FEASIBILITY STUDY
A-0009C TUNNEL PROJECT
GRAHAM COUNTY, NORTH CAROLINA

Report to:
NORTH CAROLINA DEPARTMENT OF TRANSPORTATION (NCDOT)
HIGHWAY DIVISION 11

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INTRODUCTION

The project is located in southwestern North Carolina near the Tennessee and Georgia borders. The proposed route transits through swaths of the Nantahala National Forest and sections of Tribal Land holdings. Transportation options in the area are limited and primarily consist of a few narrow, two-lane roads that have sharp curves and steep grades. Two tunnel options are under consideration near Stecoah Gap, North Carolina; S2 with a length of approximately 4470 linear feet and SW1A with a length of approximately 5408 linear feet. The south portals for each of the two tunnel alignments are at the same location, but the S2 alignment trends northeast of the SW1A alignment. When completed, the tunnel would include single lanes of traffic in each direction and would facilitate efficient passage of motor vehicles through this the region.

SITE CONDITIONS

Topography and Slopes

The maximum ground cover above Alignment S2 is about 635 feet at Station 65+00. The maximum ground cover over SW1A is about 670 ft at Station 68+00. The maximum apparent slope above the tunnel alignments is about 55° on the upper north slope of Sweetwater Gap.

Regional Geology and Stratigraphy

Both tunnel options would be bored through the Late Proterozoic Ammons Formation. The Ammons Formation is approximately 5,000-ft thick and, in the vicinity of the tunnel alignments, represented by the Horsebranch Member which strikes N to N20°E and dips steeply or vertically. A right-lateral strike-slip fault with approximately 3000-ft of offset is mapped in the proximity of the proposed alignments. The bedrock is a dark gray, graphitic and sulfidic mica schist and metasiltstone interbedded with muscovite schist and metagraywacke. Overlying the bedrock materials are soil units that are composed of residual soils, colluvium, and alluvium of varying thicknesses. In shallow sections of the alignments the crown of the tunnel may be within the surficial soils. Groundwater levels are assumed to be deeper than the rock/soil interface.

Future Geotechnical Explorations to Characterize the Tunnel Alignments

Due to the limited access and steep slopes above the tunnel alignments, conventional vertical and angled geotechnical borings will be difficult to perform. Brierley proposes performing horizontal boreholes through the tunnel horizon to characterize the geology along the entire alignment. Holes will be drilled from each portal towards the tunnel center, and continuous HQ sized core will be acquired. Geophysical monitoring, water pressure testing, and laboratory testing of recovered samples will also be performed.

DESIGN OPTIONS

Portals

Both the northern and southern portals of each alignment will commence with vertical cuts at the rock face and require spiling above the crown down to each springline to support the excavation. The length of the spiles should be one equivalent tunnel diameter long to provide adequate longitudinal support to the tunnel crown. Each spile would be spaced at approximately 18-in centers.

Tunnel

The tunnel for either alignment will be a horseshoe shaped tunnel with approximate dimensions of 52 feet wide at the invert and 39 feet high at the crown. The tunnel will be designed to be constructed as a two-lane road with a traffic barrier and an elevated pedestrian walkways on both sides. The tunnel will include a waterproof membrane. Ventilation and fire suppression systems will be installed in compliance with applicable codes. An exterior administrative and maintenance building will be built onsite and will house the tunnel ITS/SCADA systems.

CONSTRUCTION CONSIDERATIONS

Portal Construction

The portal work site would likely require several preparatory tasks including coordination with local landowners/tribes for access, locating utility lines in the subsurface, construction of an access road from NC 143 to the work pad, felling trees along the alignment, leveling ground for machinery and drill rigs, and excavating into hillslopes. Also, significant cut sections arriving to the portal(s) will require handling and disposal of large quantities of soil and rock muck materials. Feasibility level estimates of muck are about 380,000 bank cubic yards for the S2 alignment and 465,000 bank cubic yards for the SW1A alignment assuming a 1.45 swell factor.

Tunnel Construction

Anticipated Rock Type and Behavior

Overburden materials above the top of rock are typically less than 40-ft thick. A weathered and highly fractured/jointed interval commonly occurs beneath the overburden soils and is generally no thicker than 50-ft. Below the weathered interval, the rock is inferred to be hard and relatively fresh. Lithologies logged from nearby boreholes include metagraywacke, metasiltstone, and schist. The quality of rock is inferred to vary between “fair” to “very good”. The rock will require support after excavation, particularly in the areas near the portals where the rock is of poor quality. Potential support systems could include local rock bolt patterns, wire mesh, lattice girders, and shotcrete.

Anticipated Tunnel Excavation Methodology

Foliation planes and other sources of weakness are anticipated to be present in the schistose portions of the excavated bedrock. Other sections particularly in the metagraywacke will be massive potentially without jointing for distances of feet or tens of feet. Although a roadheader will likely efficiently mine the schistose rock, it will not have adequate production rates in the metagraywacke and therefore, drill and blast techniques have been used to assess constructability and prepare the feasibility level cost estimate for the tunnel. The Sequential Excavation Method is recommended, using a single bench and twin headings, with the tunnel excavated upslope from north to south. Removal of the excavated materials will be performed by rubber-tired loaders into off road articulated trucks and hauled away. All suitable material should be used as fill material for the roadway construction, if possible.

Feasibility Level Cost Estimates for Tunnel Construction and Operations/Maintenance

The feasibility level costs for construction and operations/maintenance (O&M) were estimated for each tunnel alignment. For the construction costs, Class 4 Feasibility Study guidelines in accordance with ACEE (2005) were used to provide an expected accuracy range of -30% to +50% of the estimated cost. Using this method, the estimated cost for construction of the S2 alignment ranges from $151,634,469 to $324,931,005 and for the SW1A alignment from $183,453,962 to $393,115,632.

Using available costs from similar highway tunnel projects in the Appalachian region, the annual O&M budgets are estimated to be about $3,800,000 for the S2 alignment and $4,200,000 for the SW1A alignment.

1. INTRODUCTION

The North Carolina Department of Transportation (NCDOT) is considering development of the A-0009C Tunnel near Stecoah, North Carolina. This report assesses available geotechnical data and earlier reports related to previous alignments considered by NCDOT, and applies this information to the feasibility and preliminary cost estimates for two alignments currently under consideration. This project is part of Corridor K of the Appalachian Development Highway System – a network of road corridors that Congress established in 1965 to provide a safe, efficient transportation system for the Appalachian Region. Corridor K extends from Dillsboro, NC in Jackson County westward to I-75 in Cleveland, Tennessee. The project is located in southwestern North Carolina near the Tennessee and Georgia borders. The proposed route transits through swaths of the Nantahala National Forest and sections of Tribal Land holdings in the westernmost portion of North Carolina (Figure 1).

Given the challenges associated with the region's rugged, mountainous terrain and the presence of natural and cultural features, the proposed project is among the last of the Appalachian Development Highway System corridor sections to be completed. Transportation options in the area are limited and primarily consist of a few narrow, two-lane roads that have sharp curves and steep grades. Roads in the region are prone to closure due to landslides, limited visibility due to fog conditions, heavy snowfalls, and other weather-related effects. This project, originally proposed under the Appalachian Regional Commission, which was established by an act of Congress in 1965, has reached various points of project development over the past several decades. After a pause in 2011 to conduct a regional study and develop County Comprehensive Transportation Plans, the project was restarted in 2015.

This feasibility study was conducted to consider geologic and geotechnical issues of a proposed highway tunnel along the current S2 and SW1A alignments. The proposed tunnels are approximately 1 mile north of existing NC 143 through Stecoah Gap. When completed, the S2 Tunnel would be 4,470 (linear feet) LF long, while the proposed SW1A Tunnel would be approximately 5,408 LF. Either tunnel would consist of two traffic lanes and would facilitate efficient and reliable passage of motor vehicles through this mountainous region.

For this feasibility study, Brierley Associates Corporation (Brierley) reviewed data, documents, and reports pertaining to the geology and geotechnical characteristics of rocks and soils near alignments S2 and SW1A, which has been proposed to pass under the physiographic feature known as Sweetwater Gap and terminate approximately 1 mile north at Johnson Gap. Both features are west of the village of Stecoah. This study contains a synthesis of these documents and previous field investigations concerning various segments of Corridor K. Additionally, this feasibility study provides our professional opinions regarding the anticipated site conditions, geotechnical characterization of rocks and soils, design options for the tunnel, and construction considerations, including preliminary opinions of probable cost.

2. PROJECT BACKGROUND

2.1 Proposed Alignments

North Carolina resource and transportation agencies met in 2016 to explore design and alignment options. The project team identified locations where NCDOT and FHWA should evaluate improving existing roadways and other areas where improving the existing roadways might not be feasible. In these areas where proposed roadways were deemed infeasible, it was agreed that NCDOT and FHWA would study options for alternate alignments. After the 2016 Design Workshop, NCDOT and the Federal Highway Administration (FHWA) began evaluating design options. As part of taking a fresh look at the project, the team used the software "Quantm" (Trimble) to generate potential design options. Quantm is an alignment optimization software that NCDOT used to find and evaluate alignment options.

As a result of this Quantm study, two tunnel alignments (along with improving existing facilities) were recommended for detailed analysis by the project team. These two proposed tunnel alignments were:

S2: This new location design option includes a two-lane tunnel with a portal to portal length of 4,470 feet under existing NC 143 and the Appalachian Trail (AT). This tunnel option varies in depth from approximately 75 feet to 646 feet below ground surface (bgs). The alignment originates at NC 28 and follows the north side of the Stecoah Valley, then turns south, crossing NC 28 and NC 143 south of their intersection, before ascending to a tunnel passing under the Appalachian Trail, after which the corridor turns south paralleling NC 143 to the east before converging with existing NC 143.

SW1A: This new location design option includes a two-lane tunnel with a portal to portal length of 5,408 feet under existing NC 143 and the AT. This tunnel option varies from approximately 89 feet to 721 feet bgs. Proposed alignment SW1A would begin near the western intersection of proposed alignment S2 and trend to the north-northeast. The alignment will pass beneath Sweetwater Gap and terminate north at Johnson Gap, intersecting NC 28 (also known as Fontana Road).

When compared to the range of other Quantm-generated options, this scenario was the shortest new location option and presents opportunities for including climbing/passing lanes. Of all the Quantm scenarios in the Stecoah area SW1A is expected to have the least impacts on the Nantahala National Forest and the lowest potential for visual impacts for foot traffic along the AT. Figure 2 at the end of this report shows an aerial view of the proposed S2 and SW1A alignments. Additionally, Brierley created preliminary interpreted geologic profiles along both alignments included as Appendix A.

3. ANTICIPATED SITE CONDITIONS

3.1 Topography and Slope

The S2 and SW1A alignments are located in Graham County, North Carolina, approximately 1.5 miles due west of the village of Stecoah. Much of both of these alignments lie within the Nantahala National Forest, which contains some of the state's most rugged terrain. Natural hillsides are steep and irregular with slopes up to 30° common in the area. Local topography along the alignments varies between 2,500 feet and 3,500 feet above mean sea-level (msl).

The invert of the southern portal of the S2 Tunnel is located at EL 2,670 ft and is located approximately 200 feet south of where the Appalachian Trail crosses Sweetwater Gap. The invert of the southern portal of the SW1A Tunnel is at the same location and elevation as the S2 Tunnel portal. The invert of the northern portal of the S2 is located along NC 28, at approximately at El 2,568 feet, approximately 1,000 feet southeast of the intersection of NC 28 and NC 143, while the northern portal of SW1A is located about 1000 feet north of the northern portal of S2 at El 2,510 feet.

The proposed alignments pass through a section of Tribal Land holdings. The headwaters of Sweetwater Creek originate near the southern portal of the proposed alignment and the creek flows south to enter Hiawassee Lake via the Valley River.

3.2 Regional Geology

Proposed alignments S2 and SW1A would pass through the Late Proterozoic Ammons Formation, which is part of the Great Smoky Group (Southworth, et al., 2012; Wiener & Merschat, 1992). The Ammons Formation is estimated to be approximately 5,000 feet thick and contains primarily thick-bedded metasandstone that is interlayered with phyllite, argillite, and schist.

Alignments S2 and SW1A would both be excavated through the Horsebranch Member of the Proterozoic Ammons Formation. The Horsebranch Member is described as a dark gray, graphitic and sulfidic mica schist and metasiltstone interbedded with muscovite schist and metagraywacke. Minor rock type characteristics include bluish-white quartzite and porphyroblastic schist (garnet and biotite). This member unit contains a significant component of sulfidic and graphitic schist (Mohr, 1973; Wiener & Merschat, 1992) which could have the potential to affect concrete and steel design for the constructed tunnel and should be further considered during Final Design.

The northern end of the tunnel alignments is located just south of the contact between the Horsebranch Member and the Wehutty Formation. The Wehutty Formation is lithologically and structurally similar to the Horsebranch Member, although it contains a relatively higher abundance of schist and less metagraywacke with respect to the Horsebranch Member. The Wehutty Formation can be characterized as a dark-gray graphitic and sulfidic fine-grained schist interbedded with metagraywacke and metaconglomerate interlayered with minor muscovite schist (Wiener & Merschat, 1992).

A regional map (Wiener & Merschat, 1992) shows open folds and faults in the proximity of the proposed S2 and SW1A alignments. Figure 3 below is a simplified geologic map showing the location of proposed alignments with respect to known local geologic structures. It is important to note that given the complex structure and heavy vegetated cover of this part of the Appalachian Mountains that other, undetected fracture zones might be present and intersect the alignments.

3.3 Stratigraphic Conditions

3.3.1 Overburden Materials

Surficial deposits adjacent to the study area are inferred to be of three geologic origins: residual soils, colluvium, and alluvium. For this feasibility study, Brierley relied on a report from 1995, (Acker & Reed, 1995) as well as a geophysical survey that was conducted southeast of Stecoah Gap for information regarding the nature, thickness, and extent of overburden soil units (Trimble, 1998).

Residual soils (including saprolite) range in depth between 0 feet and 30 feet below ground surface near the southern portal of both alignments S2 and SW1A. Soils are frequently deeper in the low hills and valleys east of the alignments. These soils are brownish-tan to reddish-brown and can be classified as micaceous sandy silt or clayey silt. The thickness of weathered rock below the saprolite zone is approximately 30 to 50 feet thick. This is discussed in greater detail below.

Colluvium (the surficial layer of loose rock and soil emplaced by gravity on steep slopes) varies between approximately 5 feet and 40 feet thick and depths up to 60 feet could be anticipated along the proposed alignments. These soils include debris avalanche deposits and tend to develop in the steeper terrain near the alignments and are typically silty with many large rock fragments and occasional boulders. Results from the 1998 Trimble geophysical survey suggest that the high seismic velocity rock line (assumed as the boundary between weathered rock and fresh rock) underlying the colluvium generally occurs between approximately 55 to 100 feet below ground surface.

Alluvium is composed of sediments deposited by water flow such as streams, creeks or rivers. Boulder and gravel debris flow alluvium occur throughout the tributary valleys of Stecoah Creek and Sweetwater Creek. Alluvial deposits occur as fans, lobes, and elongated valley trains originating at the mouth of ravines and extending into the valleys. At their distal ends, these debris flows grade into valley floodplain deposits. Alluvial deposits can become potentially unstable when water saturated, especially when slopes approach their angle of repose, typically above 30°.

3.3.2 Structural Geology

The proposed tunnel alignments will be located in the foliated, interlayered schist, argillite, and metagraywacke layers as described above. The tunnels will be oriented sub-parallel to the strike or foliation and bedding planes, which both dip at steep angles. Vertical joints in this area typically strike north-south and show minor offsets.

Bedding and foliation in this region typically show two dominant orientations: 1) striking N to N20°E and dipping steeply perpendicular to strike or vertically; and 2) striking approximately NW to SE and dipping steeply toward the south. A less statistically significant population of strike and dip data indicates that some bedding planes also strike NE and steeply dip to the SE (Figure 4).

3.3.3 Faults and Shear Zones

A right-lateral strike-slip fault with approximately 3,000 feet of offset has been mapped in the proximity of the proposed S2 and SW1A alignments, parallel to and east of the tunnels (Figure 3). The existence of this fault has been inferred from apparent offset between the Horsebranch Member and the underlying Wehutty Formation. Recent geologic mapping (Southworth, et al., 2012) suggests that the kinematic movement along this fault is normal (hanging wall moves down with respect to foot wall), versus strike-slip. It is entirely plausible that this fault has both normal and right-lateral strike-slip kinematic components, as observed in other faults in the Appalachian Region. The proposed alignments should not intersect this fault as mapped because they are oriented roughly parallel to each other. However, it is important to note that joints showing offset have been observed in local outcrops. These features have the potential to facilitate groundwater migration along these planes and could lead to wedge instability within the tunnel envelope if not properly supported. Figure 3 shows the location of proposed alignments S2 and SW1A with respect to local geologic structures. It is important to note that given the complex structure and heavy vegetated cover of this part of the Appalachian Mountains that other, undetected fracture zones may be present and could intersect one or both of the proposed alignments.

3.3.4 Preliminary Geotechnical Characteristics of Bedrock Materials

Very limited geotechnical information is available for the project area. During subsequent phases of this project, we propose to determine if other existing borings have been completed near the project area and we will perform project-specific geotechnical investigations that will allow us to more accurately characterize the subsurface.

Florence & Hutcheson (1996) prepared a subsurface investigation report for NCDOT, which included four exploration boreholes completed along NC 143 near Stecoah Gap. The borings were performed to depths ranging between 18 feet and 500 feet below ground surface. Boring logs were included in the report, which indicated that the bedrock materials encountered consisted of interlayered schists, metasiltstones and occasional metagraywackes, generally similar to the materials anticipated for Alignments S2 and SW1A as described above.

Extensive sets of core photos were included but were of insufficient image resolution to assess rock character and quality. No laboratory tests were presented for the recovered rock cores, but the boring logs provided details as to the material types and provided conventional rock classification information such as Rock Quality Designation (RQD = the percentage of the core run that was recovered in intact core pieces greater than 4 linear inches in length) and Total Recovery percentage for each core interval, and included summaries of weathering, color, joint frequency/orientation/condition for each core run.

The report indicates that in general the materials ranged from poor to very good rock quality materials, with RQDs typically ranging from 0 to over 70% and Total Recoveries typically ranging from 65 to 100%. The following table provides a summary of additional information concerning the materials encountered in each boring.

Table 1: Geotechnical Properties summarized from Explorations by Florence & Hutcheson (1996)

Properties	Boring-1	Boring-2	Boring-3	Boring-4
Ground elevation	3,087 ft	2,929 ft	3,090 ft	3,090 ft
Termination depth	383 ft	250 ft	204 ft	18 ft
Depth of overburden	43 ft	30 ft	15.5 ft	18 ft
Overburden material	Silty soil with rock fragments and boulders	Silty sand soil with rock fragments and boulders	Silty soil with rock fragments	Silty soil with rock fragments
Bedrock type	Interbedded schist and metasiltstone	Interbedded schist, metasiltstone, phyllite with occ. quartz veins	Interbedded schist and metasiltstone with occ. quartz veins	Terminated at rock contact, no core recovered
Assumed bedrock quality by Brierley based on core logs	Poor to fair to 150 ft, becoming fair to good below 150 ft	Poor to fair to 115 ft, becoming good to very good below 115 ft	Poor to fair to 88 ft, becoming good to very good below 88 ft	N/A
Groundwater below ground surface	66 ft	79 ft	67 ft	Not encountered

3.4 Groundwater Levels

Groundwater elevation data was presented in three of the four borings as shown above in Table 1. These borings were located east of the tunnel alignments on the eastern slopes of the north-south trending Stecoah Gap ridge and indicate that groundwater elevations in this area vary between EL 2874 and EL 3038. The data above indicates that groundwater levels are generally at a deeper depth than the soil/rock interface in these materials. However, in the absence of site specific data near to the proposed alignments, groundwater levels in the vicinity of the tunnel alignments are unknown.

Brierley was unable to locate United States Geological Survey or equivalent groundwater well data for the majority of Graham (and adjacent Swain) County. Therefore, future field investigations along the recommended alignment should include clarifying the depth to groundwater specifically along the alignments as there is a large range of surficial cover ranging from less than 30 vertical feet to a maximum of about 670 vertical feet of relief over the reach of the alignment.

3.5 Natural Gas Potential

The tunnel will be classified as either non-gassy, potentially gassy, or gassy in accordance with OSHA and/or FHWA standards. Typically, the geologic formations to be excavated for the tunnel are assessed for the presence of methane and hydrogen sulfide gas. Future geotechnical investigations for the tunnel will include using environmental probes to measure gas levels. For this study the tunnel is assumed to be non-gassy based on the local geology.

4. FUTURE GEOTECHNICAL EXPLORATION PROGRAM

Although numerous field investigations were conducted in the mid-1990's for a portion of Corridor K, little data exists for the specific section along the S2 and SW1A alignments. Much of these earlier field campaigns included geophysical surveys, boring logs, and field mapping of various sections along NC 143 between Robbinsville and Stecoah. However, these surveys did not focus on geotechnical characteristics of Sweetwater and Johnson Gaps, which are the dominant physiographic features along the S2 and SW1A alignments.

4.1 Potential Methods

Two feasible methods exist to explore the geotechnical characteristics beneath Sweetwater and Johnson Gaps. These include 1) vertical and sub-vertical to steeply angled borings and 2) horizontal (possibly including directional) borings. This section of the feasibility study explores both of these methods.

4.2 Advantages and Disadvantages of Vertical and Angled Borings

Vertical and sub-vertical to steeply angled borings are traditionally performed in geotechnical exploration programs to determine the nature and extent of overburden materials, bedrock, and groundwater conditions. This method of performing explorations has been the standard for subsurface projects for over 100 years. Since vertical and sub-vertical angled borings only encounter the actual tunnel zone for short intervals at perpendicular or near-perpendicular angles, they provide limited information on the materials to be encountered during tunnel excavation between borehole locations. They require a lot of "access drilling" to collect data in the zone of interest at the tunnel horizon.

In order to provide a reasonable characterization of the subsurface materials along the tunnel alignment, vertical and sub-vertical angled borings must be relatively closely spaced at regular, intervals to provide an understanding of the lateral variation along the tunnel alignment. Industry standards for tunnel exploration programs generally vary from about 2,000 feet horizontal spacing in preliminary phases of studies to about 500 feet spacing in advanced design phases.

Some advantages of using vertical and sub-vertical angled borings include:

- Good understanding of vertical variability in soil / rock properties in individual borings,
- Accurate determination of depth to groundwater and hydraulic conductivity of the bedrock,
- Accurate determination to top of rock and the weathered-fresh rock boundary, and
- Samples are collected in the same orientation as testing is usually performed, allowing for a good understanding of horizontal variation in bedding and geologic structure,
- Drilling logistics are more "standard" and can be performed by more vendors, often at lower unit price costs,

Some disadvantages of using vertical and sub-vertical angled borings include:

- Very limited core recovery from the actual materials within the tunnel horizon
- Limited understanding of lateral variability across project site (especially when bedding or foliation is steeply dipping),

- Requirements to access and prepare multiple drill pads is difficult in remote areas, and
- High cost of access to remote drill pads which can require road construction over long distances, or helicopter support.

Therefore, there are many instances where vertical borings may not be the most appropriate choice during the field exploration campaign. This is especially true in areas of multiple land use and ownership with problematic access permit issues. In these cases, it may be more beneficial to use horizontal bores that advance along the tunnel horizon instead of vertical/angled borings for ground characterization. It is Brierley's understanding that permits will not be issued by the USFS until the SCOTUS has issued a ruling on the Cowpasture River case. This case questions whether the USFS has authority to grant ROW through lands crossed by the AT within National Forests. Horizontal borings also have advantages for tunnels with portals, if accessible, as noted below.

4.3 Horizontal Geotechnical Boring

Horizontal geotechnical boring (with and without steerable horizontal directional drilling technology) is a more recent drilling technique application that has been successfully employed by Brierley on remote and urban tunneling projects to better constrain lateral variability along or through a tunnel alignment. Recent advances in horizontal bore technology has allowed for longer distance bores, comparable core diameters to conventional holes, and specialized in situ tools that can directionally steer the borings, seal boreholes, grout fracture zones, and measure physical properties along horizontal reaches.

Some of the advantages of horizontal direction drilling include:

- Better definition of lithology variations including behavior at the borehole scale,
- Continuous record of rock quality parameters within the tunnel horizon,
- Continuous record of permeability conditions within the tunnel horizon,
- Fault zone discovery and characterization,
- Continuous samples from the tunnel horizon for strength and TBM performance testing, and
- Identification of hard and/or abrasive rock zones within the tunnel horizon.

Additionally, horizontal geotechnical borings can provide supplemental information such as:

- Continuous survey of the borehole via gyro survey tools records azimuth and dip to maintain the bore within the tunnel horizon, if necessary,
- Ability to capture 3-dimensional view of borehole wall via in hole cameras,
- Determines orientation of any planar feature intersecting borehole,
- Calculates frequency and aperture of features via televiewers, and
- Provides recovery of rock core along the entire alignment for laboratory testing.

Due to the factors described above, Brierley recommends that a horizontal bore be completed through the most of or the entirety of the preferred tunnel alignment. This could be done by advancing a single, slightly uphill directionally drilled boring from the North Portal to the south portal. Alternatively, this could be accomplished by two, shorter borings that might not need more sophisticated directional drilling equipment ("conventional horizontal drilling"), one drilled from each portal. Portal development at the more remote South Portal will ultimately be needed for project access and “pioneer” development of this portal for geotechnical investigations may be worthwhile.

This method will result in better characterization of the subsurface materials within the tunnel horizon as compared to several widely-spaced vertical and angled boreholes performed from above the tunnel into the tunnel zone. This method will produce the most comprehensive results regarding rock and structural geologic variability along the length of the alignment. This is especially important considering that rock beds and foliation dip at steep angles and these features would likely be missed in vertical bore holes. Reducing risk uncertainty in the available geotechnical data for a tunnel always reduces risk contingency in the design and construction costs of the project. Collection of more and better geotechnical data needs to be viewed as a value investment in the project, the cost of which is returned many times over during design and construction.

Appendix B presents a cost estimate to perform horizontal borings from portal to portal, prepared by Brierley and based on preliminary cost information from a geotechnical drilling contractor experienced in successful completion of long horizontal geotechnical borings, Crux Subsurface of Spokane Valley, Washington.

5. DESIGN OPTIONS

5.1 Portals

Both the northern and southern portals of both alignments will require spiling or a pipe arch canopy above the crown to pre-support the excavation. The length of the canopy pipes (drilled horizontally) would be at least approximately one equivalent tunnel diameter long to provide adequate longitudinal pre-support to the tunnel crown in the anticipated soil and/or weathered rock conditions. Spiles (drilled "looking up" at a shallow angle) would be drilled in advance of each round, and of sufficient length to achieve overlap of two to three spile rounds spanning over each excavation round.

A general spiling design consists of #8 tensioned bar grouted into a 2-inch drill. Spiles are typically installed above the tunnel crown downwards to each springline. Each spile would be spaced at approximately 18-inch centers depending on geology. Alternatively, the more robust grouted pipe-spile arch canopy using approximately 4-in diameter drilled steel pipes could be installed. It is important to note that the north portals have limited rock cover and likely will be entirely constructed within weathered rock, and possibly soil depending upon portal development excavation prior to turning under to begin tunneling. This may require additional stabilization such as supplemental, more closely spaced spiles, grouting, or soil nails, or the pipe arch as noted.

5.2 Tunnel Configuration

Figure 5 presents a schematic of the tunnel cross section showing assumed tunnel dimensions and space utilization used to prepare the feasibility level cost estimate. It is similar to an earlier tunnel cross section presented by Stantec (2008) in a previous project related report, which is reproduced as Figure 5a. The tunnel cross section assumed for this report would contain two 12 foot travel lanes, two 9 foot shoulders and an elevated pedestrian walkway (Figure 5b). There would be cross-passages along the tunnel at regular intervals installed in a longitudinal plenum wall constructed during tunnel finish work to facilitate the evacuation of vehicle occupants in the event of an emergency.

The tunnel would consist of one bore that would be constructed using the Sequential Excavation Method (SEM) designed to be excavated and supported in sequential stages as twin top headings and a single bench. The top heading would consist of two side drifts, left and right, followed by the bench. The dimensions for the bench would be about 18 feet high and the full tunnel width of 52 feet. The combined top heading drifts are estimated to be advanced 12 feet per day in individual blast rounds of 8 to12 feet. The bench is estimated to be advanced 30 feet per day in 10 to 15 foot rounds, with the top headings staggered horizontally during the excavation sequence to provide additional sidewall and crown stability during construction.

We have assumed that it will take different methods to support the tunnel during the mining operation including the use of rock bolts, rock dowels, shotcrete, lattice, girders, grouted and self-drilled spiles and possibly a grouted pipe canopy for initial arch support at the portals. The design of the above support systems will be dependent on rock type and quality, water inflow, and the means and methods employed by the Contractor. It is recommended the final lining be cast-in-place concrete backed by a waterproof membrane installed from invert to crown on each side of the tunnel, and a drainage fleece. We estimated final lining production at approximately 35 feet per day.

Additional information concerning tunnel construction considerations is presented in Section 6.

5.3 Ventilation Options

It is required considering the length of either tunnel alignment that mechanical ventilation be provided for congested conditions and for a fire emergency condition per the National Fire Protection Association (NFPA) 502, Standard for Road Tunnels, Bridges, and Other Limited Access Highways. Chapter 7 of the Standard requires mechanical ventilation for tunnels with a length greater than 790 feet.

Regarding the ventilation system, the cost estimate considers a longitudinal application with a diaphragm/plenum wall connected to an overhead crown plenum for moving air with a ventilation structure at the portal. An alternate application would be a transverse application with ventilation ducting in the walkways with a Type F Jersey Barrier separating the traffic flow.

5.4 Fire Suppression Systems

The fire suppression system assumes an 8-inch diameter fire water line to be installed on each side of the tunnel but the system is not designed to have automated fire suppression features, just nominal standpipe/connection locations for local fire department hook-ups. This estimate only addresses the basic delivery of the fire suppression medium (water) and does not address any foam, sprinkler, or automated water delivery valves/standpipes etc.

5.5 Emergency Egress Options

Tunnel egress systems using a longitudinal ventilation system would dictate installing pass through openings at nominal 750 foot centers in the diaphragm wall. Walkways are assumed to be installed on each side of the tunnel having a width of 60-inches wide. Although ADA guidelines state a minimum of 36-inches width, this smaller width requires installing passing niches at locations relevant to the length of the path. Designing with 60-inches width walkways relieves the requirement for the passing niches.

5.6 Intelligent Transportation Systems/ Supervisory Control and Data Acquisition (ITS/SCADA) Requirements

ITS/SCADA systems would be dependent on FHWA, NCDOT, NFPA, and FIRE LIFE SAFETY requirements. Closed Circuit Television (CCTV), smoke detectors, and exhaust emission sensors are assumed to be included in the tunnel design in order to monitor the tunnel environment. The ITS/SCADA systems are assumed to be installed in a separate, secure building adjacent to the tunnel just outside one of the portals.

For this Feasibility study we have assumed the SCADA system will be able to monitor and send alerts regarding air quality, air flow, ambient temperature, conditions of traffic lanes and informational boards for motorists, but that there will be no design innovations that will exceed current standards regarding interaction of vehicles within the tunnel or in the vicinity of the tunnel (i.e. automated vehicles or connected vehicles).

6. CONSTRUCTION CONSIDERATIONS

6.1 Portal Work Sites

Both the North and South Portal work sites will need to be prepared and levelled prior to both the horizontal drilling campaign and excavation of the tunnel. This is particularly important at the southern portal work site (for both S2 and SW1A) as they are located in a rugged and heavily forested area to the south of a hair-pin turn on NC 143 (Figure 2). The portal work sites would likely require several preparatory tasks including coordination with local landowners/tribes for access, locating utility lines in the subsurface, construction of an access road from NC 143 to the work pad, felling trees along the alignment, leveling ground for machinery and drill rigs, and excavating into hillslopes. Also, the southern portals will have significant approach cut sections arriving at the portals that will result in up to ~2 M ft3 of excavated rock and soils material. Brierley recommends using this material as general fill for the highway approach to the portals from the south.

The northern portal will require less site preparation than the southern portal of either alignment. The northern tunnel portal of S2 terminates at Johnson Gap a few hundred feet south of the intersection of NC 28 and NC 143 near Stecoah, NC. The northern portal of alignment SW1A terminates approximately 70 feet north of the same intersection. Google Maps imagery indicates that a paved parking lot and relatively cleared, grassy lot (Figure 6) already exists for both alignments at their north portals.

Additional work such as felling trees, leveling ground, and cutting into the exposed outcrop to create space will still be required to prepare the north portal work site of S2. The northern portal of alignment SW1A would also require a substantial amount of site preparation work including clearing trees, leveling the ground, and constructing an access road from NC 28 to the portal. Brierley recommends coordination with NCDOT to determine ownership, locating utility lines, access, and modification to this parcel of land.

6.2 Tunnel Construction

6.2.1 Anticipated Rock Mass Classification

Assumed ground conditions summarized earlier in this report includes encountering overburden materials above the top of rock that are typically less than 40 feet. A weathered and highly fractured/jointed interval commonly is expected to occur beneath the overburden soils and should be typically no thicker than 80 feet. This interval had low RQD (generally less than 40 percent), indicative of poor to fair quality. Below the weathered interval, the RQD values of cores significantly increased and generally ranged between 70 to 100%, indicating good to excellent quality rock. Rock was described as relatively fresh in this zone. These observations demonstrate that the quality of rock typically increases significantly with depth. The boring logs commonly describe joints as being smooth and stained with iron-oxide (indicative of water migration through the fracture). The most frequent lithologies logged include metasiltstone, schist and metagraywacke.

Brierley assessed the core photographs (Florence & Hutcheson, 1996) and outcrop photographs (Acker & Reed, 1995) to provide a rough estimate for anticipated rock mass classification for rock along the S2 and SW1A alignments. Using the rock mass rating system (RMR) (Bieniawski, 1989), Brierley expects the quality of rock to vary between “Fair” to “Very Good”. The rock will need to be supported after excavation, particularly in the areas near the portals where there is minimal rock cover above the tunnel and the rock is more weathered and has a lower RMR value. Potential support systems could include (and are not limited to) local rock bolt patterns, wire mesh, lattice girders, and shotcrete.

Groundwater levels are anticipated to be above the tunnel crown for the majority of the tunnel alignments. The excavation of the tunnel may result in a temporary lowering of groundwater levels and may provide a conduit for groundwater infiltration into the tunnel face. Groundwater entering the excavation is anticipated to be of relatively low volumes due the impervious rock and should be readily controlled by runoff into a sump pump. If fracture zones or other zones of anomalously high inflow are encountered, they would be controlled by grouting the rock formation in advance of the tunnel advancement. The cost estimate in Appendix C does not consider the requirement to grout the rock face to control high inflow since no site-specific geotechnical investigations have been performed.

6.2.2 Anticipated Ground Behavior

Understanding how the ground will behave during construction is paramount to the successful and safe completion of any tunnel. Ground behavior during construction is typically a function of numerous factors including strength and structure of the excavated material, local groundwater conditions, and excavation method. Brierley has estimated the rock class and rock load factor classification (Terzaghi, 1946), which predicts how rock in a tunnel will behave as a function of its quality (Figure 7). Based on Brierley’s preliminary analysis of the available information and our experience, we anticipate the ground to range from Class II “hard stratified and schistose” to Class IV “moderately blocky and seamy” as shown in Figure 7.

6.2.3 Roadheader vs. Drill and Blast Construction Methods

Due to the geologic nature of the Horsebranch Member of the Ammons Formation, two methods of excavating alignments S2 and SW1A can be used. The Horsebranch Member consists of primarily two distinct lithologies: schist and metagraywacke. Schist typically displays strong foliation (the planar alignment of minerals), while metagraywacke often display massive bedding with individual layers varying in thickness on the order of feet to tens of feet.

The foliation planes in schist form preferential planes of weakness (Figure 8a), which can be exploited during excavation. Brierley is confident that a roadheader could be used to excavate sections of schistose type rock along the proposed alignments. A roadheader is essentially a piece of excavating equipment with a boom mounted cutter-head. Because roadheaders are mounted on a crawling traveler track, they are highly mobile and facilitate rapid excavation in favorable ground conditions. They also cut irregular and variable cross section shapes readily. They can be problematic without sufficient rock structure to “break to” and excavation in massive ground without structure can be tedious and time consuming. A roadheader could potentially provide a cost-effective means of excavation. A geotechnical field exploration campaign would first be required to determine the extent of schist vs. metagraywacke along the alignment, and additional laboratory strength testing would be required to confirm the relative feasibility and advantages of a roadheader for excavation.

It is unlikely that a roadheader would be able to efficiently excavate at least portions of the massively bedded metagraywacke (Figure 8b) units in the Horsebranch Member. This lithology is assumed to be stronger and does not contain frequent preferential planes of weakness that can be exploited with a roadheader. For this type of rock, it is likely that conventional drill-and-blast techniques will be required to excavate through the stronger, massively bedded units. Drill and blast sequences would typically be performed in rounds of 8 to 12 feet.

A typical excavation cycle by drill and blast is as follows:

- Drill holes into rock face and load with explosives,
- Detonate blast,
- Ventilate to remove blast fumes,
- Remove blasted rock via mucking,
- Scale crown and walls to remove the loose rock,
- Install initial ground support, and
- Advance ventilation system and utilities (water and power).

Tunneling by drill-and-blast is still the most common method in the underground mining industry. When the geological formation of underground construction is in hard, competent rock, drill-and-blast mining can be very efficient and economical. However, it is important to note that a drill-and-blast option also requires explosives permitting and other considerations including delivery, handling, and storage.

6.3 Muck Handling and Disposal

The method of removal for the excavated materials (muck) from the tunnel is a critical decision to be made by the Contractor as part of their successful construction strategy. As the excavation advances, the muck must be transported back toward the portal for collection and disposal while the tunnel's support system is simultaneously being advanced. Movement of these materials past each other along with requirements for personnel access, ventilation, lighting, power, and water create an ongoing logistical challenge for the Contractor.

Considering that the Horsebranch Member can be graphitic and sulfidic, Brierley recommends an assessment of the material recovered during the geotechnical drilling program to determine whether or not special treatment, handling, and/or disposal of the muck would be required under North Carolina statutes. Brierley also recommends that the Contractor confirms with NCDOT concerning the load criteria on local roads through the regions and ensure that selected equipment for muck transport do not exceed these restrictions. It is noted that the cost estimate contained in this report does not consider potential impacts of environmental restrictions on muck removal, transport, and/or disposal due to contaminated materials.

The most feasible muck removal system for the S2 and SW1A alignments would be to transport the muck back to the portals in rubber tired loaders with side dump buckets and then transferring the muck to articulated haul trucks. Brierley recommends that a beneficial use determination be carried out on the potential muck material, such as using the material as NCDOT roadway aggregate rather than haul 100% of the muck away for off-site disposal. The

Contractor may even consider muck utilization for sand and aggregate for on-site shotcrete and concrete batching in lieu of importing ready mix shotcrete and concrete, which facilities are at least 30 minutes from the site. NCDOT's need for produced muck for other uses can be reevaluated by tunneling contractors at the time of bidding and construction.

Otherwise, once the muck is loaded onto dump trucks, it will be hauled off site for disposal. NCDOT should dictate preferred haul roads and restrict traffic patterns as desired by conveying this information through the bid documents. Adequate provisions for dust and erosion control, vehicle wash down, and roadway sweeping should be incorporated into the bid documents and enforced during construction.

Estimated muck yields would be 380,000 bank cubic yards for alignment S2 and 465,000 bank cubic yards for alignment SW1A. The estimates assume a swell factor of 1.45 for the muck materials.

6.3.1 Geotechnical Instrumentation

Geotechnical instrumentation for this tunnel project will be determined during subsequent design phases of the project. Since the tunnel will be excavated in hard rock with thick overburden and bedrock above the crown, any ground deformation that will propagate toward the surface could take a substantial amount of time to cause surficial settlement or heave, if any. Generally, routine ground disturbance and ground losses during tunneling are accommodated by the ground "bulking" in response to the disturbance/ground loss within a zone within approximately three tunnel diameters above the crown. Furthermore, given the remote and rugged conditions above the proposed tunnels, potential settlement will generally not be a threat to structures. Because of the remote, rugged location, any desired geotechnical instrumentation data collection from physical instruments installed at the site is expected to be by remote sensing technologies. In recent advances in detection of millimeter amounts of deformation using orbiting satellites is possible and may be the most effective method. InSAR (Interferometric Synthetic Aperture Radar) methods are now being used on tunnel projects throughout the world. Collecting information on regular cycles as frequently as 11 days, and relatively unimpacted by above ground foliage or precipitation, these methods are secure, reliable and repeatable.

Additional monitoring of the tunnel surroundings using conventional techniques should be used in conjunction with the InSAR imagery. Surface monitoring, reflectorless survey points, vibrating wire piezometers, inclinometers and extensometers all are used to record ground and groundwater conditions pre-construction, during tunnel excavation, and post-excavation.

7. CONSTRUCTION COST ESTIMATE

The summary table giving the estimated tunnel construction costs is included as Appendix C. The summary table and cost estimate were prepared in general accordance with the methods proposed by ACEE (2005). Table 2 below shows that the project design has progressed to the Class 4, Study or Feasibility level with a level of project definition between 1% and 15%. We consider it to be well less than 10%. Based on this characterization, and ACEE guidance, we have applied an accuracy range of -30% to +50% to our total tunnel estimates presented in Appendix C.

Table 2: Cost Estimate Classification Matrix (ACEE, 2005)

	Primary Characteristic	*Secondary Characteristic*			
ESTIMATE CLASS	**LEVEL OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]	**PREPARATION EFFORT** Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment, or Analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4

It is important to provide context on what assumptions were made to prepare our cost estimate. The following assumptions were made in developing the construction cost estimate.

<u>The overall tunnel cost estimate was based on tunnel drive SW1A with the following assumptions, then applied proportionally to tunnel drive S2 based on the relative lengths of each drive.</u>

- Tunnel configuration to be horseshoe shape.
- Tunnel(s) to utilize conventional drill and blast method.
- Tunnel will be excavated using a multiple top heading and bench sequence.
- Temporary support will be rock bolts, lattice girders and shotcrete, with lattice girders at nominal 4 foot-0-inches center to center.
- Rock classifications dictate temporary support class.
- Finished concrete dimension of arch portion to be nominal 18.8 foot radius with vertical sidewalls.
- 3 eight-hour shifts undertaken daily, 5 days per week.
- FHWA, NFPA, and NCDOT regulations govern Life Safety Installations in tunnel interior and electrical and mechanical installations; requirements are not defined at this time.
- The spoils from the tunnel excavation (rock/soils/groundwater) are assumed to be free of contaminants and require no special handling for collection, transport, and disposal.

<u>Assumptions used for SEM Excavation</u>

- Advance rates for excavation of top heading include drilling, blasting, muck removal, and installation of temporary support (lattice girders and shotcrete) to advance at a rate of 12 LF/day, or about 60 LF per week.
- Advance rates for excavation of bench include drilling, blasting, muck removal, and installation of temporary support (lattice girders and shotcrete) to advance at a rate of 30 LF/day, or about 150 LF per week.
- Cycle times adjusted using a percentage-based timeline as follows:
  - Drilling - 33%
  - Loading Hauling - 24%
  - Rock Support - 20%
  - Scaling - 6%
  - Ventilation and Linear Plant - 3%
  - Charging Drill Holes - 14%
- Top heading will be advanced total length before bench excavation starts.

8. OPERATIONS AND MAINTENANCE COST ESTIMATE

The estimated costs for Operations and Maintenance (O&M) for each of the tunnel alignment options are presented in Appendix D. These costs were estimated by using information obtained from an undated US Department of Transportation Federal Highway Administration presentation titled “Tunnel Operation Costs and Considerations for NCDOT” that was reviewed during a joint meeting in Raleigh, North Carolina on March 19, 2020 and provided to Brierley for use in preparing this Feasibility Report.

The presentation includes construction and O&M metrics for four transportation tunnels in the Appalachian region. These include the Squirrel Hill Tunnel from Pennsylvania, the Cumberland Gap Tunnel crossing between Kentucky and Tennessee, and twin Interstate 77 tunnels in western Virginia, the Big Walker Mountain Tunnel and the East River Mountain Tunnel. For each tunnel, the tunnel size and length were provided, along with the number of staff, staff costs (salary and indirect costs), and annual utility costs.

In order to estimate O&M costs for the future A-0009C Tunnel, the information provided by NCDOT for these tunnels was assessed by Brierley and values for numbers of staff, staff costs (salary and indirect costs) and annual utility costs were averaged on an annual basis and on a basis of linear length of the tunnels. These average values per tunnel length were then corrected for the S2 and SW1A alignments and the resulting O&M cost estimates were presented in Appendix D.

No other Appalachian tunnels, or tunnels operated by NCDOT within the state, were researched for this cost estimate. It is anticipated that these O&M rates would represent high end values given the smaller footprint and ITS innovations anticipated for the proposed A-0009C tunnel.

9. LIMITATIONS

This report has been prepared for NCDOT as a Feasibility Level study for specific application to the S2 and SW1A Alignments of the A-0009C Tunnel Project as understood at this time, in accordance with generally-accepted geotechnical and civil design and engineering practices common to the local area. Nothing contained in this report shall be construed to create, impose, or give rise to any duty owed by Brierley to any individual or entity other than NCDOT. This report is for the sole use and benefit of NCDOT and may not be used or relied upon by any other individual or entity without the express written approval of Brierley. No other warranty, express or implied, is made.

The test boring reports and related information described in this report were produced by other companies and Brierley takes no responsibility for any errors or discrepancies of the data presented within and used from these reports. The reports depict subsurface conditions only at the specific locations and at the particular time designated on the reports. Soil and bedrock conditions at other locations may differ from conditions encountered within these boring. Also, the passage of time may result in a change in the subsurface conditions at these boring locations. The transition between materials may be gradual. The nature and extent of variations between explorations may not become evident until construction.

10. REFERENCES

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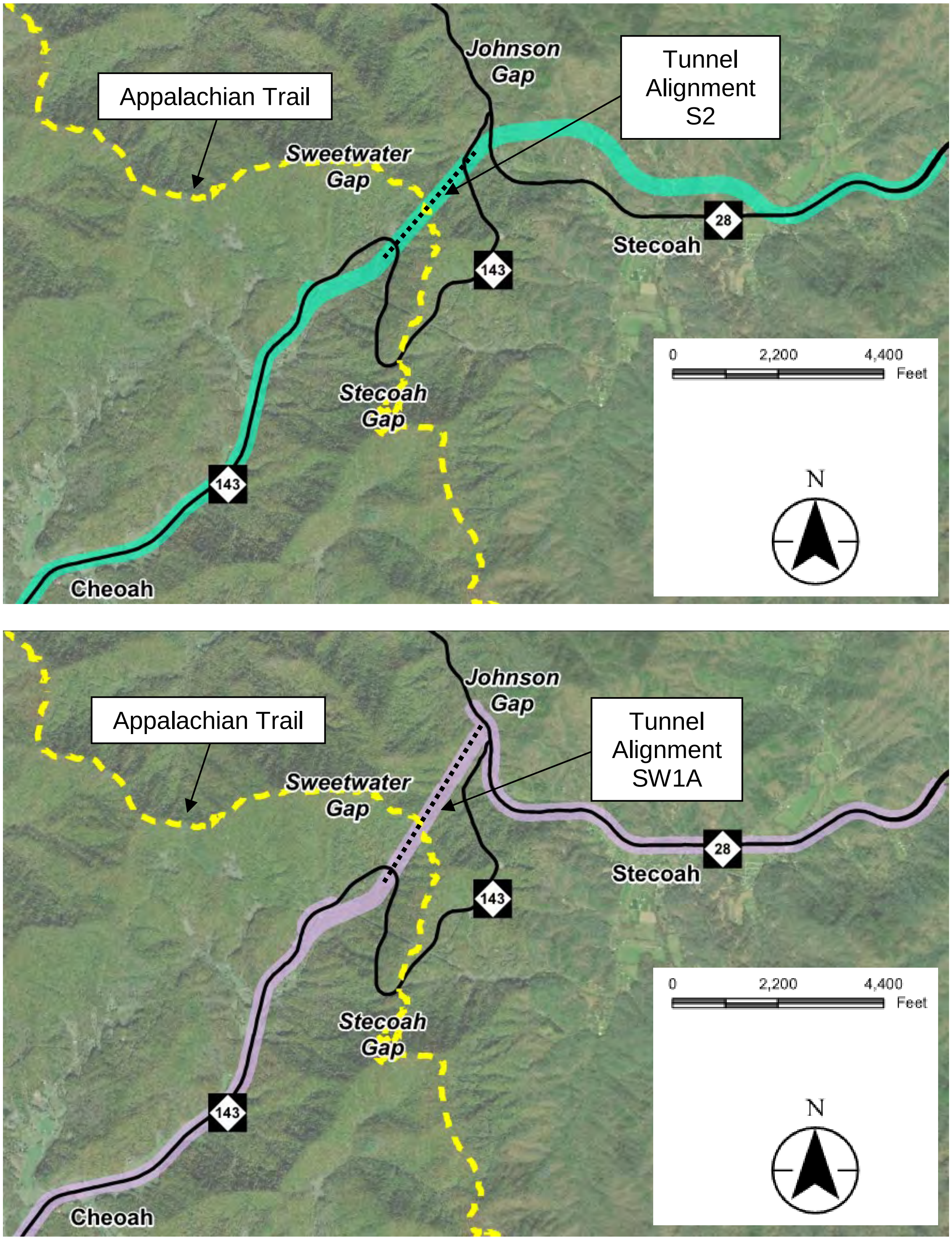

Figure 1: Map showing examples of proposed tunnel alignments studied for this feasibility report. Black dotted lines represent tunnel sections.
a) Alignment S2. b) Alignment SW1A.

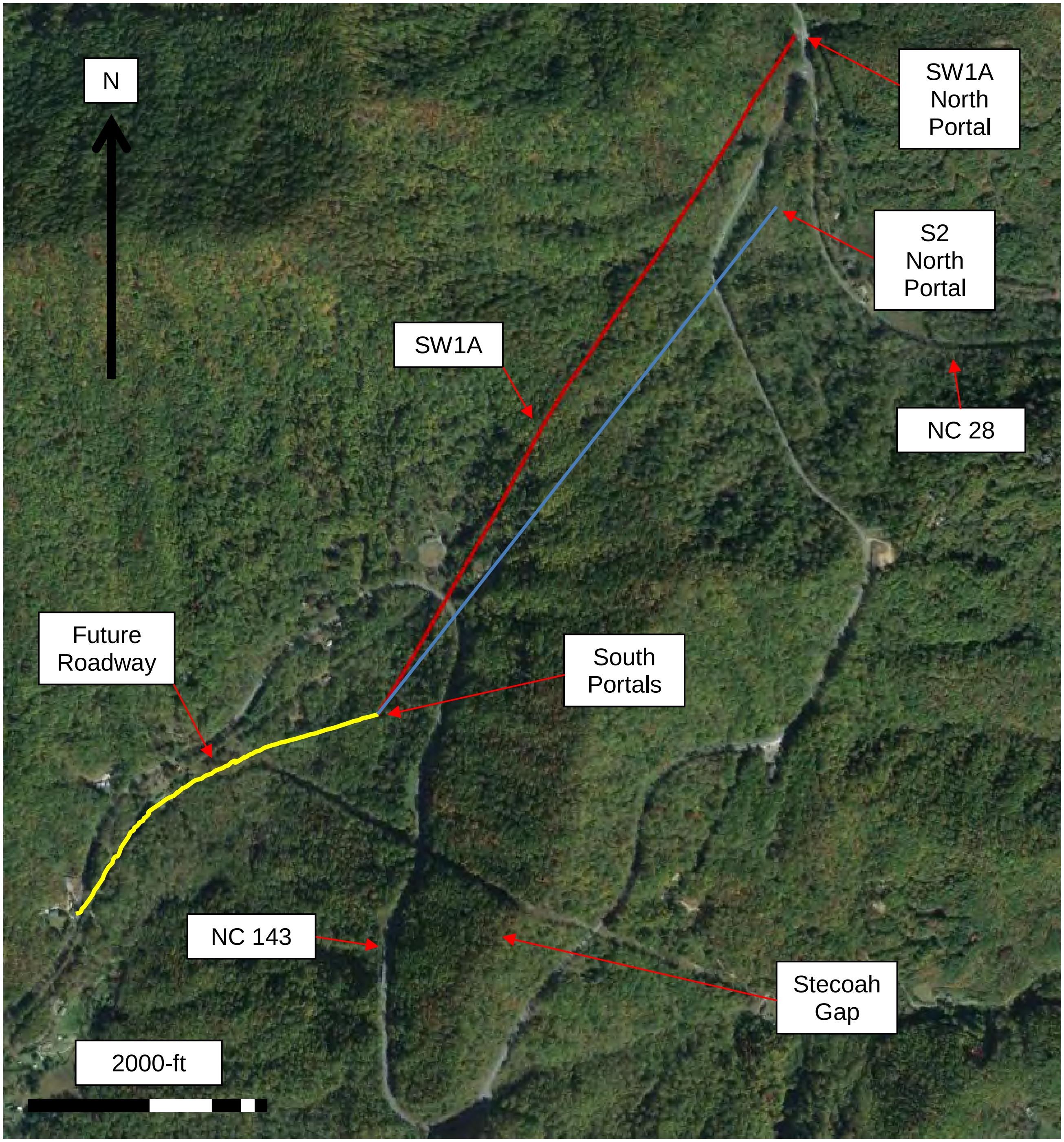

Figure 2: Proposed alignments S2 and SW1A shown in blue and red, respectively. The yellow line shows a roadway that has yet to be constructed, leading to the southern portal of tunnel SW1A. Image from Google Earth.

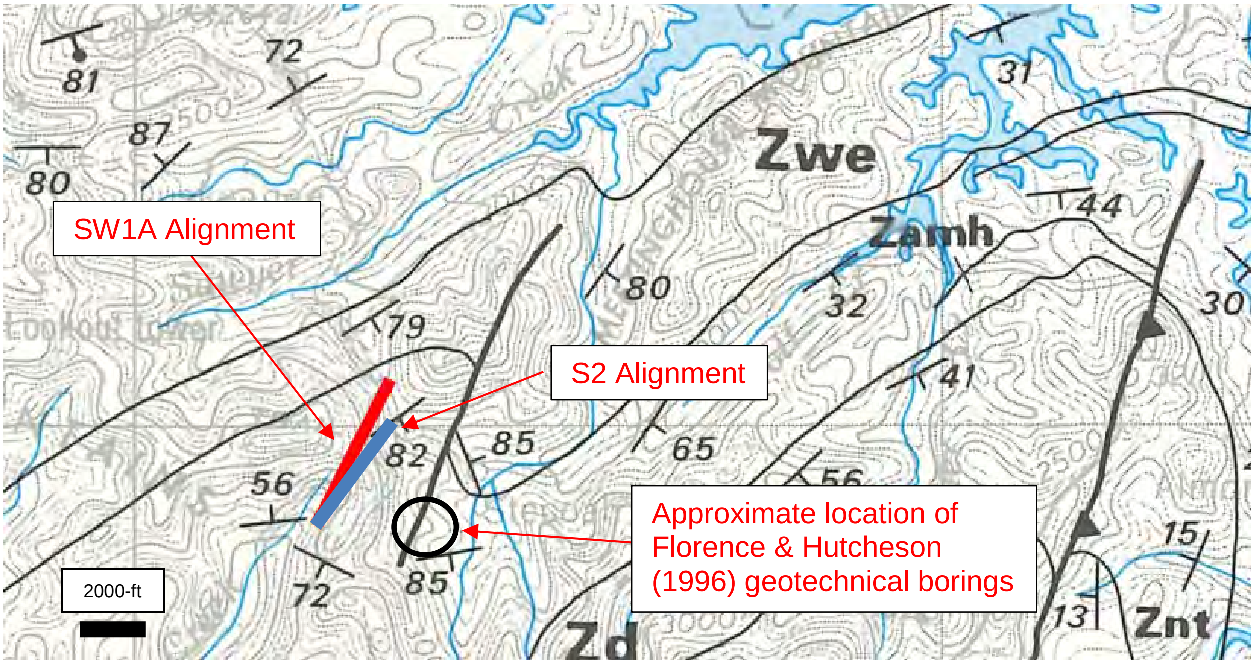

Figure 3: Simplified geologic map showing theS2 and SW1A alignments with respect to local geologic structures. Modified from Wiener & Merschat (1992). The proposed tunnel would be located within the Horsebranch Member (Zamh).

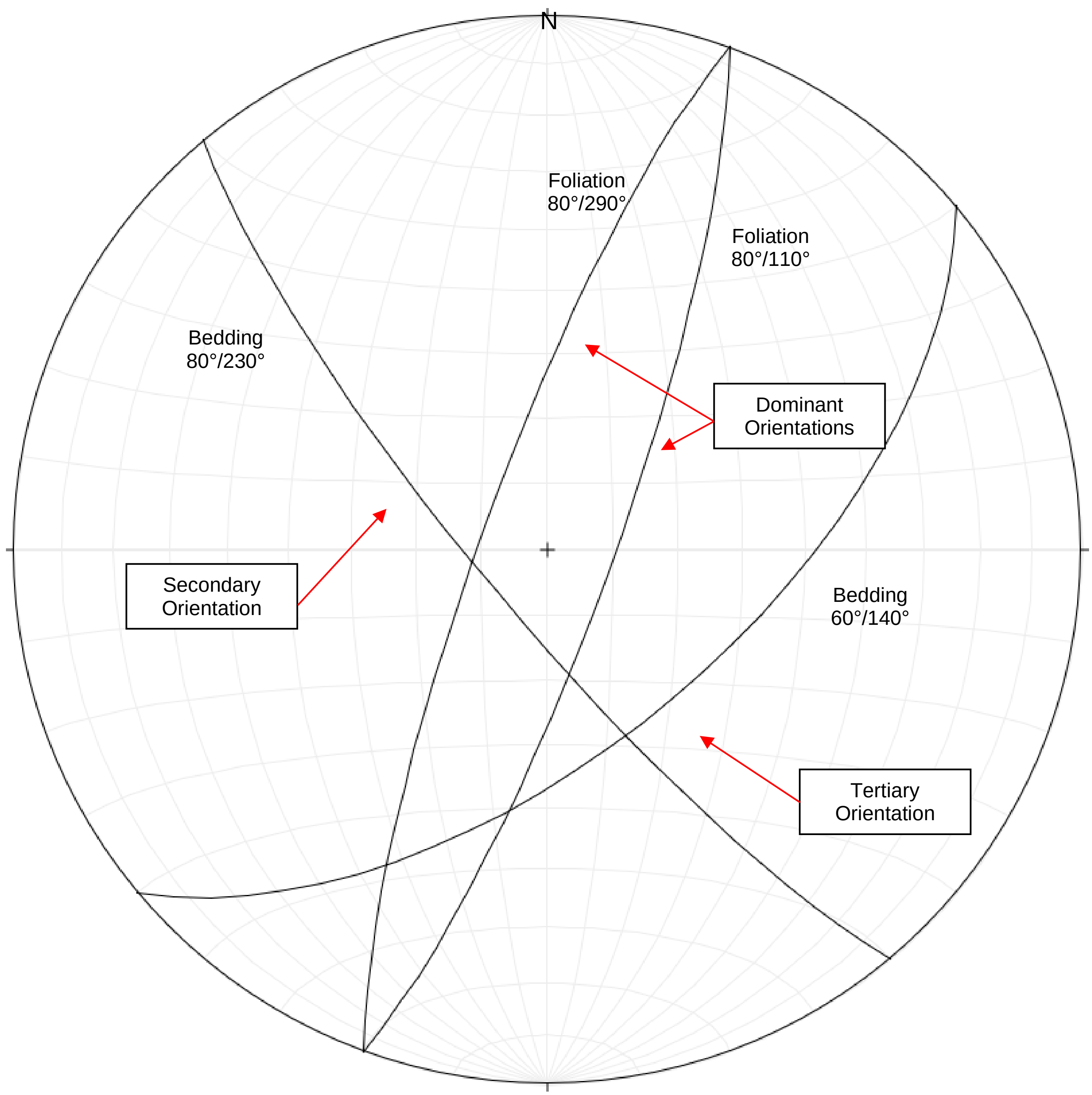

Figure 4: Stereonet showing dominant orientations of bedding and foliations planes

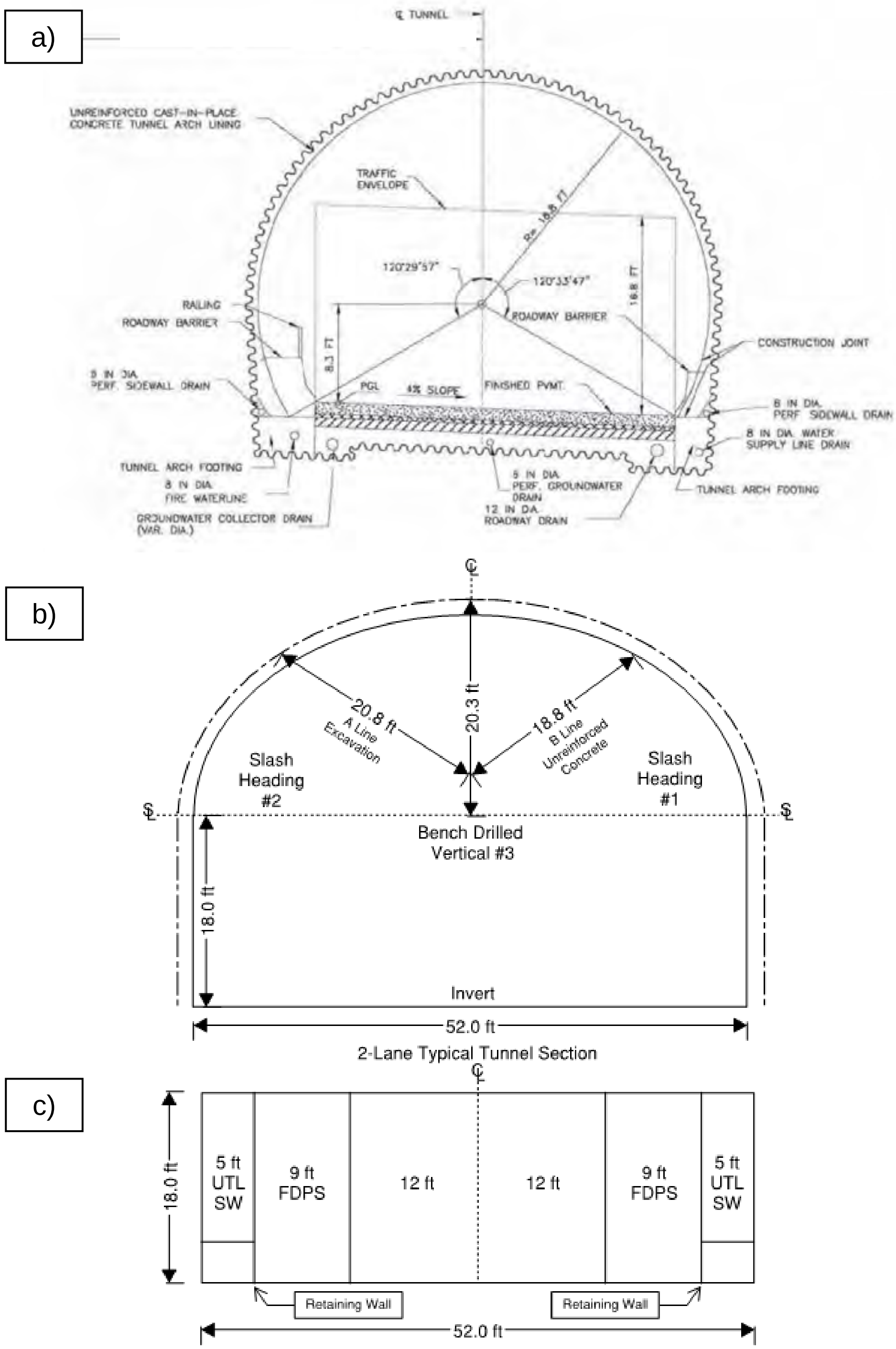

Figure 5: Tunnel schematics showing assumed tunnel dimensions and design elements.
a) Cross section of tunnel face prepared by Stantec (2008) showing tunnel dimensions
b) Modified Cross section showing dimensions of SEM tunnel headings and bench
c) View of tunnel bench showing dimensions of lanes and ancillary structures

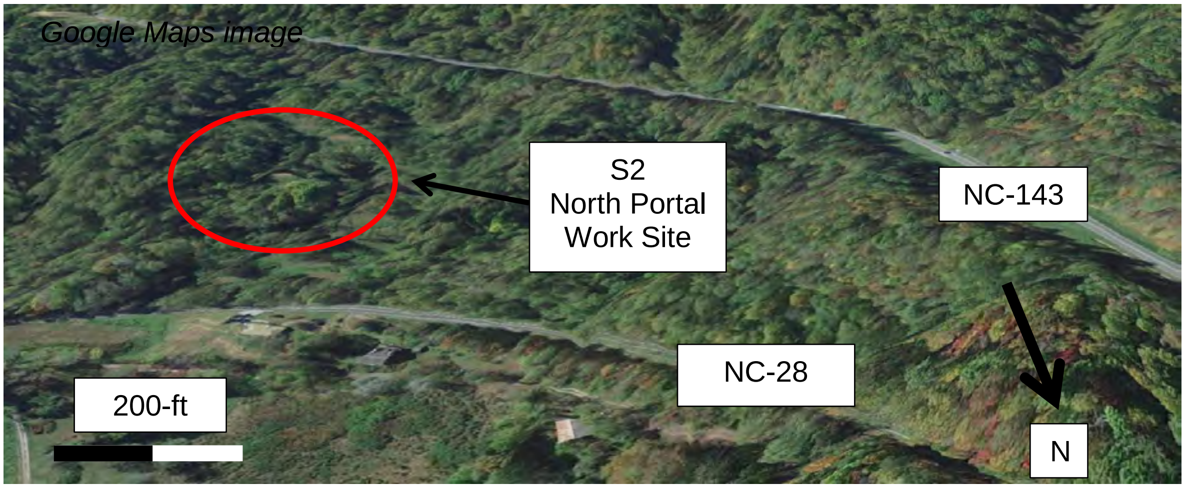

Figure 6: Aerial image from Google Maps showing the north portal worksites for alignments S2 and SW1A

Rock Class	Definition	Rock Load Factor Hp (in feet, B and Ht in feet)	Remark
I. Hard and intact	Hard and intact rock contains no joints and fractures. After excavation, the rock may have popping and spalling at excavated face.	0	Light lining required only if spalling or popping occurs.
II. Hard stratified and schistose	Hard rock consists of thick strata and layers. The interface between strata is cemented. Popping and spalling at the excavated face is common.	0 to 0.5 B	Light support for protection against spalling. Load may change between layers.
III. Massive, moderately jointed	Massive rock contains widely spaced joints and fractures. Block size is large. Joints are interlocked. Vertical walls do not require support. Spalling may occur.	0 to 0.25 B	Light support for protection against spalling.
IV. Moderately blocky and seamy	Rock contains moderately spaced joints. Rock is not chemically weathered and altered. Joints are not well interlocked and have small apertures. Vertical walls do not require support. Spalling may occur.	0.25 B to 0.35 $(B + H_t)$	No side pressure.
V. Very blocky and seamy	Rock is not chemically weathered and contains closely spaced joints. Joints have large apertures and appear separated. Vertical walls need support.	(0.35 to 1.1) $(B + H_t)$	Little or no side pressure.
VI. Completely crushed but chemically intact	Rock is not chemically weathered and highly fractured with small fragments. The fragments are loose and not interlocked. Excavation face in this material needs considerable support.	1.1 $(B + H_t)$	Considerable side pressure. Softening effects by water at tunnel base. Use circular ribs or support rib lower end.
VII. Squeezing rock at moderate depth	Rock slowly advances into the tunnel without a perceptible increase in volume. Moderate depth is considered as 150 ~ 1000 m.	(1.1 to 2.1) $(B + H_t)$	Heavy side pressure. Invert struts required. Circular ribs recommended.
VIII. Squeezing rock at great depth	Rock slowly advances into the tunnel without a perceptible increase in volume. Great depth is considered as more than 1000 m.	(2.1 to 4.5) $(B + H_t)$	
IX. Swelling rock	Rock volume expands (and advances into the tunnel) due to swelling of clay minerals in the rock at the presence of moisture.	up to 250 feet, irrespective of B and H_t	Circular ribs required. In extreme cases use yielding support.

Figure 7: Rock class and rock load factor classification by Terzaghi for steel arch supported tunnels Terzaghi (1946)

a)

b)

Figure 8: Photographs of rock outcrops in the vicinity of the S2 and SW1A alignments.
a) Example of foliated mica schist common in outcrops near Stecoah Gap. Note the steeply dipping foliation planes that form preferential zones of weakness.
b) Example of massively bedded metagraywacke near Stecoah Gap

APPENDIX A

INFERRED GEOLOGIC PROFILES OF TUNNEL ALIGNMENTS S2 AND SW1A

APPENDIX B

COST ESTIMATE FOR GEOTECHNICAL CHARACTERIZATION USING HORIZONTAL BORES

		Bid Qty	Unit	Unit Price	Total Price	Comment
Mobilization		Bid Qty	Unit	Unit Price	Total Price	Comment
1	Third Party Contractor Site Preparation at Portals	2	LS	$ 15,000	$ 30,000	TGS Engineers
2	Geotechnical Contractor Mob per Rig/Crew	2	LS	$ 50,000	$ 100,000	Crux Subsurface or Equivalent
3	Geotechnical Consultant Mob per Geo/Engr	2	LS	$ 7,500	$ 15,000	Brierley, includes third party charges
4	Permits, Utility Clearances	1	LS	$ 10,000	$ 10,000	TGS Engineers
5	Project Management by Brierley	1	LS	$ 10,000	$ 10,000	Brierley
6	Contingency, 10% of total	1	LS	$ 16,500	$ 16,500	TBD
				Estimated Total Mob		**$ 181,500**
Field Program		Bid Qty	Unit	Unit Price	Total Price	Comment
1	Geotechnical Contractor Daily Rate for Rig/Crew	160	DAY RATE	$ 6,100	$ 976,000	Crux Subsurface or Equivalent
2	Drilling Materials/Consumables (cost + 15%), estimated per rig	2	EACH	$ 30,000	$ 60,000	Crux Subsurface or Equivalent
3	Gyro Non-Magnetic Survey Tool	160	DAY RATE	$ 350	$ 56,000	Crux Subsurface or Equivalent
4	Geotechnical Consultant for Geo/Engr	160	DAY RATE	$ 1,950	$ 312,000	Brierley
5	Geotechnical Consultant for Geo/Engr, hotel/per diem	160	DAY RATE	$ 400	$ 64,000	Brierley, includes third party charges
6	Geotechnical Consultant Project Management	160	DAY RATE	$ 375	$ 60,000	Brierley
7	TGS Project Management	160	DAY RATE	$ 250	$ 40,000	TGS
				Estimated Total Field		**$ 1,568,000**
Lab Program		Bid Qty	Unit	Unit Price	Total Price	Comment
1	Geotechnical Laboratory Contractor, per linear feet	5420	EACH	$ 25	$ 135,500	GeoTesting Express or Equivalent
2	Geotechnical Consultant to Assign and Manage Lab Program	40	EACH	$ 250	$ 10,000	Brierley
				Estimated Total Field		**$ 145,500**
Analysis and Reporting		Bid Qty	Unit	Unit Price	Total Price	Comment
1	Geotechnical Data Report	1	LS	$ 65,000	$ 65,000	Brierley
2	Overall Project Supervision	1	LS	$ 20,000	$ 20,000	TGS
				Estimated Total Field		**$ 85,000**
			TOTAL ESTIMATED BUDGET			***$ 1,980,000***

BRIERLEY ASSOCIATES
Creating Space Underground

APPENDIX C

FEASIBILITY LEVEL COST ESTIMATES FOR TUNNEL CONSTRUCTION

PRICES BASED UPON SW1A *	Linear Feet	5408
Estimated cost per Linear Foot for Model		
TUNNEL RAW MATERIALS		$ 115,000,000
CONSTRUCTION SUPPLIES		$ 18,000,000
CONSTRUCTION EQUIPMENT		$ 14,000,000
TUNNELING LABOR		$ 10,000,000
MANAGEMENT & SUPERVISION		$ 2,230,000
CONSTRUCTION FACILITIES & UTILITIES		$ 3,550,000
TOTAL TUNNEL PRICE		$ 162,780,000
PRICE PER LINEAR FOOT		$ 30,100
** price per linear foot calculated for SW1A alignment and then*		
applied same per linear foot price for shorter S2 alignment		

Alignment S2	Linear Feet	4470		
Estimated Cost Per Linear Foot for Model		$ 30,100		
Baseline Cost for tunnel		$ 134,547,000		
Indirect Cost Additions				
Mobilization	8.0%	$ 10,763,760		
Bond/Insurance	2.0%	$ 2,690,940		
Overhead and Profit	12.0%	$ 16,145,640		
Contigency	25.0%	$ 33,636,750		
Total Indirect		*$ 63,237,090*		
Total Construction Cost Estimate		$ 197,784,090		
Design & Engineering				
Site Investigations	1.5%	$ 2,018,205		
Preliminary Engineering	3.0%	$ 4,036,410		
Advanced and Final Engr	6.0%	$ 8,072,820		
Risk Register and Procurement	1.0%	$ 1,345,470		
On Site Construction Oversight	2.5%	$ 3,363,675	*Recommended range in estimate*	
Total Design/Engineering/Oversight		*$ 18,836,580*	*per AACE Class 4 Project (2005)*	
			- 30% Estimate	***+50% Estimate***
TOTAL TUNNEL ESTIMATE - S2 OPTION		**$ 216,620,670**	***$ 151,634,469***	***$ 324,931,005***

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Alignment SW1A	Linear Feet	5408			
Estimated Cost Per Linear Foot for Model		$ 30,100			
Baseline Cost for tunnel		$ 162,780,800			
Indirect Cost Additions					
Mobilization	8.0%	$ 13,022,464			
Bond/Insurance	2.0%	$ 3,255,616			
Overhead and Profit	12.0%	$ 19,533,696			
Contigency	25.0%	$ 40,695,200			
Total Indirect		*$ 76,506,976*			
Total Construction Cost Estimate		$ 239,287,776			
Design & Engineering					
Site Investigations	1.5%	$ 2,441,712			
Preliminary Engineering	3.0%	$ 4,883,424			
Advanced and Final Engr	6.0%	$ 9,766,848			
Risk Register and Procurement	1.0%	$ 1,627,808			
On Site Construction Oversight	2.5%	$ 4,069,520		*Recommended range in estimate*	
Total Design/Engineering/Oversight		*$ 22,789,312*		*per AACE Class 4 Project (2005)*	
				- 30% Estimate	***+50% Estimate***
TOTAL TUNNEL ESTIMATE - S1WA OPTION		**$ 262,077,088**		***$ 183,453,962***	***$ 393,115,632***

BRIERLEY ASSOCIATES
Creating Space Underground

APPENDIX D

FEASIBILITY LEVEL COST ESTIMATES FOR TUNNEL OPERATIONS AND MAINTENANCE

Estimated Annual Operations & Maintenance Budget			
Estimated Number of Employees	22		
Salary + Benefits per Employee	$ 150,000		
Labor Costs		$	3,300,000
Utilities		$	500,000
Total Estimated O&M - S2 OPTION		**$**	**3,800,000**
Estimated Number of Employees	24		
Salary + Benefits per Employee	$ 150,000		
Labor Costs		$	3,600,000
Utilities		$	600,000
Total Estimated O&M - SW1A OPTION		**$**	**4,200,000**