4. Construction Considerations (Tunnel Specific)

This section discusses the methods GEI anticipates will be used by the Contractor during construction of the shafts and tunnel at the I-25 crossing.

3.1.4.1. Shafts

Two construction shafts (launch and receiving shafts) will be required for the tunnel. Due to available space for equipment and staging and industry preference for mining uphill, the anticipated direction of tunnel excavation is from East to West such that the launch shaft will be on the East and the receiving shaft will be on the West side of the interstate.

The shafts will be excavated in Cohesive soil and Non-Cohesive soil. These materials are anticipated to be excavated with conventional equipment and will not require the use of blasting or hydraulic rock breaker attachments. The individual geologic unit discussions in Section 2.3 include the baselines regarding ground behavior. The table below presents baseline excavation relative volumes of each geologic unit that will be encountered during shaft excavations.

Table 3-2. Baseline Shaft Excavation Volumes by Geologic Unit (I-25 Crossing)

Geologic Unit	Shaft Excavation Volume (%)	
	Launch	Receiving
Cohesive Soil	50	55
Non-cohesive Soil	50	45

Unless watertight shaft systems are used, dewatering will be necessary for successful construction and use of the shafts. Deep wells are likely to be effective in this ground. The Contractor is also encouraged to plan for a means of handling precipitation, internal nuisance or construction water as necessary, such as sump pumps.

A variety of ground support methods can be successful in this ground. Best practice in the baselined ground conditions will be to provide support as soon as practical after excavation in stages or concurrent with excavation. Possible non-watertight shoring methods include slide rail, sheet piles, soldier piles and lagging, and liner plates. Possible watertight shoring methods include secant pile shaft and gasketed sheet piles. A concrete floor (mud mat) may be useful in controlling groundwater inflow through the non-cohesive soil and bottom instability at the shafts. If a watertight shaft is used in lieu of dewatering, a structural shaft invert plug is recommended to counteract upwelling pressures, as groundwater is baselined above the excavation bottom.

3.1.4.2. Tunnel

Microtunneling is the only method of tunnel excavation considered viable for the tunnel excavation at the I-25 crossing due to the groundwater table located above the tunnel excavation, relatively high permeability non-cohesive material to be encountered during tunnel excavation, and the importance of reducing risk of settlement to the traveling public. Initial Support must employ a jacked steel casing. A steel carrier pipe will be installed in a second pass and the annulus will be backfill grouted.

Other techniques for tunnel excavation such as guided auger boring or ramming are considered unfeasible due to groundwater levels and the planned length and diameter of the tunnel being beyond the acceptable risk tolerance for these techniques. A TBM or other open-faced techniques do not provide suitable control of groundwater and face stability.

The tunnel will be excavated within Non-Cohesive soil. The table below presents baseline excavation volumes of each geologic unit that will be encountered during tunnel excavation. The baselines specific to subsurface characteristics and ground behavior are included in Section 2.3.

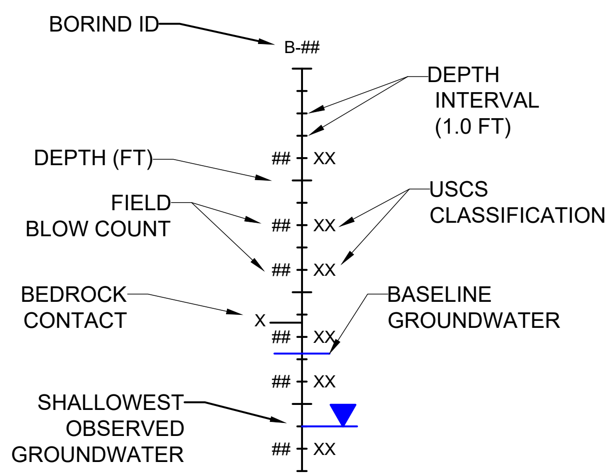
Table 3-3. Baseline Tunnel Excavation Volumes by Geologic Unit (I-25 Crossing)

Geologic Unit	Tunnel Excavation Volume (%)
Cohesive Soil	5
Non-cohesive Soil	95

With pipe jacking a MTBM (Microtunnel Boring Machine), a properly selected jacking frame will be sufficient to install the casing pipe under tolerable jacking loads in the baselined ground conditions and for the length and diameter of the proposed tunnel using construction best-practices. While the Contractor is responsible for selecting means and methods appropriate to the ground conditions and tunnel layout within the limitations set by the contract documents, use of an Intermediate Jacking Station (IJS) is not anticipated for this tunnel, but may be considered by the Contractor.

Figure 3.1 Baseline Geologic Profile (I-25 Crossing)

BORING LOG KEY:



BASELINE GEOLOGIC UNTS:

- COHESIVE SOIL
- NON-COHESIVE SOIL
- BEDROCK

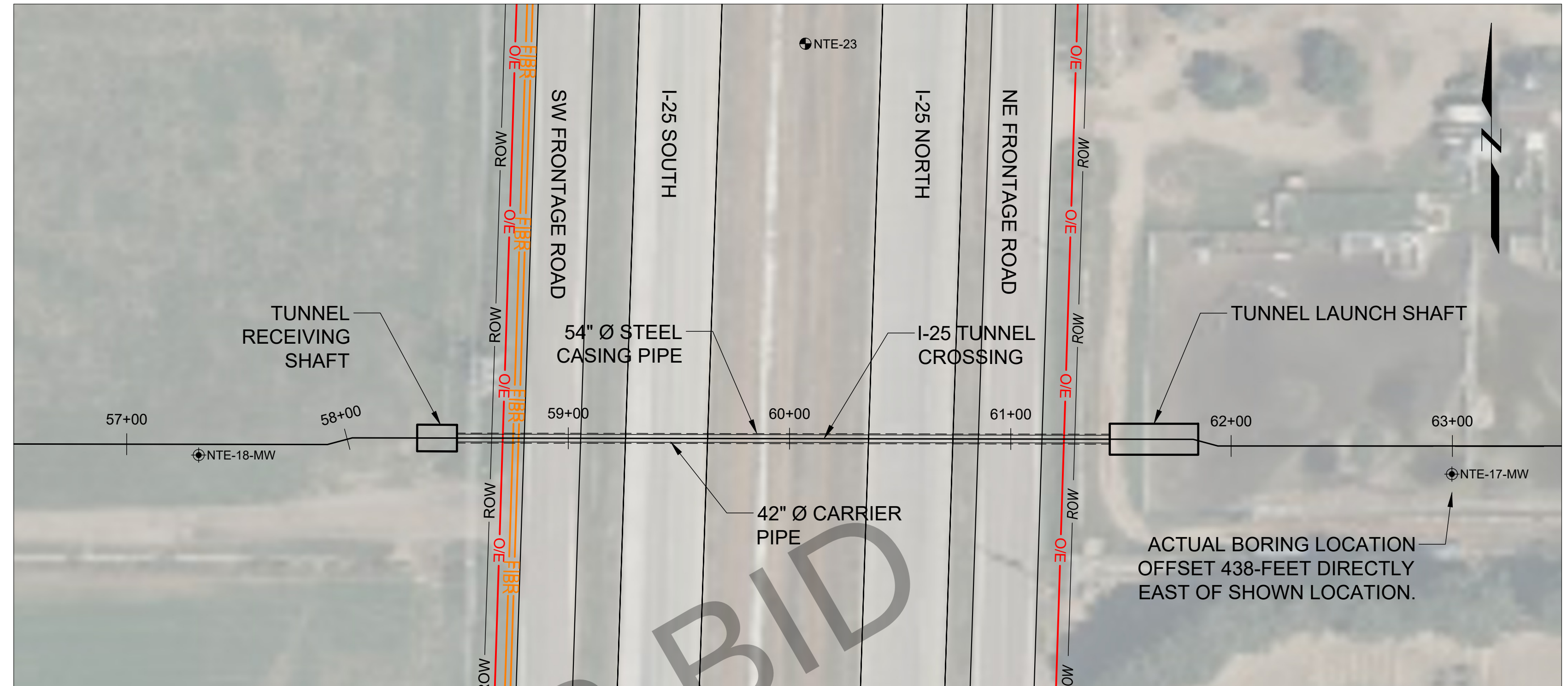
LINE TYPES AND SYMBOLS LEGEND:

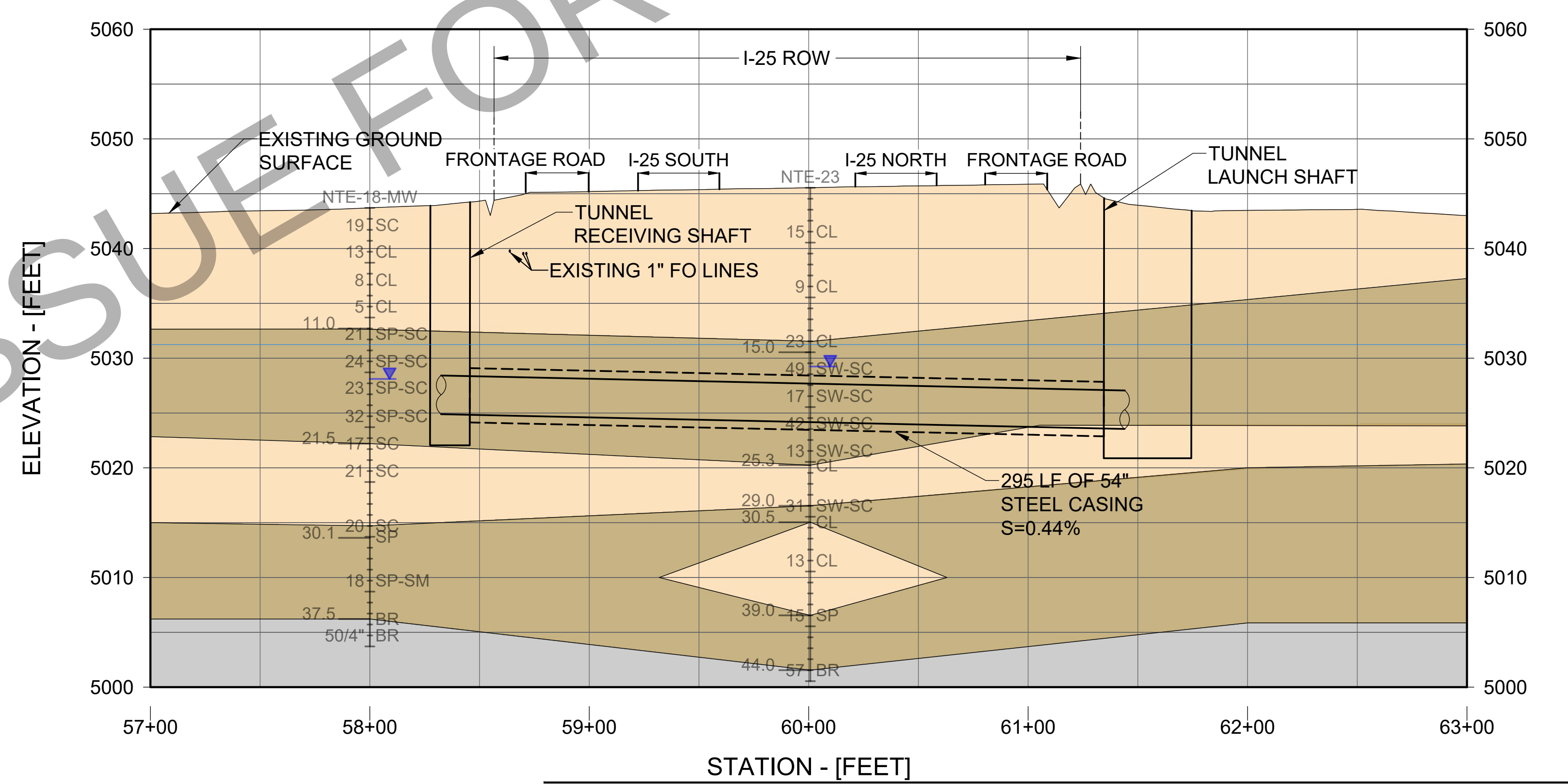
- CARRIER PIPE
- CASING PIPE
- BASELINE GROUNDWATER DEPTH
- GEOTECHNICAL BORING
- MONITORING WELL

BORING OFFSETS FROM TUNNEL ALIGNMENT		
BORING ID	OFFSET (FT)	OFFSET DIRECTION
NTE-17-MW	550	EAST
NTE-23	175	NORTH
NTE-18-MW	200	WEST

SHAFT DEPTHS[1,2]	
SHAFT	APPROXIMATE DEPTH (FT)
LAUNCH	23.6
RECEIVING	22

[1] NOTE: SHAFTS ASSUMED TO EXTEND 2-FEET BELOW CASING PIPE INVERT
[2] SHAFT DEPTH BASED ON SURVEY INFORMATION FROM HDR.





NOTES:

1. 5:1 VERTICAL EXAGGERATION
2. ALIGNMENT AND INFRASTRUCTURE ARE AS SHOWN IN CONTRACT DOCUMENTS, BY HDR ENGINEERING, INC. DATED FEBRUARY 2026, AND PROVIDED HEREIN FOR INFORMATIONAL PURPOSES ONLY. REFER TO THE CONTRACT DOCUMENTS FOR FURTHER INFORMATION ON EXISTING UTILITIES.
3. GEOTECHNICAL BORINGS ARE AS SHOWN IN THE GEOTECHNICAL DATA REPORT (GDR) (GEI CONSULTANTS, 2026) AND ARE PROVIDED HEREIN FOR INFORMATIONAL PURPOSES ONLY. DETAILED DESCRIPTIONS OF THE GEOTECHNICAL BORINGS CAN BE FOUND IN THE GDR.

0 80 160
SCALE, FEET

Geotechnical Baseline Report
Thornton Water Project - Segment F.2
Fort Collins, Colorado

HDR Engineers, Inc.
Denver, Colorado

GEI Consultants

Project 2505320

I-25 Crossing Geologic Cross Section

August, 2026

Fig. 3.1

3.2. CR 52 Crossing

This tunnel crosses beneath CR 52 and local utilities. The total tunnel length is 81 feet at a slope of 0.51% down from South to North. A 42-inch-diameter steel carrier pipe will be installed within a 54-inch-minimum-diameter steel casing pipe. The launch and receiving shafts are planned within undeveloped land. The baseline geologic profile is shown in Figure 3.2.

3.2.1. Subsurface Characteristics and Ground Behavior

The soil characteristics and ground conditions described in this section constitute the baseline geotechnical conditions to be anticipated during construction of the shafts and tunnel. Geologic baselines include percent by volume of material anticipated to be encountered, groundwater elevation, and potential for obstructions. Baseline values and discussion pertinent to the geologic conditions from which the baselines are derived are provided below.

3.2.2. Geologic Units (Tunnel Specific)

Borings NTE-9 and NTE-10-MW were used to create the Baseline Geologic Profile shown in Figure 3.2. Geologic units that will be encountered in tunnel and shaft excavations consist of cohesive soil and bedrock. The sections below discuss the geologic and geotechnical characteristics of these units.

3.2.2.1. Cohesive Soil

Cohesive soil will be encountered within the shaft excavations but not within the tunnel excavation at the CR 52 crossing. Cohesive soil consists of lean clay with varying amounts of sand (CL) and clayey sand (SC). Cohesive soil will be encountered above and below groundwater.

3.2.2.2. Bedrock

Bedrock to be encountered within the tunnel and shaft excavations at the CR 52 crossing consists of interbedded sandstone, clayey sandstone, and shale. Bedrock will be encountered below groundwater.

3.2.3. Groundwater

Groundwater was encountered during drilling of both borings at the CR 52 crossing. A monitoring well was installed at boring NTE-10-MW and depth to water was periodically measured thereafter. Shaft and tunnel construction will encounter groundwater. The baseline groundwater elevation is shown in Figure 3.2.

The local aquifer at the site is unconfined within surficial deposits. Unconfined aquifers are highly influenced by storm water runoff and infiltration, storm events, and drought conditions; however, this is accounted for in the baseline groundwater elevation. Section 2.4 discusses the maximum baseline hydraulic conductivity of materials found onsite.

3.2.4. Construction Considerations (Tunnel Specific)

This section discusses the methods GEI anticipates will be used by the Contractor during construction of the shafts and tunnel at the CR 52 crossing.

3.2.4.1. Shafts

Two construction shafts (launch and receiving shafts) will be required for the tunnel. Due to available space for equipment and staging and industry preference for mining uphill, the anticipated direction of tunnel excavation is from north to south such that the launch shaft will be on the north side and the receiving shaft will be on the south side of the roadway.

The shafts will be excavated in cohesive soil and bedrock. For baseline purposes, the Contractor shall account for a minimum of 2 concretions with a maximum dimension of 2-feet to be encountered in each shaft excavation. These materials are anticipated to be excavated with conventional equipment and will not require the use of blasting or hydraulic rock breaker attachments. The individual geologic unit discussions in Section 2.3 include the baselines regarding ground behavior. The table below presents baseline excavation relative volumes of each geologic unit that will be encountered during shaft excavations.

Table 3-4. Baseline Shaft Excavation Volumes by Geologic Unit (CR 52 Crossing)

Geologic Unit	Shaft Excavation Volume (%)	
	Launch	Receiving
Cohesive Soil	50	40
Bedrock	50	55

Water management systems internal to the shafts such as sumps are anticipated to be sufficient for construction at this location. Deep wells are unlikely to be effective in this ground due to the relatively low hydraulic conductivities and shallow bedrock. The Contractor is also encouraged to consider handling precipitation, internal nuisance or construction water as necessary.

A variety of ground support methods can be successful in this ground. Best practice in the baselined ground conditions will be to provide support as soon as practical after excavation in stages or concurrent with excavation. Possible methods include trench boxes, slide rail, sheet piles, soldier piles and lagging, and liner plates with dewatering. Bedrock may prove difficult for driving/raising sheet piles depending on how deep the piles are advanced below the shaft bottoms. A concrete floor (mud mat) may be useful in providing water resistant and structurally sound working surface at the shaft bottoms.

3.2.4.2. Tunnel

Three methods of tunnel excavation are considered viable for the tunnel excavation including guided auger boring, TBM, and MTBM. If the Contractor elects to use guided auger boring, a machine suitable for the baselined ground conditions should be selected, such as certain models manufactured by McLaughlin. Use of a MTBM with a pressurized face is permitted, though is it unlikely to be necessary when considered with the other open face, non-pressurized methods listed. Initial Support must employ a jacked steel casing. A steel carrier pipe will be installed in a second pass and the annulus will be backfill grouted.

Other techniques for tunnel excavation such as guided ramming or shield mining are considered unfeasible due to baseline ground conditions and the planned length and diameter of the tunnel being beyond the acceptable risk tolerance for these techniques.

The tunnel will be excavated within bedrock. The table below presents baseline excavation volumes of each geologic unit that will be encountered during tunnel excavation. The baselines specific to subsurface characteristics and ground behavior are included in Section 2.3.

Table 3-5. Baseline Tunnel Excavation Volumes by Geologic Unit (CR 52 Crossing)

Geologic Unit	Tunnel Excavation Volume (%)
Bedrock	100

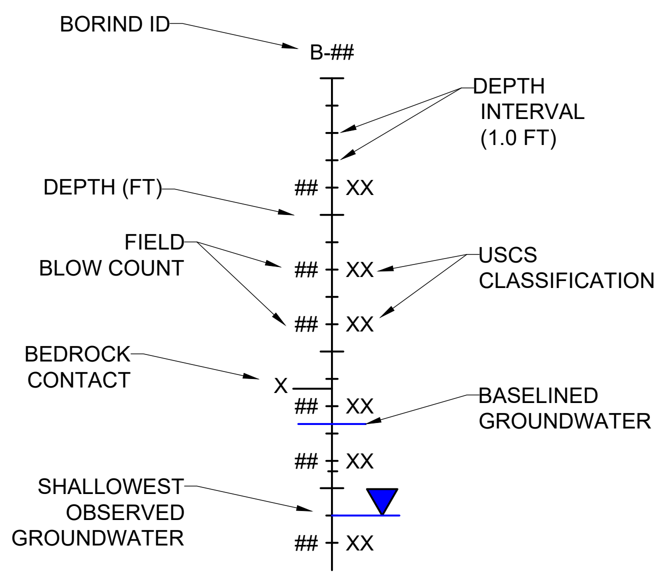
For baseline purposes, the Contractor shall account for a maximum of 2 concretions with a maximum dimension of 2-feet to be encountered in the tunnel excavation. Based on the Contractor's cutting head selection, hydraulic rock breakers may be required.

With pipe jacking a TBM, guided auger bore, or MTBM, a properly selected jacking frame will be sufficient to install the casing pipe under tolerable jacking loads in the baselined ground conditions and for the length and diameter of the proposed tunnel using construction best-practices. While the Contractor is responsible for selecting means and methods appropriate to the ground conditions and tunnel layout within the limitations set by the contract documents, use of an Intermediate Jacking Station (IJS) is not anticipated for this tunnel.

If guided auger boring is utilized, machinery should be tooled and equipped to excavate bedrock with baselined engineering properties provided in Section 3. This may include use of a steerable head or specially designed pilot tube and augers capable of excavating the non-displaceable bedrock. If a pilot tube and augers are used, the Contractor should assume a minimum of two full-length upsizings will be required to install the casing to the design alignment: one upsizing from the pilot tube to a casing between 12 - 18 inches, and one upsizing from the 12 – 18 inch casing to a 36-42 inch casing. Additional upsizings are at the discretion of the Contractor.

Figure 3.2 Baseline Geologic Profile (CR 52 Crossing)

BORING LOG KEY:



BASELINE GEOLOGIC UNTS:

COHESIVE SOIL

BEDROCK

LINE TYPES AND SYMBOLS LEGEND:

CARRIER PIPE

CASING PIPE

BASELINE GROUNDWATER DEPTH

GEOTECHNICAL BORING

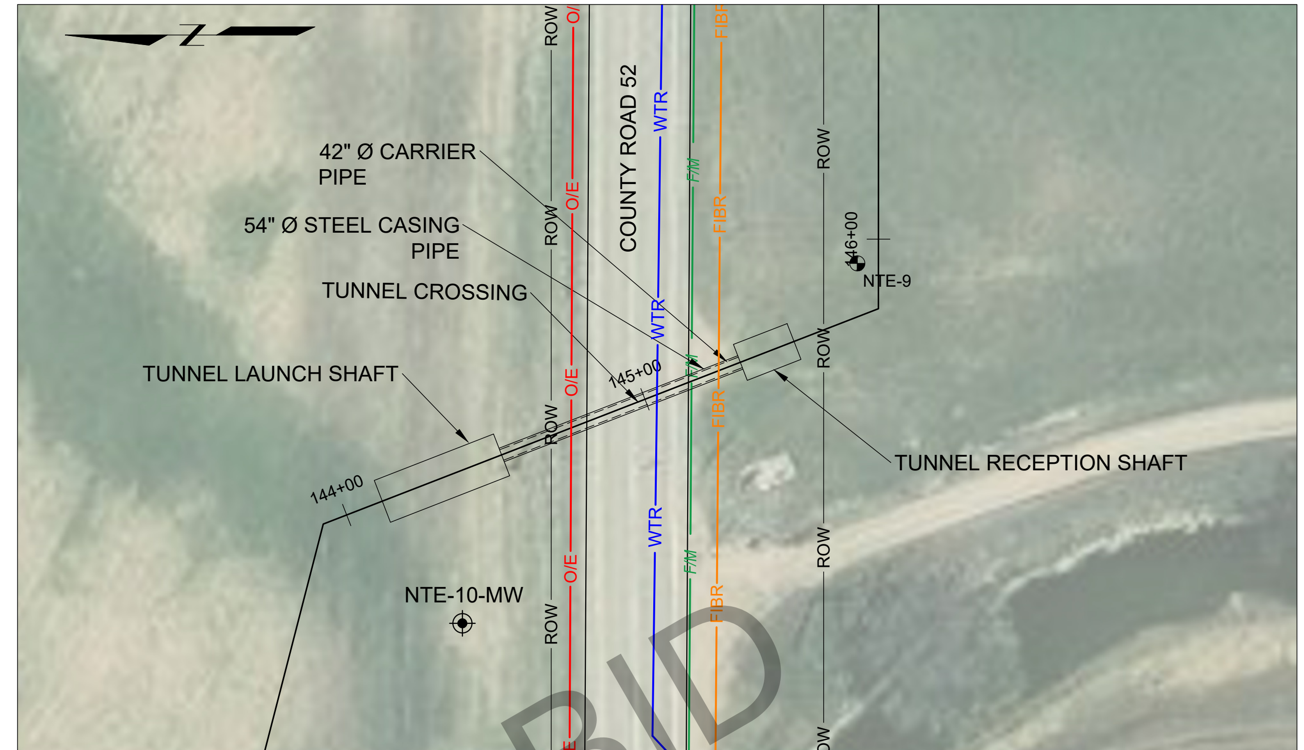
MONITORING WELL

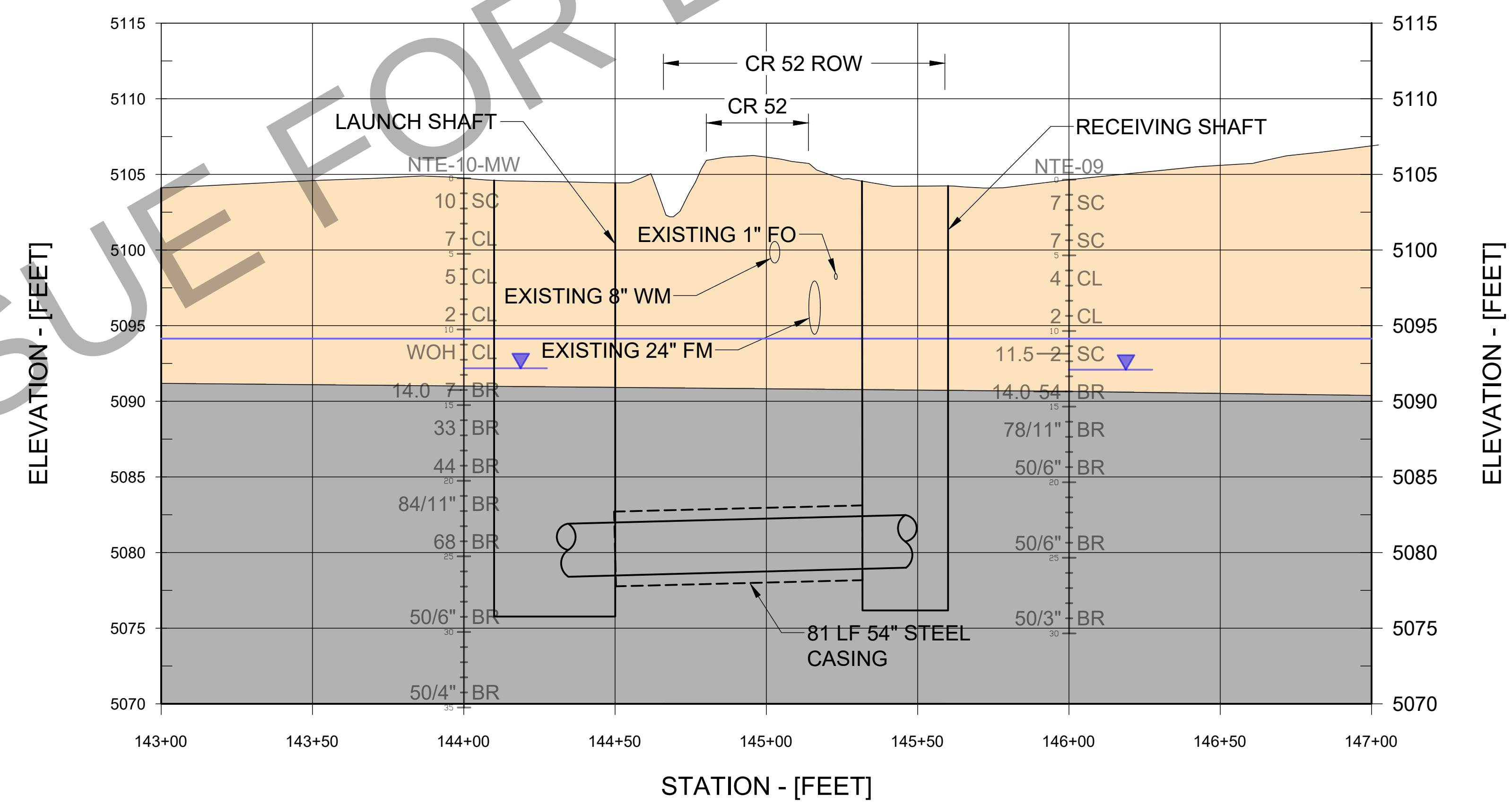
BORING OFFSETS FROM TUNNEL ALIGNMENT		
BORING ID	OFFSET (FT)	OFFSET DIRECTION
NTE-09	80	SOUTHEAST
NTE-10-MW	70	NORTHWEST

SHAFT DEPTHS[1,2]	
SHAFT	APPROXIMATE DEPTH (FT)
LAUNCH	28.8
RECEIVING	28.0

[1] NOTE: SHAFTS ASSUMED TO EXTEND 2-FEET BELOW CASING PIPE INVERT

[2] SHAFT DEPTH BASED ON SURVEY INFORMATION FROM HDR.





NOTES:

1. 5:1 VERTICAL EXAGGERATION
2. ALIGNMENT AND INFRASTRUCTURE ARE AS SHOWN IN CONTRACT DOCUMENTS BY HDR ENGINEERING INC DATED FEBRUARY 2026 AND PROVIDED HEREIN FOR INFORMATIONAL PURPOSES ONLY. REFER TO THE CONTRACT DOCUMENTS FOR FURTHER INFORMATION ON EXISTING UTILITIES.
3. GEOTECHNICAL BORINGS ARE AS SHOWN IN THE GEOTECHNICAL DATA REPORT (GDR) (GEI CONSULTANTS, 2026) AND ARE PROVIDED HEREIN FOR INFORMATIONAL PURPOSES ONLY. DETAILED DESCRIPTIONS OF THE GEOTECHNICAL BORINGS CAN BE FOUND IN THE GDR.

0 60 120

SCALE, FEET

Geotechnical Baseline Report Thornton Water Project - Segment F.2. Fort Collins, CO	GEI Consultants	CR-52 GEOLOGIC CROSS SECTION
HDR Engineers, Inc. Denver, CO	Project 2505320	August, 2026 Fig. 3.2

FAWAZ, DYLAN B:\Working\HDR\2505320 Thornton Segment F\06_DESIGN\Drawings\Thornton Segment F.2 CR 52 Crossing Plan and Profile.dwg - 8/01/2026

4. General Construction Considerations

The following sections discuss general methods GEI anticipates will be used by Contractors during construction of project shafts and tunnels. Discussed methods are not intended to dictate construction means and methods, but rather to provide GEI's opinion of various challenges to reasonable construction methods based on our experience and general practice. Within the limitations provided in the Specifications and this GBR, the Contractor is ultimately responsible for selecting shaft and tunnel excavation methods, shaft and tunnel support systems, and groundwater control plans. Of primary importance is the integrity of infrastructure, including roadways, utilities surrounding the tunnel, and other surrounding buildings and infrastructure. Existing utilities must also be crossed without damage as shown on the Contract Drawings. The Contractor's means and methods must be designed around protecting critical infrastructure while still meeting other project requirements such as safety and schedule.

The Contractor should notify and coordinate with all affected third parties in advance of shaft and tunnel construction. Third party reviews of the Contractor's construction plans and submittals may be performed, and the Contractor should allow time to address third party concerns and requirements.

4.1. Shafts

A minimum of two construction shafts (launching and receiving shafts) will be required for each tunnel. Due to available space for equipment and staging and industry preference for mining uphill, the anticipated direction of tunnel excavation is from down slope to up slope. The optimal sizing and layout of each shaft will be at the Contractor's discretion; however, it is assumed launch shafts will have approximate dimensions of 40 feet long (parallel to alignment) by 14 feet wide (perpendicular to alignment) with a depth extending to two feet below the tunnel inverts. This assumes the Contractor will use 20-foot-long jacking pipe segments. Smaller shafts are possible if the Contractor elects to use 10-foot-long jacking pipe segments. It is assumed receiving shafts will be used to recover mining equipment and place manholes connecting tunneled sections with open-cut sections. Receiving shafts are assumed to have approximate dimensions of 18 feet long by 12 feet wide with a depth extending to two feet below the alignment invert. If alternate sizing is used by the Contractor, the contractor shall notify the engineer for the relevant scaled baselines.

Shaft ground support methods are described in each tunnel section. Shaft construction will need to resist loads from the soils and bedrock such that movements of ground surface, roads, and existing utilities are kept within specified tolerances. Additional loading conditions/requirements are presented by traffic (i.e. HS-20 loading). Methods commonly employed include trench boxes, slide rail, sheet piles, secant piles, soldier piles and lagging, liner plates, ring beams, and other erected support.

Excavation is typically done by hydraulic excavator for shaft depths beneath approximately 20 feet, or with a mini-excavator working in combination with a bucket attached to a crane/excavator for greater depths. All excavated materials are anticipated to be rippable with conventional equipment. Blasting is not anticipated for any shaft on this project; however, the Contractor may assess the need for hydraulic rock breakers or other auxiliary equipment based on available geotechnical blow count data and rock engineering properties baselined in each tunnel section of this report. When considering handling of excavated materials, or “muck,” the Contractor needs to account for potential shrinkage and bulking which are defined as the change in volume of the soil from its in-situ condition following excavation, moisture conditioning, placement or compaction.

Shaft entry/exit eyes are often zones susceptible to over-excavation and running ground, particularly as a pipe or machine is jacked through the eye transition between shafts/tunnels. Over excavation at these points is often controlled by a combination of dewatering, contact grouting of surficial materials immediately outside the shafts, and incorporating a bulkhead which exposes no more ground than is necessary for excavation equipment to pass. The Contractor should assume construction of a gasketed bulkhead for tunnel excavations below the groundwater table for MTBM installations, dewatering for other techniques below the groundwater table for other techniques, and torch-cutting a hole with an appropriate overcut for tunnel excavations above the groundwater table. Lifting/raising plates/piles, or other support members at the excavation face for the I-25 crossing tunnel will not be permitted unless they are sealed prior to lifting with a cast-in-place entry or exit wall.

4.2. Tunnels

It is important the Contractor closely monitors tunnel excavation out of the launch shaft and into the receiving shaft. These locations are often where ground loss into the shaft and over-excavation of ground occurs due to disturbance from shaft construction, which can create surface settlement and/or sinkholes. If not controlled, the settlement trough can follow the path of excavation and extend beyond the immediate vicinity of the shaft and into areas where settlement control is critical, such as the roadway.

Backfill grouting and contact grouting will be required for all tunnels as further described in the Contract Specifications. Backfill grouting involves filling the annulus between initial support and the carrier pipe with an approved grout mixture. Contact grouting involves filling the annulus created by an overcut (if any) between the initial support and native ground.

4.2.1. Tunnel Excavation Methods

Tunneling methods described in this report are generally described below. The descriptions are intended to provide justification for use of each method allowed for each tunnel by describing general applicability. The descriptions are specifically excluded from the baselines and are not intended to describe means and methods nor every practical application of these techniques. These techniques are listed in order corresponding to their general ability to control baselined ground and groundwater conditions presented above using standard and readily available equipment, from least capable to most capable. Equipment or equipment modifications are sometimes used, either at the option of the Contractor or as required by the Contract Specifications, to control specific risks associated with site-specific ground conditions. Each Contractor involved in this project has been pre-qualified for use select various techniques listed below by demonstrating proficiency and success using their select method(s).

The Contractor should be aware each of the excavation techniques is subject to project challenges and it is ultimately the Contractor’s responsibility to select and perform tunnel construction best suited to their experience and capability to reduce manageable risk to affected third parties. Some of the specific challenges associated with each tunnel excavation method are described in each respective tunneling section of this report.

4.2.1.1. TBM

Excavation by TBM involves a wheeled excavator with a rotating cutting head equipped for the anticipated ground conditions. The cutting head has removeable panels and disjointed openings which limit material inflow. The TBM is propelled by a jacked casing. Excavated muck is removed from the tunnel by conveyor/bucket.

This is considered a non-pressurized, open-face technique suitable to dry/moist non-running or flowing soil or bedrock. This technique is sometimes used in combination with dewatering to promote better stability of the excavation face.

4.2.1.2. Guided Auger Bore

Guided auger boring involves excavation with a steel auger located ahead of or within a jacked steel casing. The auger teeth are equipped for the anticipated ground conditions. In bedrock such as will be encountered onsite, a specialized auger head is commonly used (e.g. “On-Target head” by McLaughlin or equivalent). An On-Target head or equivalent is steerable in baselined ground conditions and does not require a pilot tube. Auger bore systems not capable of accurate steering in both line and grade direction will require a pilot tube, which may require modifications both in cutting ability and adapters to match baselined ground density and strength. A pilot tube is pushed ahead of the auger casing to set the alignment and smaller-diameter casings (“upsizings”) may precede the final casing to prevent alignment deviation. The auger flights transmit excavated muck to the shaft where it is removed.

This is considered a non-pressurized, open-face technique suitable to dry/moist soil, cohesive soil with minimal water head, or firm bedrock. This technique is sometimes used in combination with dewatering to promote better stability of the excavation face.

4.2.1.3. MTBM

Excavation by MTBM involves a wheeled excavator with a rotating cutting head equipped for the anticipated ground conditions. The cutting head has a closed face with inflow/outflow ports. The inflow ports allow for injection of a specialized slurry, generally water, bentonite, and anti-clogging chemicals, which counteract in-situ ground pressures. The outflow ports allow for withdrawal of the slurry and excavated ground where the mixture is screened through a slurry separation plant and recycled. A surface-based operator carefully monitors slurry inflow/outflow, machine advance, and jacking loads, among other parameters, to minimize chances for over excavation. The MTBM is propelled by a jacked casing.

This is considered a pressurized, closed-face technique suitable to all ground conditions anticipated on this project. This technique prohibits worker access to the excavation face if an obstruction is encountered.

4.3. Instrumentation and Monitoring

The Contractor will be required to install, monitor, and report utility monitoring points, pavement monitoring point arrays, and surface survey points at all crossings per the Contract Drawings to assess potential ground deformation associated with tunneling. If alert threshold deformation values are reached or exceeded at any monitoring point, the Contractor will be required to perform measures to prevent further deformation. Systematic settlement analysis has been performed based on a conventional equipment overcut, and settlement in exceedance of the stipulated exceedance values is not anticipated with good Contractor practices. The Contractor should familiarize themselves with the minimum number of monitoring points, arrays, deformation values, and requirements provided in the Contract Documents.

4.4. Environmental Considerations

Measurement of subsurface gas was not completed or noted during the subsurface investigations. For baseline purposes, material encountered during shaft and tunnel excavation shall be considered "Potentially Gassy" per OSHA 3115-06R (2003).

Contaminated ground was not noted during environmental site assessments in the crossing vicinity. For baseline purposes, extra precautions or measures will not be required to handle, treat, or dispose of contaminated ground.

5. Limitations

This report was prepared in accordance with generally accepted geotechnical engineering and engineering geologic practices and principles; no warranty, express or implied is made. The subsurface conditions described in this report were based on data obtained from widely spaced exploratory borings and geotechnical laboratory testing performed by others, information provided by the client, engineering judgement, and our experience with similar subsurface conditions and projects.

This report has been prepared exclusively for our client for design, bidding, and construction purposes for the subject project. GEI is not responsible for technical interpretations by others of the data presented in this report or use of this report by others for the subject project or other projects.

The baseline values presented in this report are only intended for the proposed design and construction as understood by GEI at the time of issuing this report. If the proposed design and construction changes, GEI should be notified immediately and given the opportunity to review the proposed changes and if necessary, modify our baseline values presented herein.

An environmental assessment was not included in GEI's scope of work for this project. Any statements regarding the absence or presence of hazardous and/or toxic substances presented herein are only intended for baseline purposes. Environmental site assessments are to be conducted by others for this project.

References

References listed herein are included as information only. The Contractor may not rely upon the provided references as baseline statements in any phase of the project.

American Society of Civil Engineers, 2022, Geotechnical Baseline Reports, Suggested Guidelines, prepared by the Task Committee on Geotechnical Baseline Reports, edited by Randall Essex.

American Society for Testing and Materials International, Designation: D2487-17, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).

Colton, R. B., 1978, *Geologic Map of the Boulder-Fort Collins-Greeley area, Front Range Urban Corridor, Colorado.* Retrieved from USGS National Geologic Map Database: https://ngmdb.usgs.gov/Prodesc/proddesc_9734.htm

GEI Consultants, Inc., 2026, Geotechnical Data Report, Thornton Water Pipeline – Segment F.2, Fort Collins, CO, prepared for HDR Engineering, Inc., Issue For Bid, submitted August 2026.

Heuer, R.E., 1974, Important Ground Parameters in Soft Ground Tunneling, In Proceedings, Specialty Conference on Subsurface Exploration for Underground Excavation and Heavy Construction, ASCE, New York, N.Y., 41-55.

Hollman, F., and M. Thewes, 2012, Evaluation of the Tendency of Clogging and Separation of Fines on Shield Drives, Geomechanics and Tunneling 5, p. 574–580.

International Society for Rock Mechanics, 2007, Rock Characterization Testing and Monitoring, Pergamon Press, part a.

Jakobsen, P.D., B. Amund and F. Dahl, 2013, Review and assessment of the NTNU/SINTEF Soil Abrasion Test (SAT™) for determination of abrasiveness of soil and soft ground, Tunnelling and Underground Space Technology v.37, p 107–114.

Occupational Safety and Health Administration, 2003, Underground Construction (Tunneling), United States Department of Labor, OSHA 3115-06R.

Thewes, M., and Burger, W., 2004, Clogging Risks for TBM Drives in Clay, Underground Space USE: Analysis of the Past and Lessons for the Future, Erdem & Solak (eds), p 737–742.

Appendix A Tunnelman's Ground Classification Chart

Tunnelman’s Ground Classification Chart (Soil)

Classification	Behavior	Typical Soil Types
Firm	Material at the face is stable and holds a vertical face unsupported.	Hard clay, cemented sand
Slow Raveling	Material ravels from the face within hours after the ground has been exposed.	Sands with fines, fine sands above water table
Fast Raveling	Material ravels from the face within minutes after the ground has been exposed.	Sands with fines, fine sands below water table
Squeezing	Soil slowly advances into tunnel without signs of fracturing	Soft to stiff clays where the overburden pressure is higher than the soil shear strength.
Swelling	Soil moves slowly into tunnel, associated with a considerable volume increase in the ground surrounding the tunnel.	Highly overconsolidated high plasticity clays.
Cohesive Running	Preceded by brief period of raveling, soil will then “run” like a granulated sugar until the slope angle reaches its angle of repose.	Clean, fine, moist sand.
Running	Immediately upon exposure, the soil will “run” like a granulated sugar until the slope angle reaches its angle of repose.	Clean, coarse or medium sand above water table.
Flowing	Flows as a mixture of soil and water into the heading.	Silt, sand, and gravel beneath the water table without fines.