

Hydrogeology of Nashville, Tennessee, and
Potential Implications for the Music City Loop

Submitted to

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Executive Summary

In February 2026, The Boring Company (TBC) began tunneling beneath Nashville, Tennessee, to create the first of two transportation tunnels. These are being dug in *limestone* bedrock. Limestone is hard and strong enough that it doesn't collapse in on itself, like sand might, but not too hard that it is especially difficult to cut through. A problem, though, is *karst* geology where caves and other voids have been dissolved by groundwater within the soluble bedrock. "What makes it tricky," according to Vanderbilt University geologist Dr. Molly Miller, "is that it is sort of like Swiss cheese" (Eggers 2025).

Each tunnel is about 13 feet in diameter and targeted to be 30-60 feet beneath the ground surface and will serve as a subsurface transportation system with electric cars called the Music City Loop (MCL). A 9.5-mile path known as the Airport Alignment runs between the Nashville International Airport and downtown near the State Capital building. The path of a planned perpendicular tunnel, the Broadway Alignment, runs 2.9 miles across downtown and beneath the Cumberland River. The project uses *tunnel boring machines*, large cylindrical machines with a rotating *cutterhead* at one end that digs through and grinds the rock as it propels itself underground. The mixture of water, either natural underground water or introduced as a lubricant, and excavated material produced as the tunnel advances is called *muck*. Muck is removed by a conveyor system that brings this material to dump trucks for transport to disposal or recycling facilities. The Nashville tunnels are expected to generate 336,000 cubic yards of muck. On some tunneling projects chemicals are introduced to aid the tunneling process, and these have created environmental as well as health and safety problems, with injuries, at TBC's Las Vegas Loop effort. The company has indicated that only water will be used in this Nashville project to lubricate the cutterhead and control dust.

The purpose of this report is to describe the surface and subsurface geologic and groundwater conditions along the MCL and the potential for relevant environmental implications, with a focus on the well-developed karst aquifers that characterize the bedrock beneath Nashville. The report does not advocate either for or against any other aspect of the project. Sources include publicly available information from TBC, technical and scholarly references on geology, hydrology, and tunneling processes, and public media sources. Information has been obtained through data requests from the Tennessee Department of Transportation (TDOT), the Tennessee Department of Environment and Conservation (TDEC), the Tennessee Division of Radiological Health (TDRH), and the Tennessee Cave Survey (TCS). The data provided by TDOT includes geotechnical reports, records of well borings, and other technical data generated by TBC and contractors.

According to publicly available information, TBC was established in 2018 with a bold vision but little experience in tunneling. TBC now has eight years of tunneling experience, mostly through relatively soft unconsolidated sediments, in tunneling terms called *soft ground*, along with a geologically challenging *mixed-face* project in Las Vegas. The MCL appears to be TBC's first major project in solid rock, in this case limestone which is a relatively soft stone compared to other types of rock. There are four nearly horizontal limestone layers underlying the current project footprint beneath Nashville, stacked like a layer cake. They are, from highest to lowest:

- the Leipers-Catheys Limestone,
- the Bigby-Cannon Limestone,
- the Hermitage Limestone, and
- the Carters Limestone.

Generally, there should be relatively straight-forward tunneling conditions in the Hermitage Limestone but more unpredictable and challenging conditions in the potentially well-developed karst of the other three layers, especially the Bigby-Cannon Limestone above the Hermitage and the Carters Limestone below it. These layers have solutionally enlarged conduits, caves, and highly variable groundwater flow conditions in both space and time. These conditions create potentially severe karst-related tunneling challenges which, in previous (other than TBC) projects in other areas, have included massive water or mud inflow and flooding, sinkholes and ground subsidence above the tunneling, and machine entrapment with "stuck" TBMs.

A challenge in evaluating the potential for environmental impacts of this project is the scarcity of easily accessible, publicly available details. The project's Environmental Impact Assessment (EIA) indicates "TBC will attempt to avoid tunnel boring in areas where karst development is identified." However, that will not be possible everywhere, as the tunnel will be forced to go into the Carters Limestone beneath Browns Creek, Mill Creek, and the Cumberland River. Details in the EIA about how potential karst features will be dealt with, if encountered, are scarce. A Karst Mitigation Plan (KMP), obtained through a public records request, describes the exploratory methods that attempt to locate karst features, including core data (from wells drilled into the rock to determine whether it is solid or contains voids) and a method called *Multichannel Analysis of Surface Waves (MASW)*. This uses analysis of vibrations to non-destructively get information on underground structures. The wells for the drilling cores are spaced about 500 feet apart, a relatively coarse interval for identifying the kind of voids (feet to tens of feet) that may have impacts on tunneling. There is also equipment on the TBM itself to probe ahead into the rock as tunneling proceeds.

The KMP defines engineering actions related to small, medium, and large karst features but lacks citations or background information about methods used by previous tunneling projects in similar challenging conditions or a basis for these size thresholds. A relatively large body of technical literature and case studies exists describing causes and past examples of tunneling problems in karst, as well as strategies for dealing with them. There is little discussion about that previous experience in the KMP or the geotechnical reports where karst is discussed. A separate technical report, obtained through a records request, by a TBC contractor concludes that there is a "LOW to Moderate risk of karst feature development," (PSI 2025, p. 14, their emphasis) supported in part by their observation that (PSI 2025, p. 11) "it is anticipated that these will be in the form of soil-filled slots or seams in the bedrock." However, additional data analysis shows, in contrast, that there are several caves in the Carters Limestone on the eastern side of Nashville, one described as having passages up to 30' x 40'. Three well cores from the Bigby-Cannon Limestone in proximity to the Airport Alignment had open voids of 7.3 feet, 9 feet, and 13.5 feet, respectively.

The EIA indicates that "[g]roundwater that is encountered during excavation has the potential to contain petroleum or other contaminants due to potential historic releases from regulated facilities like gas stations or industrial facilities, which are present along the Project alignment." However, the EIA does not mention details regarding what potential contaminants might be expected to be encountered along the alignments, what the potential impacts are of the MCL disturbing contamination within *groundwater*, soil, or *ground air* vapors, or how any impacted groundwater encountered would be treated prior to disposal if necessary.

A records request from TDEC’s Division of Remediation (DOR) indicates that there are numerous listed DOR sites in the proximity of the alignments. One significant example is at the former Aladdin Industries at 703-705 Murfreesboro Road, with a history of soil, groundwater, ground air and soil gas contamination by the carcinogen trichloroethylene (TCE), other hazardous solvents, and metals that exceed regulatory EPA and TDEC Maximum Contaminant Levels (MCLs) for public groundwater. The site also has a history of contamination by the radioactive isotope thorium-232. The northern end of this property abuts Murfreesboro Pike and the Airport Alignment, but data are lacking to define the extent of contamination along that boundary.

A Note About Terminology

This report describes the geologic environment beneath Nashville to inform an understanding of conditions that may be encountered by The Boring Company's Music City Loop project, an ongoing transportation tunneling project underway beneath the city. The information is intended to be accessible to any engaged readers, some of whom may not have a technical background. But understanding the terminology is critical. The good news is that even technical details are easy to follow along if the reader has the appropriate vocabulary, including two key terms: *hydrogeology* and *karst*. Hydrogeology refers to the presence, nature, and movement of underground water (UNESCO 2016; IAH 2026). It seeks to explain how water enters the ground (as *recharge*), moves through soil (as *soil water*) and/or rock (as *groundwater*) in the subsurface, and how that water interacts with the materials within which it may come into contact, including soil, rock, gasses, and, in urban areas like Nashville, contaminants and built infrastructure.

Key to understanding underground water are the presence, geometry, and connections of the spaces in otherwise solid earth materials within which the water exists and moves. These are most commonly tiny spaces between grains of soil or unconsolidated sediment (clay, sand, or gravel) or fractures within more solid bedrock. A less common, but here especially relevant, situation occurs within especially soluble rocks such as limestone, where fractures are enlarged by groundwater forming larger conduits for water flow and in some cases even *caves* that are large enough for humans to move through, explore, and map. These areas are called karst regions, characterized by caves, underground rivers, sinkholes, and large springs. Built infrastructure in these areas is prone to environmental challenges, including groundwater that is highly vulnerable to contamination, ground subsidence through sinkhole collapse, sinkhole flooding, and contamination of ground air within the dry areas of the bedrock by volatile vapors or carbon dioxide.

Another fundamental consideration in tunneling to concerns the types of underground materials encountered: solid rock, which is limestone in this case, or *soft ground*, which is unconsolidated material such as soil, sand, clay or other sediments. Although soft ground is in some ways “easier” to dig through than rock, tunneling in such material offers challenges as it is often not self-supporting and can collapse in on itself. Various kinds of technology have been used to provide support as tunneling progresses through soft ground (see Monsees, 2009).

A glossary of key technical terms used in the report is provided in Appendix A. These terms are italicized at their first use in the report.

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Abbreviations Used in this Report

BTEX: Benzene, Toluene, Ethylbenzene, and Xylene
DNAPL: Dense Non-Aqueous Phase Liquid
DOE: Department of Energy
DOR: Division of Remediation (now Division of Land Protection- Remediation Branch)
DRG: Davey Resource Group
EIA: Environmental Impact Assessment
EPA MCL: US Environmental Protection Agency Maximum Contaminant Level
ES: Environmental Stewardship
GIS: Geographic Information Systems
IAH: International Association of Hydrogeologists
IRCK: International Research Center on Karst Under the Auspices of UNESCO
ITA: International Tunnelling and Underground Space Association
LVCC Loop: Las Vegas Convention Center Loop
MASW: Multichannel Analysis of Surface Waves
MCL: Music City Loop
OSHA: Occupational Safety and Health Administration
R&D: research and development
REC: recognized environmental conditions
TBC: The Boring Company
TBM: tunnel boring machine
TCE: trichloroethylene (also called trichloroethene)
TCEQ: Texas Commission on Environmental Quality
TCS: Tennessee Cave Survey
TDEC: Tennessee Department of Environment and Conservation
TDOT: Tennessee Department of Transportation
TDRH: Tennessee Division of Radiological Health
TPDES: Texas Pollutant Discharge Elimination System
TPH: total petroleum hydrocarbons
TVA: Tennessee Valley Authority
UN: United Nations
UNESCO: United Nations Educational, Scientific, and Cultural Organization
USEPA: United States Environmental Protection Agency
USGS: United States Geological Survey
VOAP: Voluntary Cleanup, Oversight, and Assistance Program

1. Introduction

The purpose of this report is to describe the surface and subsurface geologic and underground water (hydrogeologic) conditions along the path of the MCL and the potential for associated environmental implications. The report does not advocate for or against any other aspect of the project.

Although resources for the use of Geographic Information Systems (GIS) computer mapping tools were available to assist with the preparation of this report, the data used to prepare the figures in this report were created from a range of data sources, images, and scans, so maps were made using tools other than GIS, such as Word, Adobe Lightbox, and Adobe Photoshop. For this reason, mapped features are not georeferenced. The author takes responsibility for any resulting map errors.

TDEC's Division of Remediation is currently undergoing a name change to the Division of Land Protection - Remediation Branch, and references to both names can be found in various TDEC online sources while the name change takes effect. For consistency, this report uses the former name throughout.

2. Project Background

In February 2026, The Boring Company (TBC) began tunneling beneath Nashville, Tennessee, to create the first of two parallel tunnels beneath the city, each 13.12 feet in diameter and targeted to be 30-60 feet beneath the ground surface (DRG 2025). This is planned to serve as a subsurface transportation system using Tesla vehicles called the Music City Loop (MCL). A 9.5-mile path known as the Airport Alignment, which runs from downtown Nashville to the Nashville International Airport (Figure 1, running from upper left to lower right).

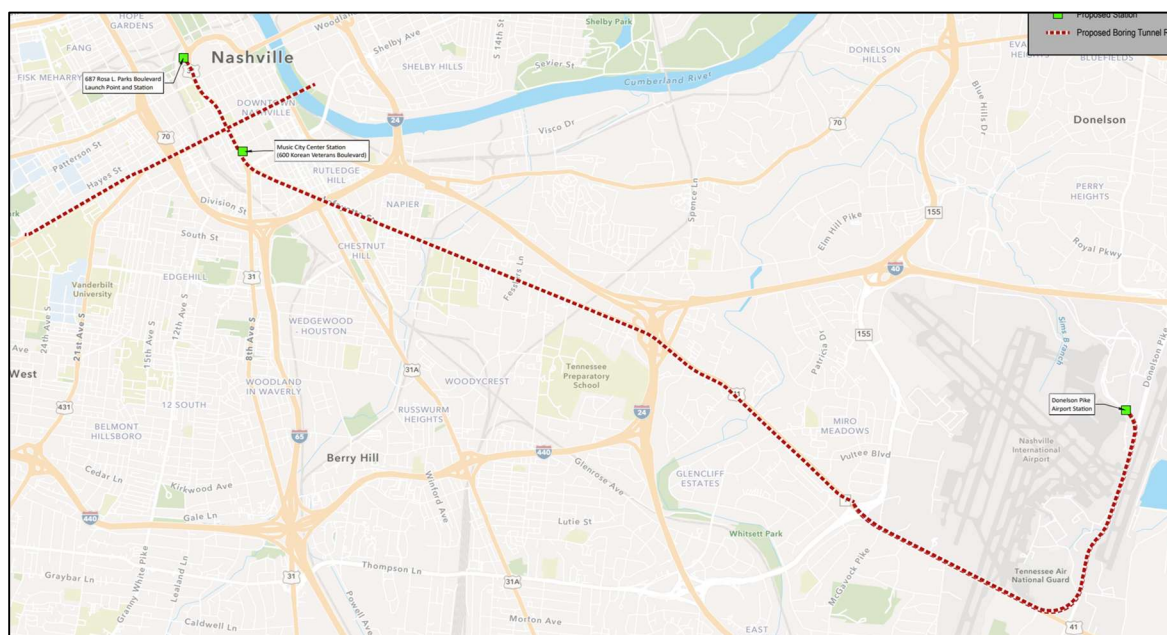


Figure 1. Pathways of the Airport and Broadway Alignments (DRG 2025).



Figure 2. Northwestern entrance to the TBC Airport Alignment at 637 Rosa Parks Blvd. This is looking down from the Tennessee State Capitol Hill (photo Chris Groves).

The route begins where tunneling has started at 637 Rosa Parks Boulevard in the shadow of the State Capital building (Figure 2). The path goes from there towards the southeast and ends at the Nashville International Airport. Also in the downtown area, the pathway of a planned, perpendicular tunnel, referred to as both the Broadway Alignment and West End Connector, runs 2.9 miles across downtown and beneath the Cumberland River.

The tunnels are being dug with two tunnel boring machines (TBM) (Figure 3, and see TBC, 2025a, 2026a, 2026e) designed and built by TBC. TBMs known as Prufrock MB-1 and MB-2 have been at work since spring 2026, and plans are to add two more. A rotating cutterhead on each of these machines grinds the rock as it advances, lubricated by water that also helps to control dust. Often, chemical additives are introduced to impact properties of the rock and the TBM/rock interaction. The mixture of water and excavated material, called *muck*, is removed from the tunnel by a conveyor system that brings this material to a *muck pit*, where it is loaded onto dump trucks for transport to disposal or recycling facilities,

although information about the locations where the muck will be taken is not publicly available. The tunneling process is expected to create two to three dump truck loads per hour, creating 266,000 cubic yards of muck from the Airport Alignment and 70,000 cubic yards from the Broadway Alignment (DRG 2025).

Figure 3. An example tunnel boring machine (TBM) in this case being used to dig the Yucca Mountain nuclear waste repository in Nevada in the 1990s. Though this TBM is about twice the diameter those being used by in the Music City Loop project, it illustrates an overall similar design with the rotating cutterhead to the right (Department of Energy photo). The smaller wheels on this style of cutterhead are the cutters that fracture and crush the rock as boring proceeds. See TBC (2025a) for images and videos of TBC's Prufrock machines.



3. Geological Background of TBC's Projects Based on Public Information

The Boring Company seems to have been born out of a post on the social media platform X in December 2016 by Elon Musk, TBC's founder and CEO, who wrote, "Traffic is driving me nuts. Am going to build a tunnel boring machine and just start digging..." (Musk, 2016). With a documented style of figuring things out as they went along—"We have no idea what we're doing—I want to be clear about that" Musk said in early 2017 (Marshall 2017)—TBC has built several tunnels through soft ground. In 2017 TBC dug an experimental, fifty-foot long test trench through unconsolidated sediments in Hawthorne, California (Castro and Padilla 2022). TBC eventually dug a 1.14 mile Research and Development (R&D) Tunnel using an existing but modified TBM built by a Canadian company. TBC eventually developed and tested their own TBMs, resulting in six additional R&D tunnels—three in Adelanto, California, and three in Bastrop, Texas (TBC 2025b). Like the first R&D tunnel in Hawthorne, these projects dug through mostly unconsolidated soft ground.

Along with the technical differences between tunneling in soft ground and solid rock, another principal environmental issue for tunneling projects is related to how the tunneling operation interacts with water. In Adelanto, where the top of the groundwater is relatively deep (see Stamos *et al.* 2001, Figures 7 and 8), TBC tunneling was close enough to the surface that conditions were within relatively dry material. The Bastrop tunnels were also constructed in unconsolidated (soft ground) material (Sellards, E.H., 1929), but with their close proximity to the Colorado River, the groundwater at that location is relatively shallow, and there appears to have been significant interaction with groundwater based on dewatering activities (see ES, 2023).

A short 1,000-foot-long tunnel in Austin, Texas, known as the Cybertunnel (TBC 2025c, 2025d), was built to deliver the company's newly completed Cybertrucks from the factory and under an adjacent eight-lane highway. TBC gained additional experience in the project tunneling through saturated conditions and through relatively soft material that includes clay and soft variety of limestone called *marl* (Garner and Young 1976). These materials presented particular challenges due to the way they can periodically swell when wet and then shrink upon drying.

TBC's first public access tunneling project, the Las Vegas Convention Center (LVCC) Loop, opened in Las Vegas, Nevada, in April 2021 (TBC 2025e). This was the first, 1.7-mile segment of a project that is still under construction and that has approval from Clark County and the City of Las Vegas for a total of 68 miles of tunnels and 104 stations (TBC 2025f). This project has presented new challenges for TBC in several ways, including that the tunneling is often underwater through shallow groundwater (Akers 2026). This not only presents engineering problems—underwater scuba-diving welders were brought in to repair leaks along 2.5 miles of steel plate seams—but the water there is also polluted from urban activities and irrigation with fertilizers and other contaminants (*e.g.* Bashor 1993). TBC has also used chemical additives to aid the tunneling process, including *accelerants* to help concrete cure more quickly, with reports of chemicals being corrosive enough that workers on the project have been burned, leading to fines from the Occupational Safety and Health Administration (OSHA) (Akers 2024). This also creates regulatory challenges because polluted water that has been removed from the ground by dewatering in tunneling operations must be disposed of properly. Though TBC has a water treatment system in Las Vegas (Akers 2026), there have been well-publicized environmental

incidents, including a fine for more than \$493,000 for illegally disposing untreated drilling water into the local sewer system, which TBC paid (Akers 2026).

There has been a technical geologic challenge in Las Vegas as well. Based on publicly available information, the Las Vegas project was TBC's first tunnel in materials other than soft ground. The area has a variety of geologic layers, and while much of it is unconsolidated clay, sand, and gravel (Plume 1984), these are interspersed with much harder layers of *caliche* (pronounced like "kuh-lee-chay") which are irregular layers, lenses, and nodules of naturally cemented sediments that behave like hard, intact bedrock (see Motamed, 2016, pp. 25-26). This creates difficult *mixed-face* conditions (see Hung *et al.* 2009 section 8.2.7), where the cutting tools on the rotating cutterhead at the front end of the TBM can simultaneously meet varying resistance and produce different kinds of muck.

In February 2026, TBC signed agreements for a tunneling project in Dubai in the United Arab Emirates (TBC 2026c).

4. Hydrogeologic Setting for Nashville and the Music City Loop

4.1 Fundamental Groundwater Concepts

As with any tunneling project, along with the rock and/or sediment type, another principal issue for the Music City Loop project is related to how the tunneling operation interacts with water. In different locations along the currently proposed MCL path, the TBM will go through a variety of rock types. Also, some underground areas through which the machines will bore are relatively dry and some are completely underwater, and there are challenges to tunneling in each. This section explains some basic ideas about how water exists and moves underground and uses these ideas to describe relevant conditions along the Airport and Broadway Alignments.

Hydrogeology refers to the science of how underground water is distributed and moves through the soil (as soil water) and rocks (as groundwater) beneath the surface. It is also concerned with the quality of that water and how its chemical composition is impacted by interactions with rocks, gases, biological processes, surface waters, and human sources of contamination. The distribution and movement of groundwater in a particular location is impacted by the types of rock or sediment through which it flows and the nature and geometry of the spaces within the rock that give the water a place to reside and move. These bodies of rock that contain and transmit significant quantities of water are called *aquifers*. The networks of voids below ground might be small spaces between sand grains, fractures, relatively large conduits, or even caves large enough for humans to move through. Large conduits or caves are common in particularly soluble rocks like the limestones that underlie Nashville where fractures have been enlarged by dissolution.

Two fundamental terms that describe the nature of these spaces within the otherwise solid materials are *porosity* and *permeability*. They are related but describe two different properties. Porosity describes the ratio of the volume of void spaces within a sample of otherwise solid material to the total volume of the sample. If half the volume of a rock or sediment sample is void space and the other half is solid material, the porosity is 50%. Permeability describes how easily the material transmits fluids. Permeability requires a material to have porosity, but to be able to

transmit water or other fluids, the spaces also need to be interconnected in a way that creates continuous pathways through which the fluids can flow.

Within underground materials, both soil and rock, there are two broad regions defined by whether the spaces within the rock are filled with water or air. A way to think about this is to imagine having a pot full of soil that is completely dry, so the tiny spaces between the soil grains are all filled with air. If water is sprinkled on the top, that water will drip downwards between the grains under the influence of gravity until it reaches the bottom of the pot. If the bottom of the pot is sealed, the water that reaches the bottom will begin to accumulate, and as those spaces get filled, it will begin to saturate them and the water will back up. After this happens and we stop the input of water to the top, we could imagine a situation in which the spaces in the lower part of the pot are completely filled with water, or saturated, while the spaces higher up will be essentially filled with air. There may still be some bits of water dripping downwards or clinging to soil grains, but generally speaking, air will fill most of that space. So we could imagine now there are two zones: a lower *saturated zone* filled with water between the grains and a higher *unsaturated zone* where they are essentially filled with air. The surface separating the two zones is the *water table*. If a straw was stuck vertically down through the soil into the saturated zone, the water in the straw would rise to the level of that surface. These ideas are illustrated in Figure 4.

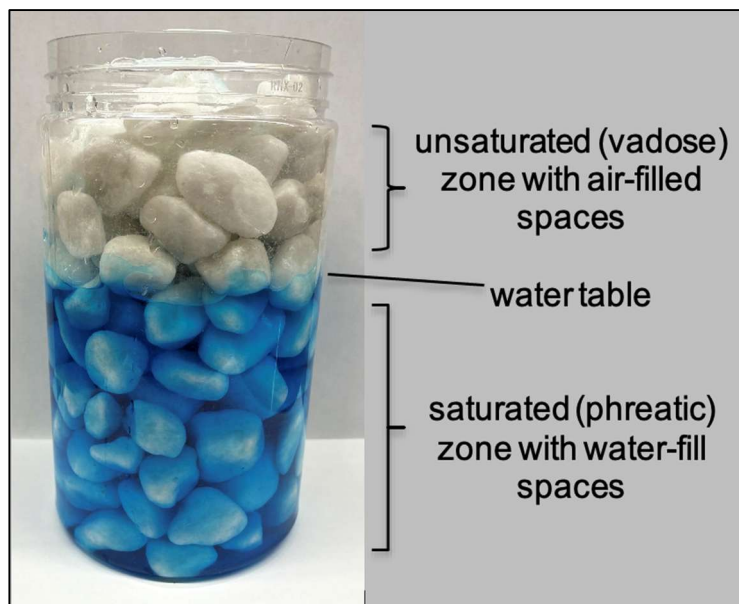


Figure 4. Simulated gravel “aquifer” illustrating the unsaturated and saturated zone (photo CG).

A very similar situation often occurs at a larger scale in natural geologic materials (Figure 5), whether soil, unconsolidated sediment (clay, sand, gravel, etc.), or fractured rocks, with a lower saturated zone, or *phreatic zone*, forming below a higher unsaturated, or *vadose*, zone. In such natural geologic settings, the surface that separates them is called the *water table*. Like the straw example, generally speaking, if a well is drilled from the ground surface downwards through the vadose zone and into the phreatic zone, the water in the well will rise to the level of the water table. In most natural geologic settings, the water table is typically not horizontal but is often like an attenuated version

of the ground surface above—higher under hills and lower under valleys. Groundwater typically moves from higher areas of the water table to lower, so if we were to drill a collection of wells across the landscape and note the elevations of the water table in each one, we could use this information to predict the directions of groundwater flow. Of course, this description is somewhat idealized, and variations in rock type—and their porosity and ability to transmit fluids—also influence the movement of water underground.

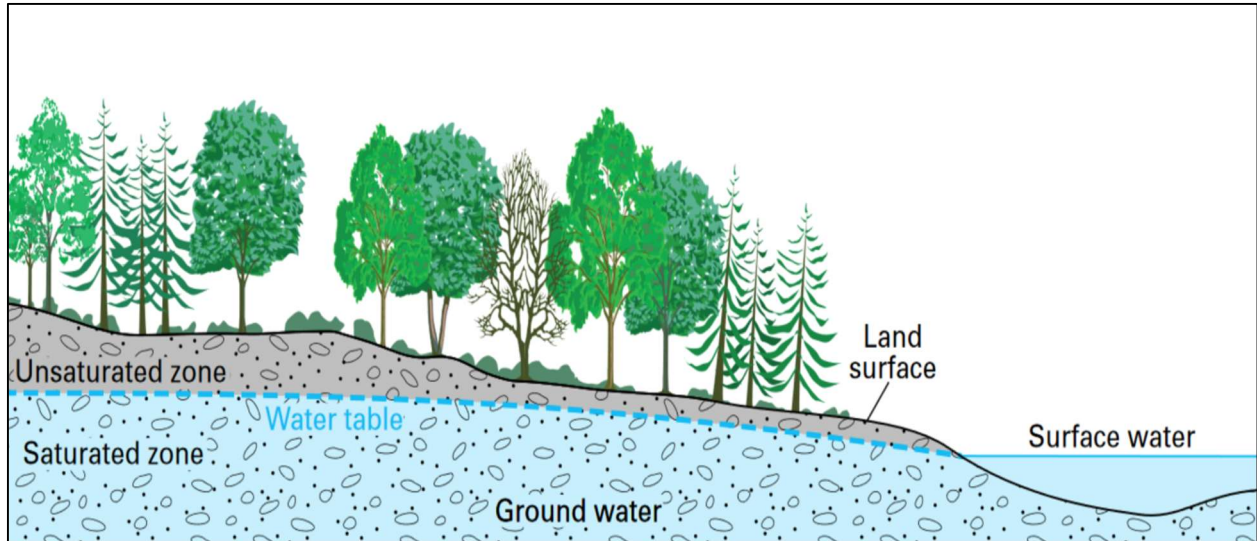


Figure 5. Field-scale, diagrammatic representation of the unsaturated and saturated zones, and water table (US Geological Survey). The body of rock through which the water is flowing would be an aquifer. One could imagine that digging tunnels would be different in the two regions of the aquifer

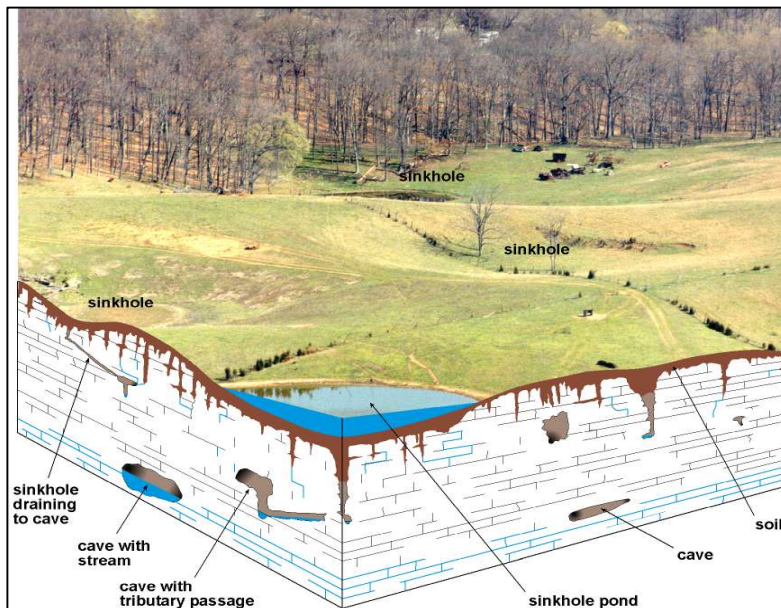


Figure 6. Block diagram showing common surface and subsurface karst features such as caves, sinkholes, and underground streams (Kentucky Geological Survey, 2015).

4.2 Karst Landscapes and Aquifers

The presence and movement of water on the surface and underground in the Nashville area is highly influenced by karst development in the landscape and underlying aquifer systems, with underground water primarily flowing through solutionally enlarged openings within the purer limestones (Brahana and Bradley, 1986; Wolfe *et al.* 1997; Shofner *et al.* 2001). Karst landscapes and their associated aquifers are hydrogeological regions where bedrock is especially soluble, resulting in the formation of features such as caves, large underground rivers, sinkholes and

large springs (Figure 6). The form of the landscape at the surface and underground often have a dominant control on the movement of water and associated dissolved constituents. karst landscapes, the bedrock often becomes so dissolved out that rain soaks into the ground at or close to where it lands instead of flowing across the surface, and surface drainage can be nearly or totally absent. Infiltrating water rapidly moves through the underground “plumbing system” of crevices, conduits and caves. It eventually reemerges at the surface at a spring that flows into the local area’s base level stream. Whatever dissolved substances or suspended sediments are in the water can also be carried into and through the subsurface, so karst groundwater systems, including within the

limestones of Tennessee's Central Basin, are often highly vulnerable to contamination (e.g. Brahana and Bradley 1986; Hanchar, 1991; Farmer and Williams 2001; Goldscheider 2005; Ford and Williams 2007; Croskrey and Groves 2008).

4.3 Geology of Nashville

The landscape of Nashville lies within Tennessee's Central Basin (Figure 7), which has a relatively simple regional geologic setting. It consists of a broad blanket of nearly horizontal rock layers that were deposited as sediments on the floor of an ancient ocean during the Ordovician geologic period, roughly 450 million years ago. The layers have been warped upward in a gentle dome-shape in the area surrounding Nashville (Figure 7), but over shorter distances, as within the city, they are essentially horizontal.

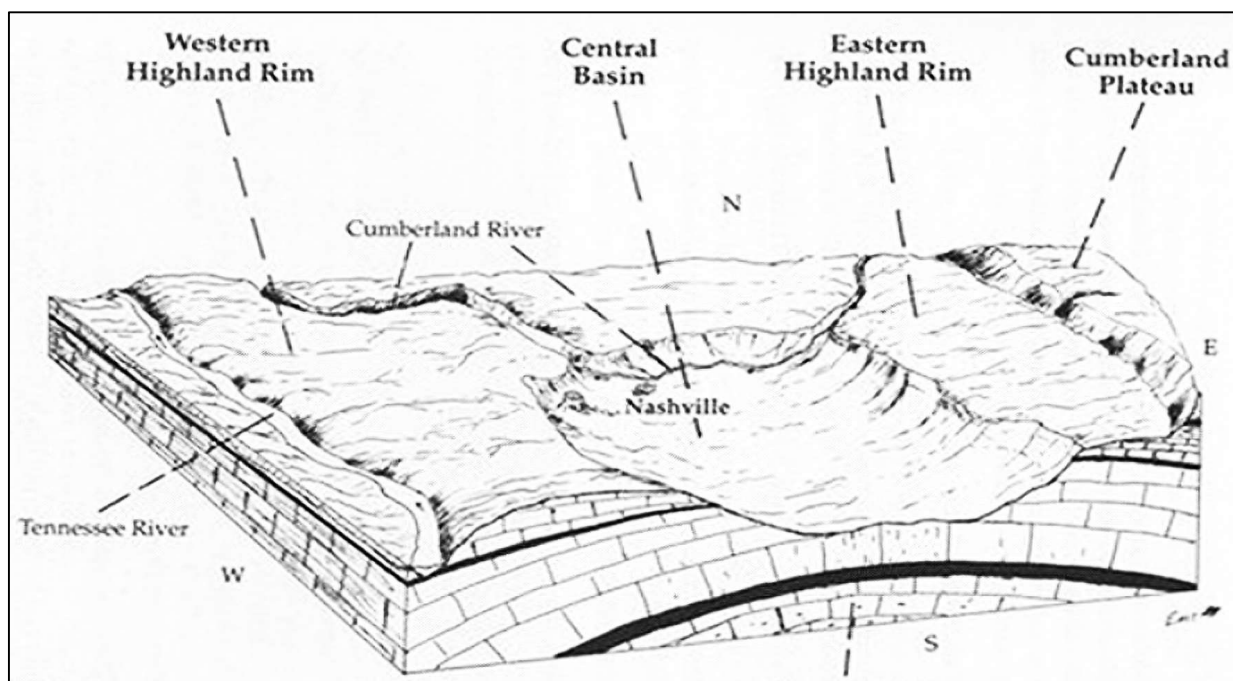


Figure 7. Regional geology of middle Tennessee highlighting the sedimentary rock layers that underlie Nashville within the area known as the Central Basin. Though the rocks have been gently domed up regionally, over limited areas in the vicinity of the center of the dome, such as within the city of Nashville, the layers are essentially horizontal. Diagram from Moore (1994).

Each layer has its own geometry and properties, including its own porosity and permeability. These properties influence whether groundwater can exist within an otherwise solid rock layer and, if so, at what rates and in which directions it flows.

The rocks that underlie the footprint of the MCL (Figures 8 and 9) include four limestone layers, or *geologic formations*, that are stacked like a more-or-less flat layer cake—from high to low:

- the Leipers-Catheys Limestone,
- the Bigby-Cannon Limestone,
- the Hermitage Limestone, and
- the Carters Limestone.

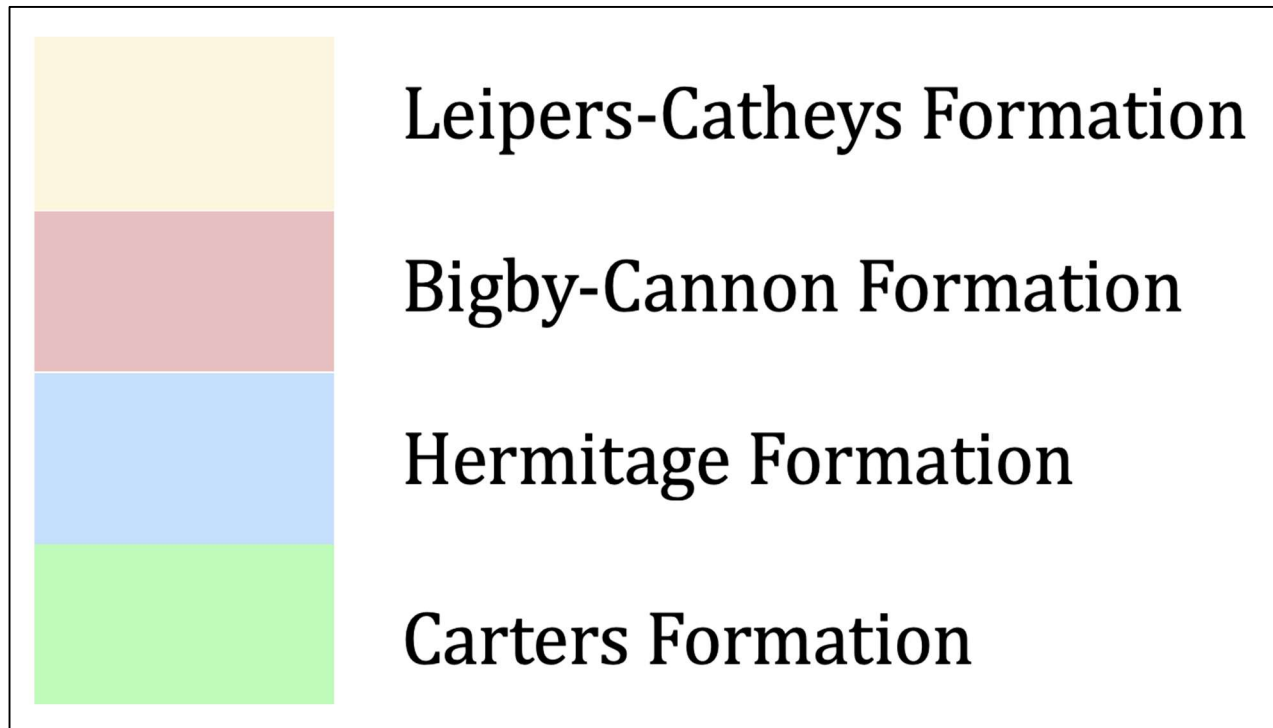


Figure 8. The four most relevant limestone layers in the proximity of the MCL. Drawn by the author based on, and with the colors corresponding to, the following geologic map provided by DRG (2026, p. 51).

The Leipers-Catheys, Bigby-Cannon, and Carters are relatively pure, and thus soluble, limestone rock layers that can often transmit water effectively because they contain conduits, caves, and other karst features that have been enlarged by dissolution as groundwater moves through the soluble limestone. Broadly, the Hermitage is less soluble and forms a "leaky" *confining layer* that doesn't easily allow water to pass through it. While it is indeed considered to be limestone, it is generally less soluble because of the presence of insoluble impurities, and the amount of this insoluble component is a major factor influencing whether limestone makes a productive aquifer or not. The purer the limestone, the better it dissolves and the more effectively it is able to form karst features and transmit water.

The geologic map (Figure 9) shows the distributions of these layers. We can imagine the four limestone layers are stacked on top of each other like a horizontal layer cake with each layer represented by a different color (colored coded as in Figure 8). If we could remove all of the surface materials of Nashville that normally cover and obscure the bedrock (soil, vegetation, roads, and so forth) and look directly down onto the rock layers from above, the colors on the map indicate which layer would be exposed in a given area. If we think about looking down onto a layer cake that has not yet been disturbed and has all the layers still intact, we would only see the top layer. The other layers are all there but hidden beneath and so not visible. If the cake was then disturbed, and various layers scooped out to various depths exposing the underlying layers, then the different colored layers would be visible when looking down, with highest layer at any point being the visible color.

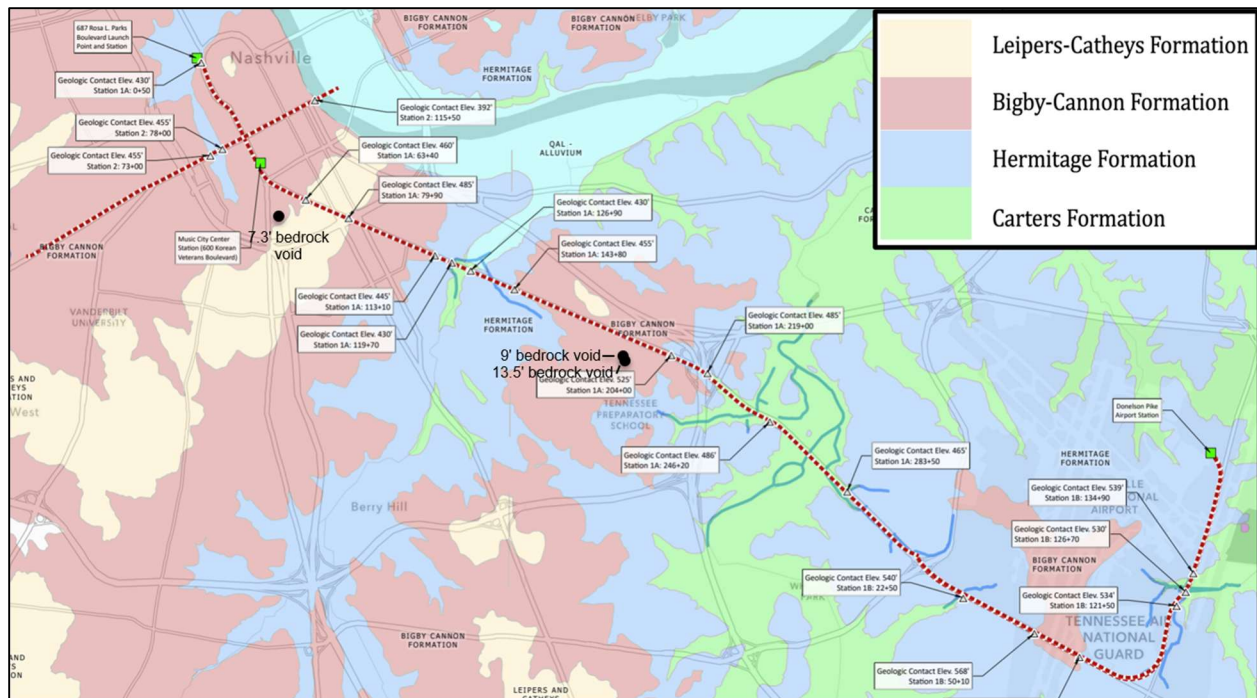


Figure 9. Geologic map of the MCL area. This map is looking down from above onto the layer cake shown in Figure 8, with everything that would normally cover the bedrock (soil, vegetation, roads, and so forth) removed. The color at any location indicates the highest rock layer, where any that were previously higher have been eroded away (map from DRG 2025). The three bedrock voids shown, hit by pure chance and thus showing how porous and permeable these karst limestones are, are shown with approximate locations in the Bigby-Cannon Limestone (TVG 2002, pp. 71 and 77; PSI 2020).

The map is conceptually similar. If Nashville's limestone layers were undisturbed, the map would be covered by the yellow Leipers-Catheys layer. But in reality, erosion of the landscape has exposed the different underlying layers indicated by the mapped colors. The highest rocks of the Leipers-Catheys Formation (yellow layer) are exposed only at the tops of hills and have been removed by erosion elsewhere, exposing the flat layers beneath. The Bigby-Cannon Limestone (red layer) is also exposed higher up in the hilly areas but only where the yellow Leipers-Catheys is gone. The Hermitage Limestone (blue layer) is visible where the two higher formations have been eroded away, and the lowest, Carters Limestone (green layer), underlies the whole area but is only exposed and visible in the area's deepest valleys, including along Brown's Creek, Mill Creek, and McCrory's Creek along Donelson Pike. The Carters is also under the Cumberland River where the Broadway Alignment crosses, but is obscured on the map by the teal-colored Cumberland River sediments (indicated on the map as QAL-alluvium).

4.4 Nashville's Tunneling Challenges: Karst Limestones and Legacy Contamination

Potential hydrogeologic challenges for the MCL include karst formations, along with contamination as might be expected in many urban areas.

Based on available public information, the MCL appears to be TBC's first project in solid rock. Here, Nashville is underlain by solid, nearly horizontal limestone layers of the Leipers-Catheys, Bigby-Cannon, Hermitage, and Carters Formations. Though the harder rock requires different tools and technology to bore through compared to soft ground, the fact that it is, in general, self-supporting offers some advantages. In contrast, soft ground, such as a bed of sand that could

collapse in on itself, can require sophisticated supporting mechanisms that are put into place as the tunnel proceeds. Within the global tunneling industry, tunnel boring machines have been widely used in both unconsolidated materials and solid rock (e.g. National Research Council 1984; Hung *et al.* 2009; ITAtech 2024). Given their experience and resources, TBC's geologists and engineers should be able to deal with any issues presented by the limestone itself. But the abundant and well-developed karst features, especially in the Bigby-Cannon and Carters Limestone (Figures 9 and 10), create considerably more uncertainty. Tennessee Cave Survey data (TCS 2026a)¹ show that four explored and mapped caves (voids big enough for people to walk around in) are located in the Carters within two miles of the Airport Alignment. One of these (Pulley Cave) has passage dimensions that reach 30 x 40 feet (TCS 2026a). As Hung *et al.* (2009) noted,

Karstic limestone is often riddled with solution cavities of various sizes. Depending on the geologic history of the locale in which it is found, cavities ahead of the excavation may be filled with water, mud, or gravel or a combination of these. Flowing water may be present in large quantities. There may be an insufficient thickness of sound rock at tunnel elevation to provide safe support for tunneling equipment. *All of these possibilities point out the need for thorough exploration before undertaking tunnel construction in limestone.*

(Italics added). Karst development appears to be among the most difficult technical challenges of the MCL project. TBC's Karst Mitigation Plan (TBC 2026d) describes the boring and geophysical methods it plans to use to identify subsurface voids. A diagrammatic yet illustrative representation of karst development in the Carters (Wolfe *et al.* 1997) highlights the highly heterogeneous distribution of voids and groundwater flow in the karst aquifer networks in that layer (Figure 10).

Of the four layers that underlie the current footprint of the project, the Hermitage is relatively impure, leading to a less permeable and more homogeneous rock mass generally more favorable for tunneling than the other three. White (1974) showed that samples from the Hermitage Formation had an average insoluble component of 48%, while a collection of the Central Basin's purer limestones, including the Carters, was only 9-10%. All things equal, purer limestones will be prone to more pronounced karst development and more problematic tunneling.

While the Leipers-Catheys does have karst development, it appears to generally be above the main tunneling levels. The Carters Limestone in this area has the most intense karst development and will likely be the most problematic to tunnel through. A separate technical report by a TBC contractor concludes that there is a "LOW to Moderate risk of karst feature development," (PSI 2025, p. 14, their emphasis)² supported in part by the conclusion that "it is anticipated that these will be in the form of soil-filled slots or seams in the bedrock" (PSI 2025, p. 11). One way to measure karst development is by comparing the extent of known, mapped caves in each of the different rock layers of the relevant area (Figure 11), which gives a useful, if partial, accounting of the of the extreme end of the limestone dissolution. There is also evidence that caves explored and mapped by humans are only a subset of the large voids within the Carters and Bigby-Cannon Limestones. For example, a 13.5-foot void and a 9-foot void (Figures 9 and 12) were recorded in the Bigby-Cannon Limestone just south of the MCL route while drilling groundwater monitoring

¹ Per the author's agreement with TCS, cave locations are not published in this report.

² Obtained through a records request to TDOT.

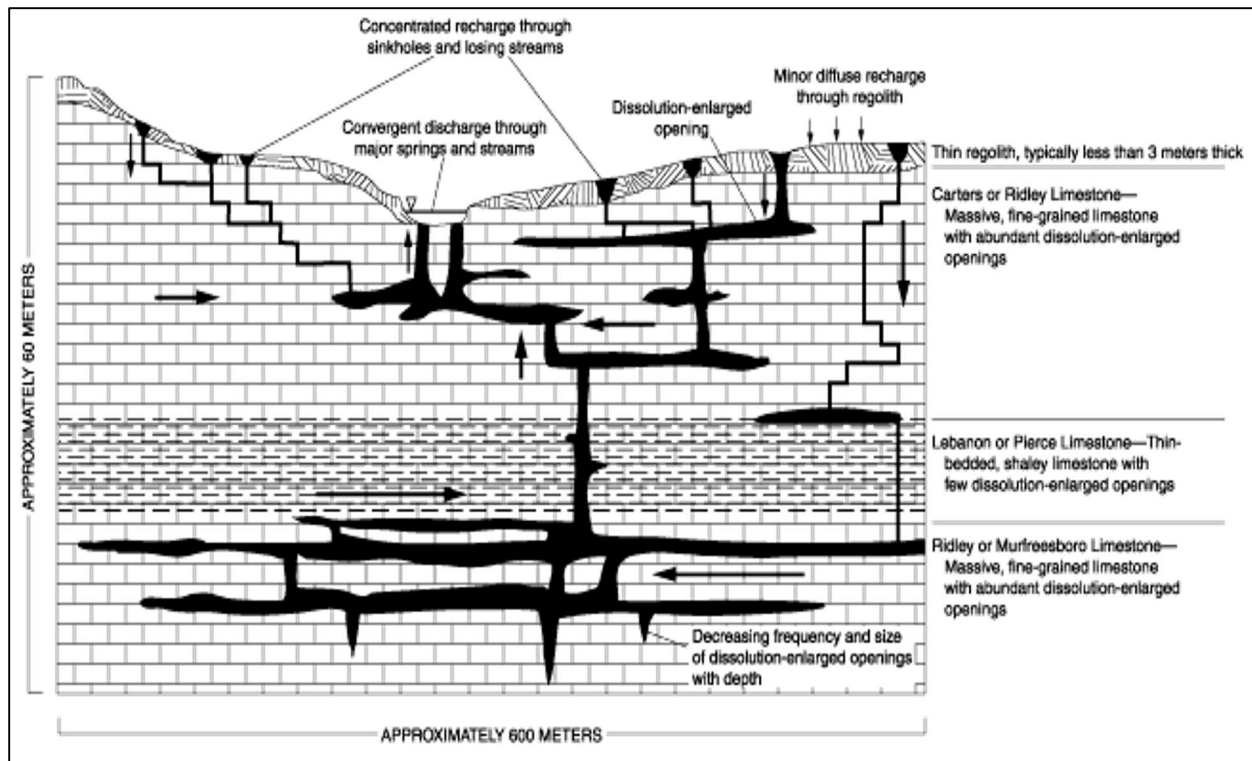


Figure 10. Diagrammatic cross-section of the Carters Limestone within Nashville's Central Basin, and layers beneath it, showing the possibility for "abundant dissolution-enlarged openings" in the Carters (Wolfe *et al.* 1997). This is the position in the "geologic layer cake" of the area beneath Browns Creek (Figure 26) and Mill Creek where the MCL will cross underneath these streams. This is generally showing conditions where the Hermitage Limestone has been eroded away, leaving green areas of Carters Limestone on the geologic maps (Figure 9).

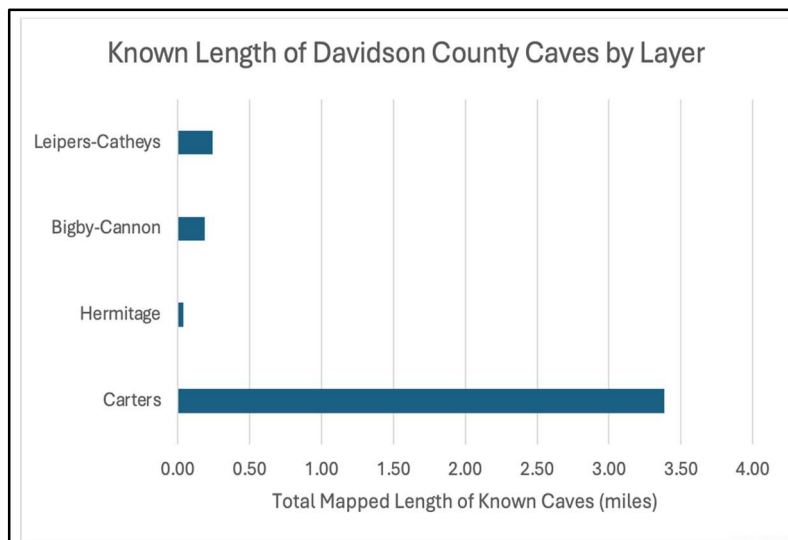


Figure 11. Distribution of explored and mapped cave passages as a measure of extreme karst development within the relevant limestones in Davidson County. The Hermitage Limestone is relatively impure which inhibits groundwater flow and karst development and while there is karst development in the Leipers-Catheys and Bigby-Cannon Limestones, it is dominated by the Carters. Graph created by the author from Tennessee Cave Survey data (TCS 2026b).

well at the former Aladdin Industries site on Murfreesboro Pike (TVG 2002). A 7.3-foot void was also found during a 2020 drilling program (PSI 2020) (Figures 9 and 13) closer to downtown and near the Airport Alignment. More broadly, scientists estimate that about 90% of the world's explorable caves have *not* yet been entered by humans (Ghosh *et al.* 2017; Kosznik-Kwaśnicka *et al.* 2022).

Other factors exert control on karst development in the Carters, and there is some difference between the pathways by which groundwater can reach the Carters downwards from above where the formation is exposed at the

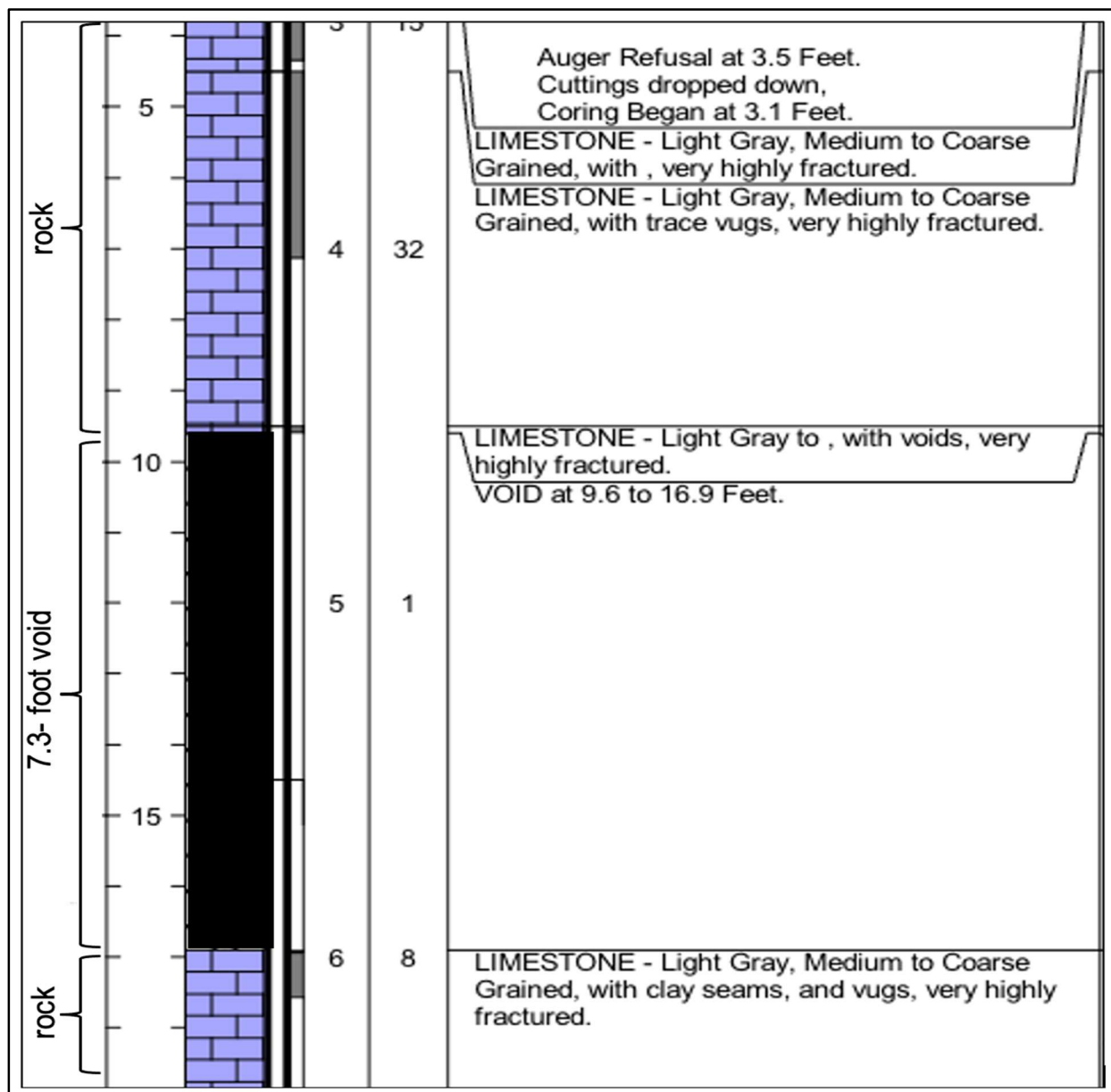


Figure 12. Explored and mapped caves are only a subset of the large voids within the Carters and Bigby-Cannon Limestones. This 13.5-foot void and a 9-foot one nearby (see Figure 9) were discovered in the Bigby-Cannon Limestone while drilling a groundwater monitoring well at the former Aladdin Industries site at 703-705 Murfreesboro Pike, just south of the MCL route (modified for clarity by the author from TVG 2002, p. 71).

surface (green areas of Figure 9). Where the Carters is beneath the less permeable Hermitage (blue areas on Figure 9), groundwater may still reach Carters but through less direct pathways. TBC's Environmental Impact Assessment (EIA) (DRG 2025, p. 30) notes that relatively favorable tunneling conditions exist in the Hermitage Formation where the project

will largely avoid zones of problematic karst development and will avoid the groundwater commonly encountered on top of rock. Portions of the proposed tunnel boring are within the Bigby-Cannon Limestone and [...] areas where the Carters Limestone is exposed as the uppermost bedrock layer. *The Bigby-*

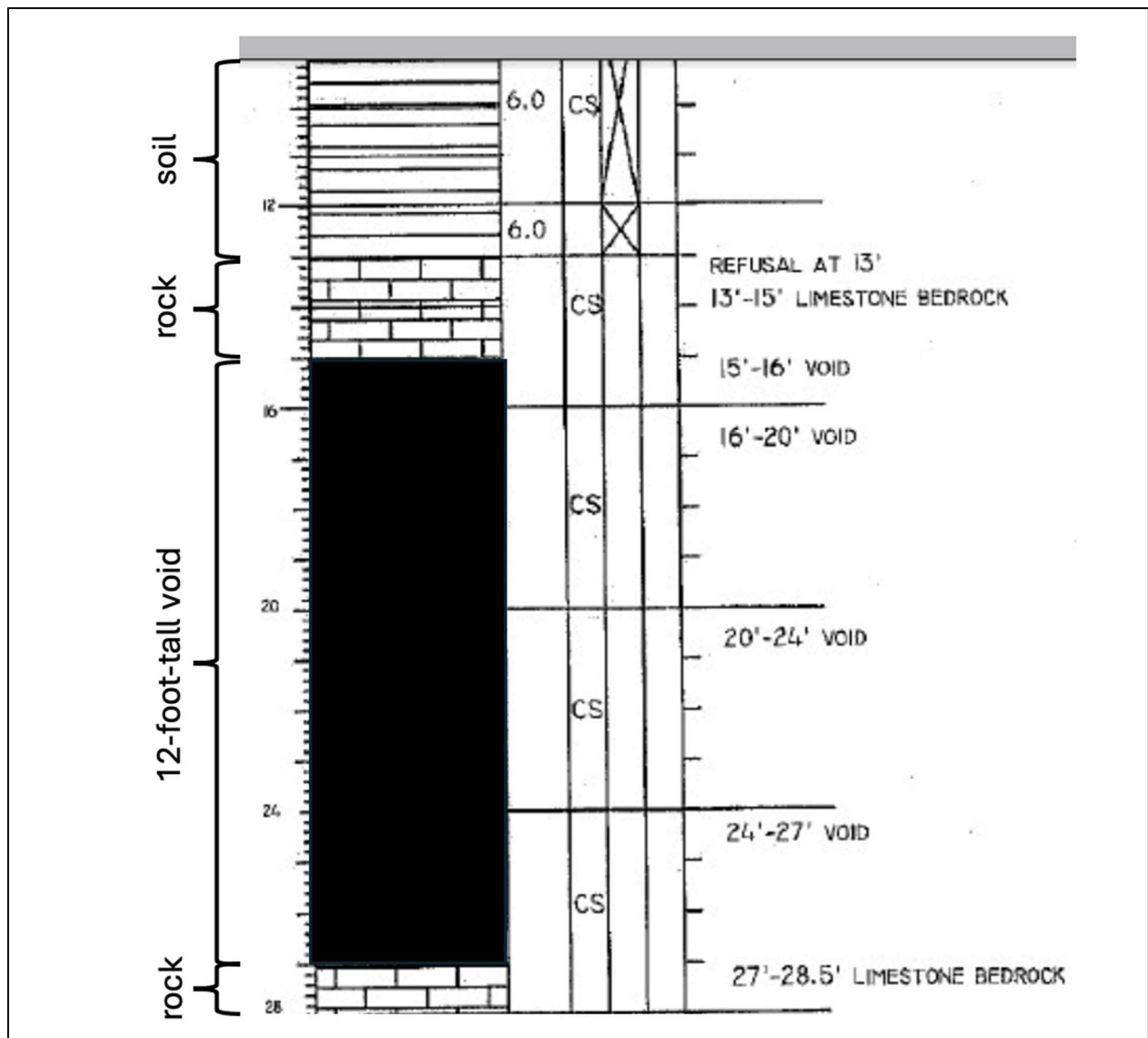


Figure 13. 7.3 foot-tall void in the Bigby-Cannon Limestone within about 400 feet of the Music City Loop along Lafayette Street (Figure 10) (PSI 2020). This and the voids shown in the previous figure were just hit by chance, and as they are tall enough for people to stand up in, though we don't know the other dimensions, might be considered to be just caves that lack humanly traversable entrances (modified for clarity by the author from PSI 2020).

Cannon and Carters Formations are susceptible to karst development and present a higher potential for groundwater intrusion. TBC will attempt to avoid tunnel boring in areas where karst development is identified and will attempt to complete most of the tunnel boring activities within the Hermitage formation whenever practicable.

(Italics added). If the Music City Loop tunnels could be wholly within the Hermitage Limestone, this would be a simpler project, and this would have been a shorter report. But there are areas, primarily the green areas on the geologic maps (Figure 9), where it is simply not possible to tunnel within the Hermitage because in these areas it no longer exists.

The publicly available data do not allow exact determination of how much of the tunnels will be in each of the four layers, but it seems likely that the tunnel will generally be below the Leipers Catheys formation. The EIA indicates that project will tunnel within the Hermitage as much as possible. The tunnel will likely avoid the Carters as much as possible, which because of the probability of well-developed karst and saturated conditions, especially beneath the streams the tunnels must cross beneath, may well be the most challenging parts of the project. At a minimum, the tunnels will be forced to go into the Carters where the Hermitage is missing, shown by the green areas on Figure 9, and beneath the Cumberland River. There are some areas where the tunnel could be in the Bigby Cannon, which also has extensive karst development as shown by the voids in Figures 9, 12, and 13.

Not only does the EIA omit details about what happens when karst-related problems occur in the limestones, but it creates what seems like potential inconsistency when it describes tunneling through the Carters Limestone beneath the Cumberland River on the Broadway Alignment (DRG 2025, p. 30):

the portion of the proposed tunnel boring that traverses beneath the Cumberland River, the regional base level groundwater discharge, is within the Carters Limestone below the assumed riverbed. The proposed boring tunnel will maintain substantial overburden beneath the Cumberland River bed (more than 25 feet). *At this depth, localized solution-enhanced features may be present, as is typical for the region; however, with the tunnel positioned within competent geologic units and well below the river bed, the potential for groundwater-related impacts is low.*

(Italics added). Which geologically competent units? The previous sentences just said the tunnel will be in the Carters there, which will likely be problematic for tunneling.

Caves such as those in the Carters (Figure 14) are just the largest expressions of the extreme dissolution of the limestone bedrock—in comparison with most other rock types—but this is very much a human-centered view because these just happen to be big enough voids for people to explore. Groundwater can flow through much smaller, solutionally-enlarged conduits that still create heterogenous and, therefore, unpredictable groundwater flow conditions within the limestone (Figure 15).

There are potential lessons from a nearby project in the Carters Limestone in Gallatin, about 30 miles northeast of Nashville. In 2019, the Tennessee Valley Authority (TVA) agreed to settle a state lawsuit to move some 12 million cubic yards of saturated coal ash to lined, dry storage at a cost of \$640M (TDEC 2019) after it had been determined at an parallel federal trial that at least 27 billion gallons of toxic coal ash slurry had been leaking through the karst aquifer of the Carter's Limestone into Old Hickory Lake on the Cumberland River (Crenshaw 2017, p. 17). The leak had been hidden for decades because the outlet where the contamination was pouring into the lake was below the surface of the lake and not visible. At the federal trial TVA testified that their preferred, less expensive “cap in place” option for the ash would have cost \$231M (US District Court 2017, p. 114). The final cost to move it, \$640M, shows that leakage of ash through the Carters Limestone in this case cost TVA the difference, about \$409M. Though the cave through which the ash flowed to the river is covered by tons of coal ash and was thus inaccessible for inspection, a short distance



Figure 14. The entrance to Demonbreun Cave within the Carters Limestone, within two miles of the TBC Airport Alignment (National Park Service photos).



Figure 15. Water (at that moment frozen) draining from the Carters Limestone along I-24 in Nashville showing the “sieve-like,” highly heterogenous groundwater flow common in this limestone layer (photo CG).

across the Cumberland River the main passage of Gallatin Steam Plant Cave (Figure 16) gives an idea of what the interior of the Carters Limestone can look like in Tennessee's Central Basin.

5. Examples of Challenges During Tunneling in Karst Aquifers

Kang *et al.* (2021, p. 1) summarized that “[t]here is high risk of water inrush (Figure 17) and ground collapse accidents when tunneling in karst areas.” Liu *et al.* (2017, p. 37) wrote:



Figure 16. This underground river in Gallatin Steam Plant Cave about 30 miles from the MCL illustrates karst feature development in the Carters Limestone (photo Corv Holliday).

If the unexpected location, irregular geometry and unpredictable dimensions of karst structures are not accurately predicted, geological disasters like destruction of surface and subsurface karst structures, large-scale water and mud inrush, and collapse are easily to occur in the process of tunneling through karst areas with structures of high catastrophability, such as underground river[s], caves and cavities, faults or fractures. Once the aforementioned geological disasters occur, [a] series of consequences follow. The inflow of water and mud will destroy machines and tools, flood the tunnel and interrupt construction process. In the worst case, it will end up with heavy casualties and serious economic losses, or, even worse, with construction cessation or rerouting of the current underground construction.

There is a relatively extensive body of technical literature describing causes of tunneling problems in karst, including case studies, and strategies for dealing with them (*e.g.* Loew *et al.* 2010; Willis 2019; Jordan 2020; Trela *et al.* 2023; Duhme and Brabant 2019; Ren *et al.* 2016; Sun *et al.* 2020; Pesendorfer and Loew 2010). Examples of these problems include 1) potentially massive water inflow and flooding (*e.g.* Li *et al.* 2016; Zhang *et al.* 2020; Liu *et al.* 2022), 2) machine entrapment and "stuck" TBMs (*e.g.* Brierly Associates 2022; Rush 2024), and 3) sinkholes and ground subsidence (*e.g.* Duhme and Brabant 2019; Song *et al.* 2012; Preisig 2013, p. 84-88). Interaction



Figure 17. Pressurized groundwater entering at the tunnel face in the R3 Metro Line tunnel in Jinan, China (Kang *et al.* 2021).

with previously contaminated groundwater, contamination of groundwater by tunneling fluids, or other disruption of water resources (*e.g.* Akers 2026; Mossmark *et al.* 2017) is not a particular karst hazard, but certainly is a concern when tunneling beneath urban areas. These might be put into two categories: the first two create problems—delays, costs, or safety concerns—for the tunneling operators; the other two potentially create environmental problems that could influence the impacted communities. Li *et al.* (2016, p. 39) summarized the impacts of water inrush events in eleven karst tunnel projects in China, with 158 separate events leading to project delays of up to two years, equipment loss, and 48 deaths. The highest flow rate of groundwater into the Wulong tunnel in Chongqing during one such burst was more than ten million gallons per hour.

6. Potential Interactions with Contamination

On some tunneling projects, chemicals are introduced to aid the tunneling process, and these have created environmental as well as health and safety problems—sometimes with injuries (Akers 2024). For TBC’s Music City Loop effort, the company has indicated that only water will be used in this project to lubricate the cutterhead and control dust.

Urban areas like Las Vegas or Nashville commonly have a legacy of contamination in soil and groundwater, and dealing with such contamination has created challenges for TBC's Las Vegas project (Akers 2026). TBC's EIA for the MCL notes that "[g]roundwater that is encountered during excavation has the potential to contain petroleum or other contaminants due to potential historic releases from regulated facilities like gas stations or industrial facilities, which are present along the Project alignment" (DRG 2026 p. 16). But TBC's EIA does not disclose plans for interventions if such contamination is encountered.

As a TDOT (2026, p. 3) report described,

Along each alignment corridor there are many properties that currently or historically use hazardous chemicals such as fuel stations, dry cleaners, auto shops, and other commercial and industrial uses. Dozens of listed TDEC [Underground Storage Tank] Facilities are along these roads. Southern downtown Nashville was heavily industrialized in the past 100+ years. Several dozen TDEC Department of Remediation sites are located along these roads and in the general area. . . . In the event hazardous materials or wastes are encountered within the right-of-way disposition shall be subject to all applicable regulations, including the applicable sections of the Federal Resource Conservation and Recovery Act, as amended; the Comprehensive Environmental Response, Compensation, and Liability Act, as amended; and the Tennessee Hazardous Waste Management Act of 1983, as amended.

6.1 Aladdin Industries

Analysis of TDEC Division of Remediation (DOR) data for this project shows that there are numerous DOR sites where TDEC has information on known or suspected hazardous waste sites in the proximity of both the Airport and Broadway Alignments (Figure 18). TDOT's (2026) analysis says that "[n]o known hazardous material sites are adjacent to the Lafayette St. temporary construction areas nor the Murfreesboro Rd. area." But there is a long and varied history of contamination at the Former Aladdin Industries at 703-705 Murfreesboro Pike (Figure 19). This property is part of TDEC's Voluntary Cleanup, Oversight, and Assistance Program (VOAP). From 1949 to 2002 Aladdin Industries manufactured vacuum bottles, school lunch boxes, insulated trays, and lamp mantles. There is a well-documented history of soil, groundwater, and soil gas contamination by the carcinogen trichloroethylene (TCE), other hazardous solvents, and metals (arsenic, cadmium, and lead) that exceed regulatory EPA and TDEC Maximum Contaminant Levels (MCLs) for public groundwater (TDEC 2020; TVG 2010). There is also a history of contamination by the radioactive isotope thorium-232 that was used to make the mantles for kerosene lanterns (TDEC undated, p. 2-211). TCE presents problems as it is a *dense non aqueous phase liquid (DNAPL)* that does not mix with water and is heavier than water, so it can settle down into fractures at the soil-bedrock interface and/or within the bedrock.

TDEC (2020, p. 1) wrote,

The Aladdin site is a complicated VOAP project with soil, groundwater, and soil gas contamination consisting of chlorinated solvents, petroleum, and metals. In addition to the hazardous substances, a radiological cleanup under the oversight of the Tennessee Division of Radiological Health occurred in the 1980's-1990's as a result of lantern mantle production.

Aladdin removed all primary sources, such as tanks and drums, prior to sale of the property; however, secondary sources, such as free-product in soil and dense non-aqueous phase liquid in groundwater exist onsite, resulting in high concentrations of contaminants in the soil, groundwater, and soil gas.

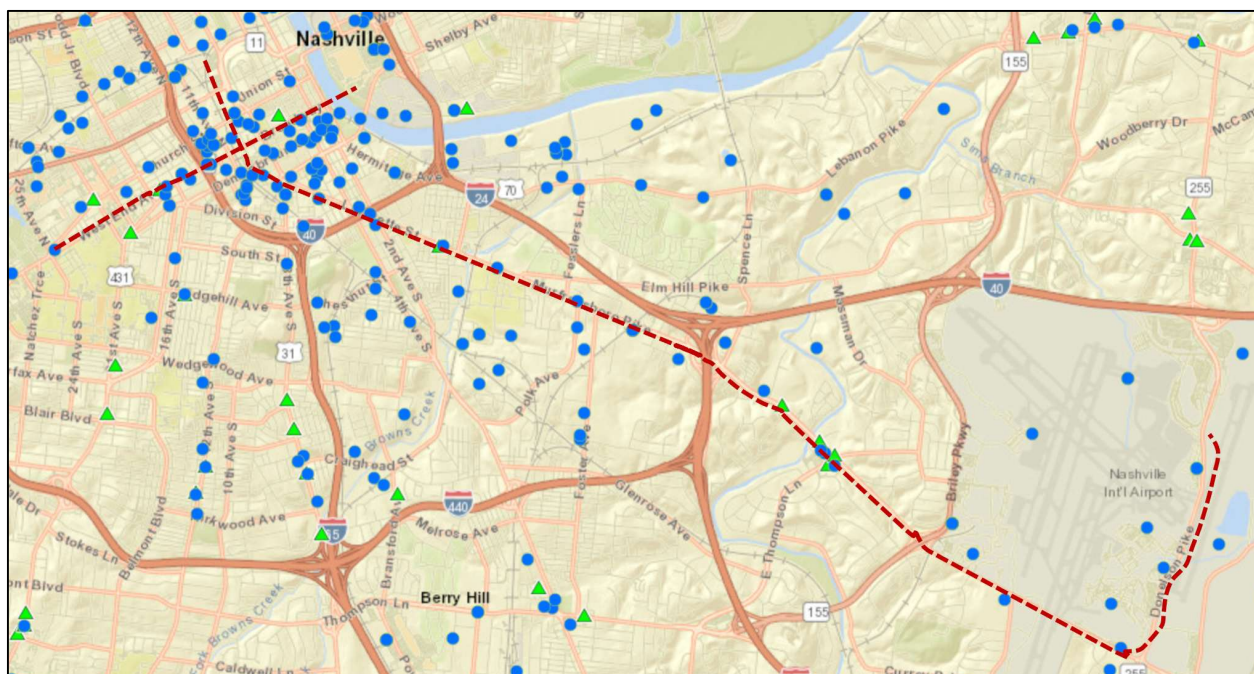


Figure 18. There are numerous TDEC Division of Remediation (DOR) sites (blue dots), where TDEC has information on known or suspected hazardous waste sites in the proximity of both the Airport and Broadway Alignments. Alignments (redrawn here from DRG 2025) are approximate, site data from TDEC (2026), see also TDEC (2025).

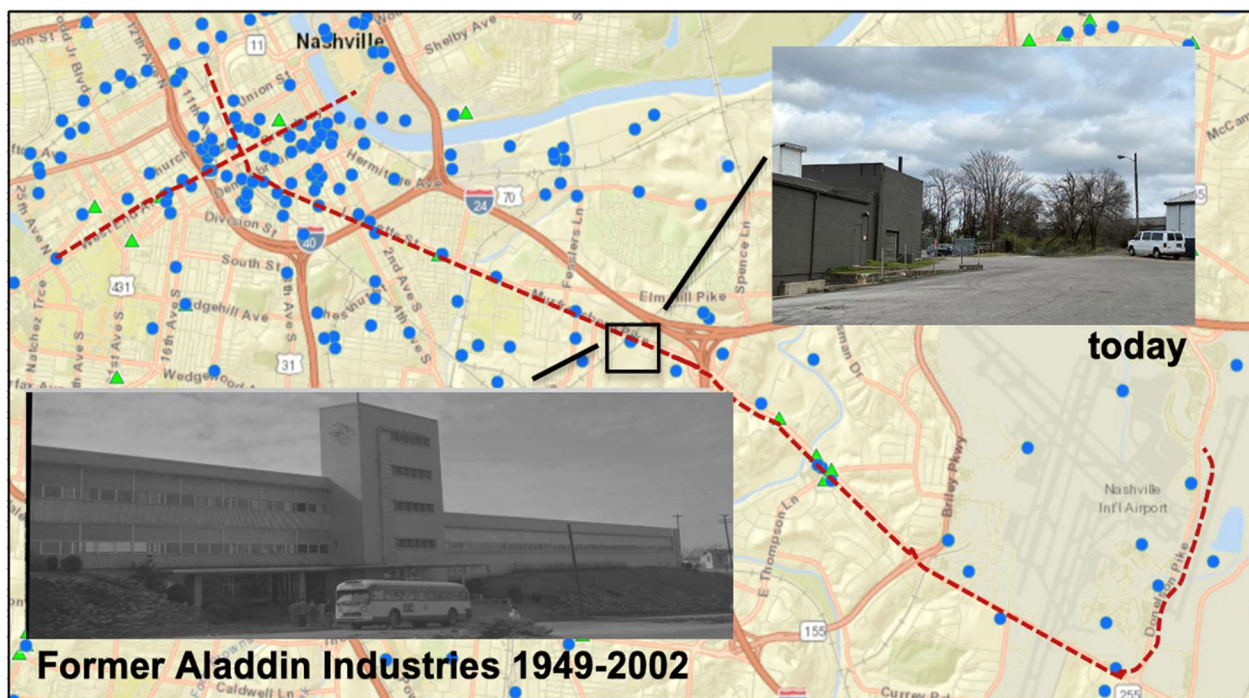


Figure 19. The location of the former Aladdin Industries at 703-705 Murfreesboro Pike has a history of contamination by chlorinated solvents, petroleum, metals, and radioactive thorium-232. There are high concentrations of the carcinogen trichloroethylene (TCE) in the soil, groundwater, and soil gas (TDEC 2010, 2020). Inset rectangle shows approximate location of Figure 20 (lower photo used with permission of the Metropolitan Government Archives of Nashville and Davidson County, upper photo CG).

Figure 20 shows a 2010 soil vapor map for TCE (trichloroethylene) (TVG 2010, 2012) at the northern part of the former Aladdin Industries property, adjacent to Murfreesboro Pike and the MCL. There are no data to the north of the property boundary, so that end of the plume is not defined. TVG (2010, p. 98-106) also shows vapor contamination of soil by tetrachloroethene, cis- & trans 1,2-Dichloroethene, benzene, BTEX (benzene, toluene, ethylbenzene, and xylene), and Total Petroleum Hydrocarbons (TPH).

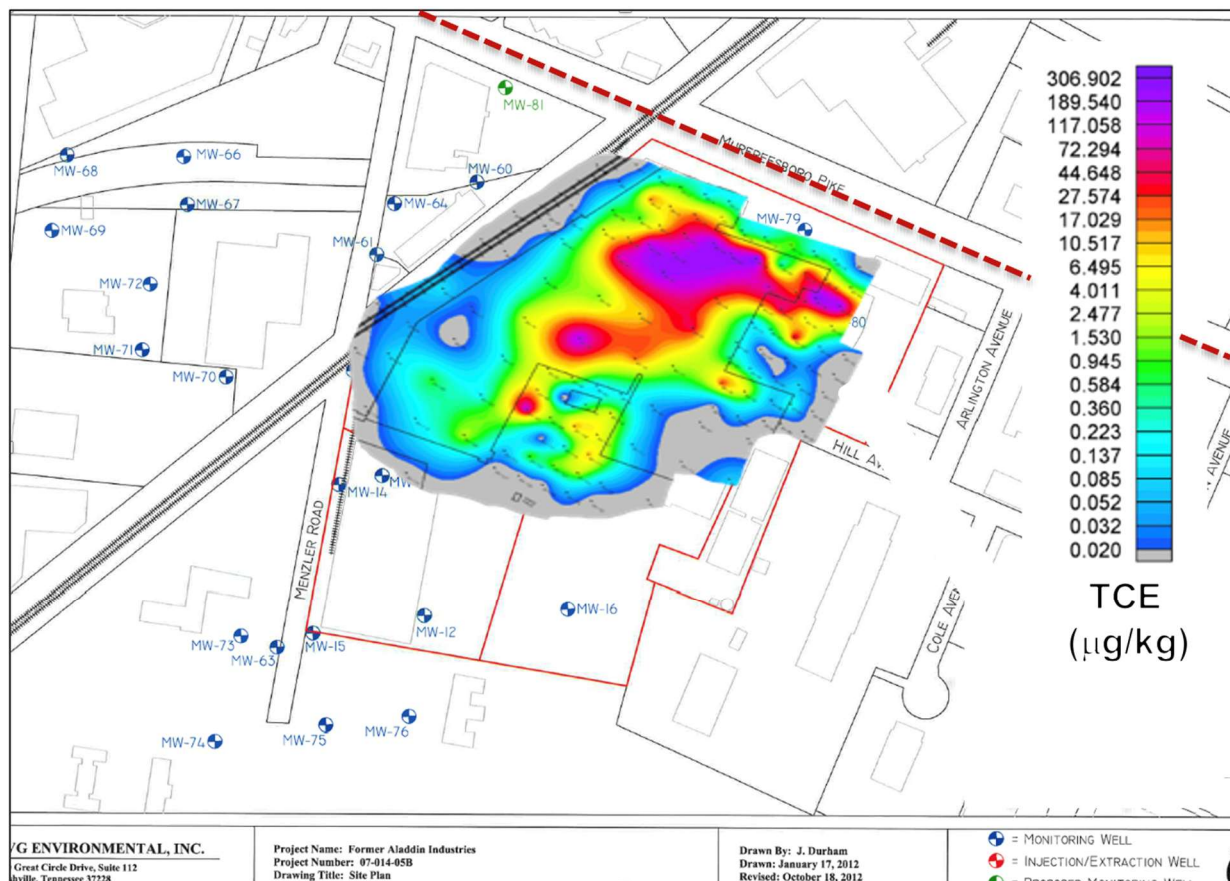


Figure 20. 2010 Soil vapor map for TCE (trichloroethylene), with units of µg/kg, at the northern part of the former Aladdin Industries property, adjacent to Murfreesboro Pike and the MCL. There are no data to the north of the property boundary, so that end of the plume is not defined. Basemap TVG (2012, p. 46) and chemical data from TVG (2010, p. 99), which also shows (TVG 2010, p. 98-106) vapor contamination of soil by tetrachloroethene, cis- & trans 1,2-Dichloroethene, benzene, BTEX (benzene, toluene, ethylbenzene, and xylene), and Total Petroleum Hydrocarbons (TPH). Alignment of TCE concentrations with respect to the basemap is approximate.

7. Conclusions

A review of surface and subsurface geologic and groundwater conditions along the MCL and the potential for relevant environmental implications indicates there are four major, nearly horizontal limestone layers beneath the project footprint, from highest to lowest the Leipers-Catheys, Bigby-Cannon, Hermitage, and Carters Limestones. Limestones are prone to dissolution in groundwater to form karst landscapes and aquifers, in which caves and other voids, underground rivers, and sinkholes forming from ground subsidence are common features. There is extensive literature that describes sometimes severe karst-related problems that in other tunneling projects have included

massive water or mud inflow and flooding, sinkholes and ground subsidence above the tunneling, and machine entrapment with "stuck" TBMs. While tunneling in the rather impure Hermitage Limestone appears to be relatively straightforward, karst development in the other formations, especially the Bigby-Cannon and Carters, will likely be more challenging due to karst development. This will particularly be in areas where the Hermitage has been removed by erosion, exposing the Carters as the shallowest layer. In that layer the tunnel will be in the saturated phreatic zone beneath Brown's Creek, Mill Creek, a tributary to McCrory's Creek, and the Cumberland River.

There are numerous listed TDEC Division of Remediation Sites in the proximity of the Airport and Broadway Alignments. One significant example is at the former Aladdin Industries, at 703-705 Murfreesboro Road, with a history of soil, groundwater, and/or soil gas contamination by the carcinogen trichloroethylene (TCE), other hazardous solvents, and metals that exceed regulatory EPA and TDEC Maximum Contaminant Levels (MCLs) for public groundwater. There is also a history of contamination by the radioactive isotope thorium-232 that was used to make mantles for kerosene lanterns. The northern end of this property abuts Murfreesboro Pike, but data are lacking to define the extent of contamination along that boundary.

The Boring Company now has nearly a decade of experience tunneling in a variety of hydrogeologic conditions, but the MCL appears to be the first project for the company in uniformly hard rocks. The limestone itself should not present big technical problems, but what makes it tricky, according to Vanderbilt University Geology Professor Molly Miller, is that in well-developed karst layers, "it is sort of like Swiss cheese."

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Appendix A: Glossary of Technical Terms Used in This Report

accelerant: a chemical mixture that can added to concrete to speed up the rate at which it cures or hardens.

aquifer: A saturated body of rock that can transmit significant quantities of water under normal conditions. For those paying close attention, technically this means normal hydraulic gradients, but for the purposes of this report “normal conditions” is just fine.

caliche: pronounced like “kuh-lee-chay”, this is formed from irregular layers or nodules of naturally cemented sediments within the soil that behave like hard, intact bedrock. These are common in arid climates like those in the southwestern United States.

confining layer: a relatively impermeable rock layer that does not easily transmit water.

cutterhead. The front end of a tunnel boring machine that rotates with hard cutting wheels to grind into the rock as the machine advances.

DNAPL: Acronym for a Dense Non-Aqueous Phase Liquid, which is one that does not readily mix with water, and is heavier than water, and so which sink downward through the water. This is opposed to an LNAPL, a Light Non-Aqueous Phase Liquid, such as gasoline, that doesn't mix with water, and floats on it.

formation: used in this context, a (geologic) formation is a relatively homogenous layer of rock that can be discriminated from other layers by its properties. Beneath Nashville, for example, the Bigby-Cannon Limestone, Hermitage Limestone, and the Carters Limestone are each formations.

geologic formation: see formation

ground air: air in the spaces within fractures or between soil or rock particles in the unsaturated or vadose zone above the water table.

groundwater: underground water in the saturated, or phreatic zone, below the water table.

hydrogeology: the branch of science concerned with the behavior, distribution and movement of water beneath the soil and rocks beneath the earth’s surface.

karst: A term which refers to landscapes and aquifers that have been created through chemical solution of especially soluble rock, most commonly limestone, resulting in characteristic features such as caves, underground rivers, large springs, and closed surface depressions called sinkholes.

karst aquifer: An aquifer with relatively high to sometimes extreme permeability with water that flows through solutionally-enlarged fractures, conduits and or caves.

limestone: a type of rock that in middle Tennessee forms extensive, nearly horizontal layers and is especially soluble in natural waters, such that in many places solution of the bedrock forms

caves, sinkholes, and other landscape features typical of karst landscapes and aquifers. Relatively pure limestones such as the Carters Limestone can dissolve readily to form highly permeable karst aquifers, while those with significant clay impurities such as the Hermitage Formation (the layer above the Carters) do not dissolve well and form confining layers that inhibit groundwater flow. The Hermitage can be considered a "leaky" confining layer.

marl: a relatively soft form of limestone that can be found mixed with clay or silt.

mixed face tunneling: tunnel through heterogeneous geologic materials that may be relatively soft and hard in different parts, so the cutterhead must be designed so it can cut through both.

muck: the mixture of water and excavated material produced by the cutting head of a TBM.

muck pit: a temporary holding area where excavated soil and rock (muck) are deposited until they can be carried away and disposed of.

Multichannel Analysis of Surface Waves (MASW): A method that explores underground geological structures from the surface by producing and then analyzing energy waves that travel through the ground and whose behavior depends on materials through which the waves travel, and their structure.

Ordovician Period: Interval of geologic time from about 485 to 444 million years ago, during which the many of the rocks of Tennessee's Central Basin, including of those that comprise the bedrock beneath Nashville, were formed. This means that the sediments that comprise a particular layer were deposited on the sea floor during that interval of time.

permeability: the ability of a rock mass to transmit fluids. This requires that a rock mass has porosity, but also that the various space elements—fractures for example—form an interconnected set of pathways to provide routes by which the fluid can move through the rock.

phreatic zone: the saturated zone of groundwater below the water table.

porosity: the volume of space compared to the total volume of a sample of rock or other otherwise solid material, expressed as a percentage. A rock mass with 25% porosity, for example, has 25% space and 75% solid rock, for a total of 100%.

recharge: rainwater or snowmelt that soaks into the ground and which in many places, including Tennessee's Central Basin, is the source of groundwater.

saturated zone: the zone of groundwater that is beneath the water table and within which fractures or spaces between rock grains are completely filled with water.

sediments: naturally occurring, unconsolidated earth materials such as clay, silt, sand, or gravel.

soft ground: In tunneling terms, unconsolidated material such as soil, sand, clay or other sediments or poorly consolidated rock.

soil water: as the name implies, water that has penetrated the ground and is residing or moving through the soil.

tunnel boring machine: a large cylindrical machine with a rotating cutterhead at one end that created tunnels by digging through and grinding the rock as it propels itself underground.

unsaturated zone: the region below the surface but above the water table and within which fractures or spaces between rock grains are nearly or completely filled with air.

vadose zone: the unsaturated zone about the water table.

water table: the surface that separates the unsaturated (above) and saturated (below) zones of groundwater.

Appendix B: Professional Qualifications

I am a hydrogeologist (Tennessee Licensed Professional Geologist 5907) with more than 40 years of professional experience in hydrogeology, geochemistry, and water resources throughout the world, including Tennessee. Much, but not all, of my work has been focused on karst aquifer/landscape systems. I serve as University Distinguished Professor of Hydrogeology at Western Kentucky University (WKU), though this report is written independently from, and is not endorsed by, WKU.

I earned a PhD in Environmental Sciences (Geology track) from the University of Virginia in 1993, where a series of papers in the journal *Water Resources Research* from my dissertation *Early Development of Karst Systems* has been collectively cited in the scientific literature more than 450 times. Since then, I have developed a collaborative international research program in hydrogeology, geochemistry and water resources with field work in 26 countries, participating in or leading five water-focused United Nations (UN) scientific efforts through the United Nations Educational, Scientific, and Cultural Organization (UNESCO) International Geoscience Program. I also currently serve as an appointed member of the Karst Commission of the International Association of Hydrogeologists (IAH). I have been awarded medals from the China Geological Survey, the Guangxi Autonomous Region, and China's government. In 2017, President Xi Jinping presented me with the International Cooperation in Science and Technology Award of the People's Republic of China, China's highest award for foreign scientists, for "great contributions to China's hydrogeology and karst geology fields."

I began exploring Tennessee caves in 1982 and helped to conduct groundwater dye traces in Van Buren County the same year. Since then I have explored, mapped, and studied caves, supervised karst aquifer evaluations and collaborated on groundwater tracing experiments in the principal karst regions of the state, including the Cumberland Plateau Escarpment, the Eastern Highland Rim, the Valley and Ridge, and the Central Basin for various state and federal agencies including the Tennessee Department of Environment and Conservation (TDEC), the US Geological Survey (USGS), the Department of Energy (DOE), and the US Environmental Protection Agency (USEPA). I was already comfortably familiar with the hydrogeology in each of these regions before my interactions with the current project and in particular the karst hydrogeology in the Central Basin, where Nashville lies. This includes a multi-year study of the hydrogeology in Sumner County near Gallatin, about 30 miles northwest of Nashville and with closely related geology. That project studied coal ash contamination of groundwater from the Tennessee Valley Authority (TVA) Gallatin Fossil Plant through a karst aquifer in the Carters Limestone (e.g. Groves 2015, 2016).

Although I have some ancillary familiarity through my professional experience, I make no claims to be an expert in either engineering or federal, state, or local environmental laws or regulations.

Appendix C: A Field Trip Along the Music City Loop

A way to really understand the geology and landscape in a deeper way, and ultimately the implications of tunneling the various layers, is to travel the route, either virtually by reading along in this report or driving the route and paying attention to changes in the landscape and geology along the way.

Start at the Farmer's Market at 900 Rosa L. Parks Avenue. Pulling out of the north end of the Farmers' Market by the Babylon Garden Center, turn left onto Rosa L. Parks Boulevard. At the split bear left onto James Robertson Parkway. As you turn left, you are driving by the northern entrance to the MCL Airport Alignment. As you look up the hill toward the Tennessee State Capitol on your right (Figure 21), you are just at the contact, or horizontal boundary, that separates the Hermitage Limestone (blue layer) below from the Bigby-Cannon Limestone (red layer) above. The very top of the hill is made from a remaining bit of the Leipers-Catheys (yellow layer); note the small yellow circle at the top of the hill on the geologic map (Figure 22).



Figure 21. Geology of the home of Tennessee's State Capitol Looking up from James Robertson Parkway at the boundary of the Hermitage Limestone (below) and the Bigby-Cannon Limestone above. The very top of the hill is capped with Leipers-Catheys Limestone. The geologic contacts are approximate (photo CG).

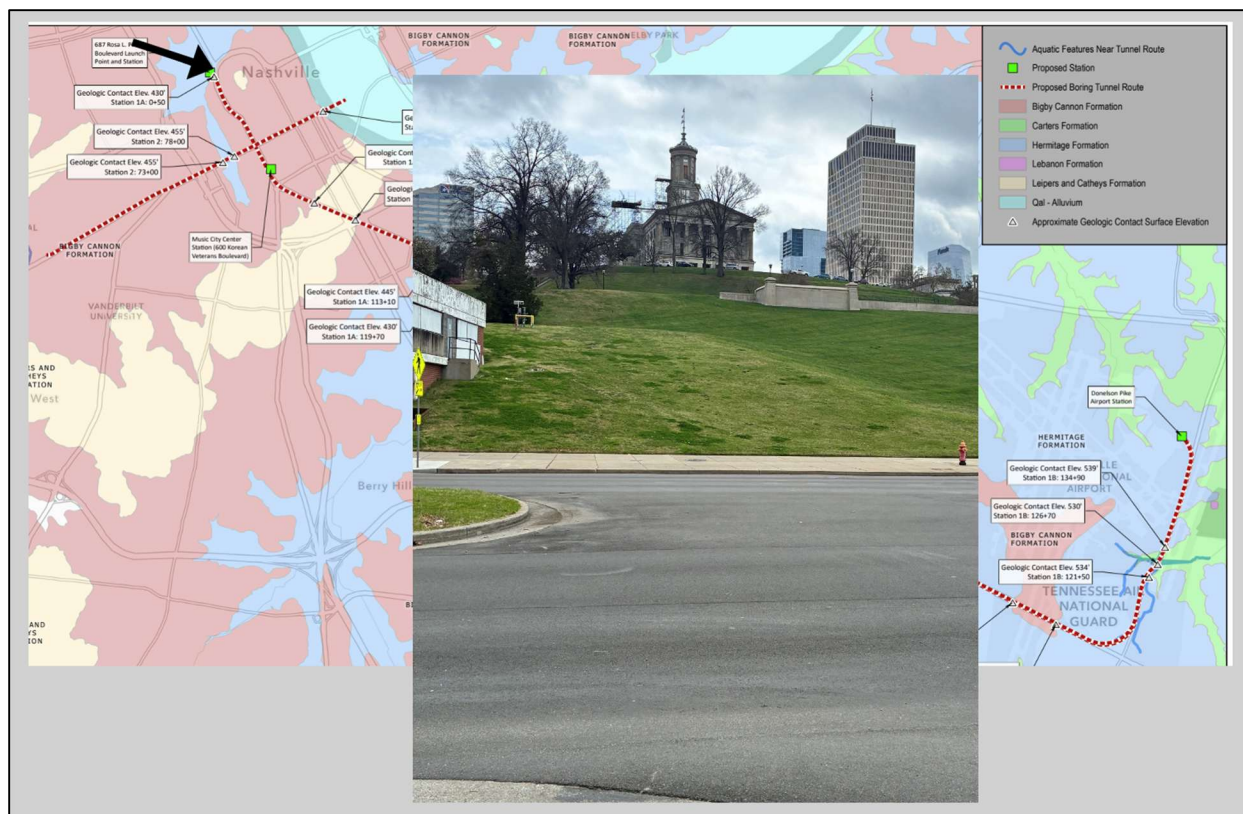


Figure 22. Looking up Capitol Hill in the direction shown by the black arrow on the geologic map. This is looking up from the top of the (blue on the map) Hermitage layer where most of the hill is made from the (reddish) Bigby-Cannon above. Note the small yellow circle at the top of the hill that marks a remnant of the Leipers-Catheys layer right underneath the Capitol Building (map DGR 2025, photo CG).

At the next light turn right on John Lewis Way. Then at the crest of the Hill turn right on 7th Street, bear left at the guard shack. Off to the right and down the hill, there is a great view of the entrance to the Music City Loop Airport Alignment where tunneling started in February (Figure 23, the white structure). This is looking down from the slopes of the Bigby-Cannon (red layer) on to the top of the Hermitage (blue layer). This is where tunneling has begun, into the upper part of the Hermitage.

At end of the parking lot turn left on Martin Luther King Boulevard. After three blocks turn right on 4th Avenue (Figure 24). As you go down 4th Avenue past the Ryman Auditorium and then across Broadway, you are driving down into and then up and back out of a valley in the Bigby Cannon Limestone (red layer). The hill on the far side of the valley is the same relatively resistant rock of the Leipers-Catheys Formation (yellow layer) that caps the top of Capitol Hill.

Go straight across Broadway then after about one mile, bear left on Lafayette Street Murfreesboro Pike. Over the crest of that hill as you make your way eventually along Murfreesboro Pike, you drop off the Leipers-Catheys, down into the valley of Browns Creek (Figure 25) as you cut down through the Bigby-Cannon and eventually reach the (green on the map) Carters Limestone as you cross the Creek (Figure 26). From there the route climbs up and after cresting another a hill, drops down to, and crosses, Mill Creek (Figure 27). Like Browns Creek, Mill Creek has cut down into and is flowing directly on the Carters Limestone. From this point the route climbs back up to

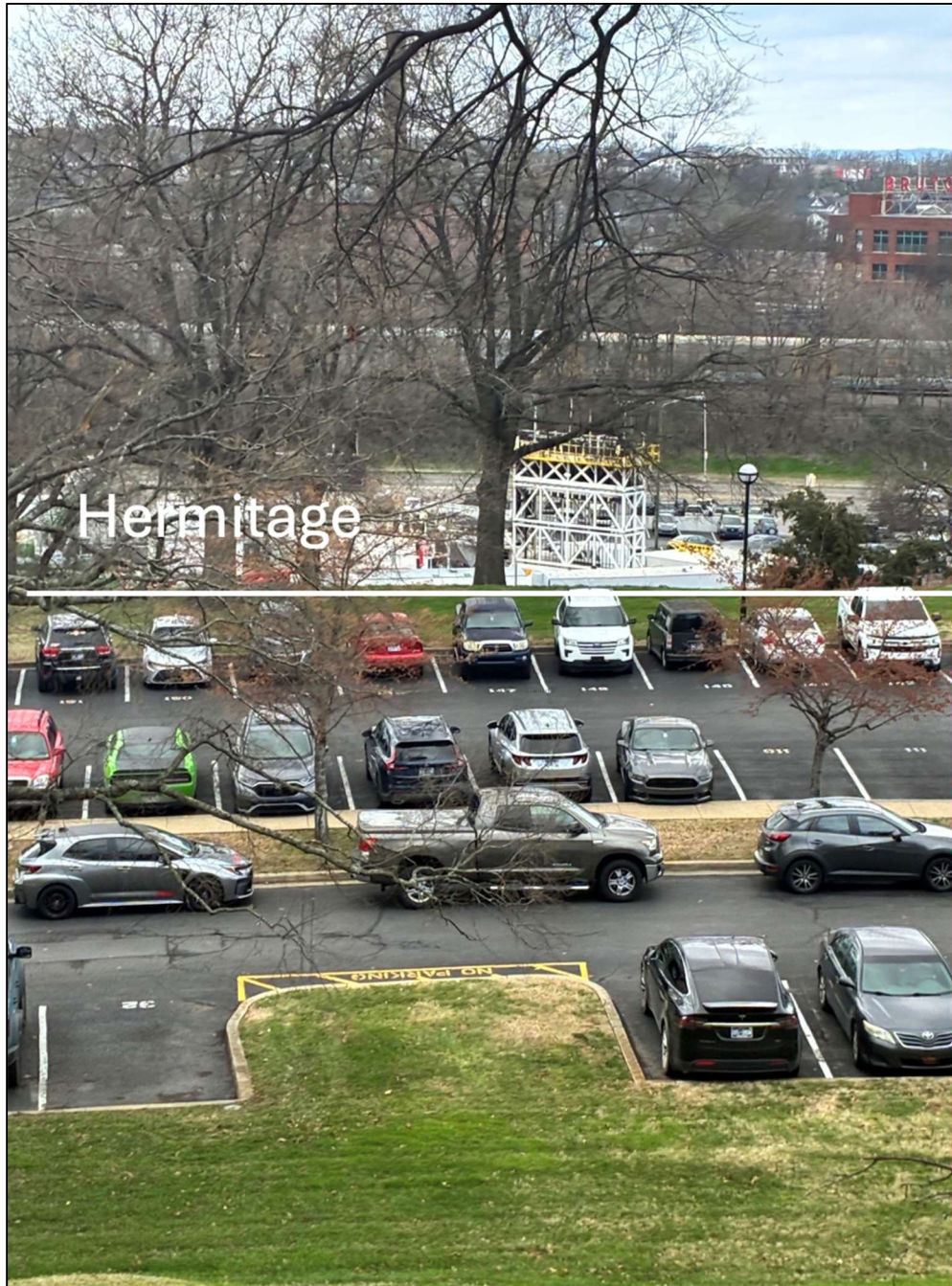


Figure 23. Looking down from the slopes of Capitol Hill on the Bigby-Cannon Limestone onto the top of the Hermitage Limestone, into which tunneling began in February 2026 (photo CG).

onto the Hermitage and a bit of the Bigby-Cannon (Figure 27) and dropping down as it turns left onto Donelson Pike. Heading north toward the airport, McCrory's Creek has cut a valley down into limestone to the right.

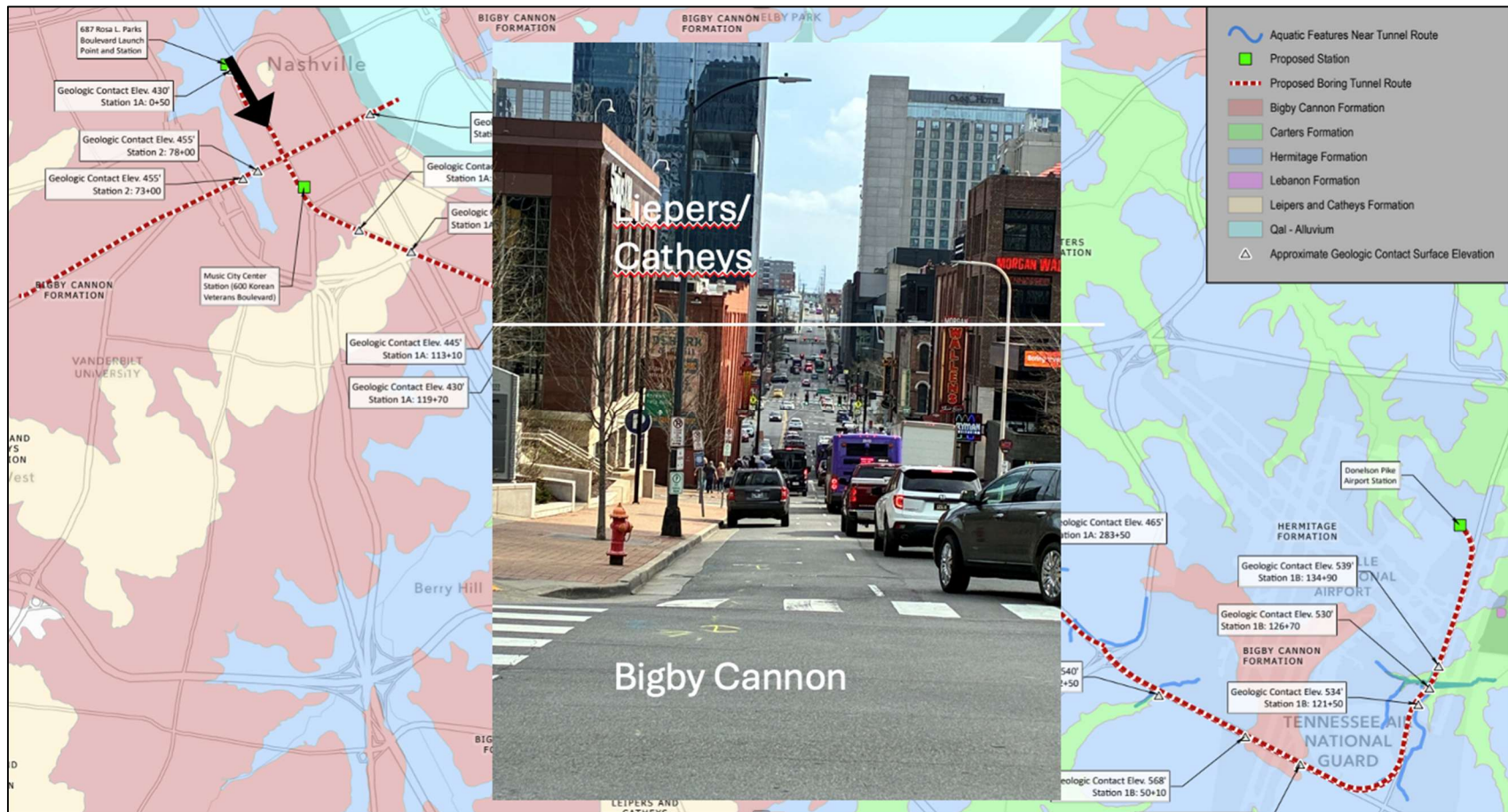


Figure 24. Continuing on our geology fieldtrip (note arrow for perspective) south on 4th Avenue, we go down into, and in the distance back out of, a valley in the Bigby-Cannon Limestone passing the Ryman Auditorium on the right and crossing Broadway. The hill in the distance is on the Leipers-Cathey's (the yellow area on map) is the same relatively resistant rock layer at the top of Capitol Hill (photo CG). Just beyond that distant hill the route drops down into the valley of Browns Creek (photo CG).

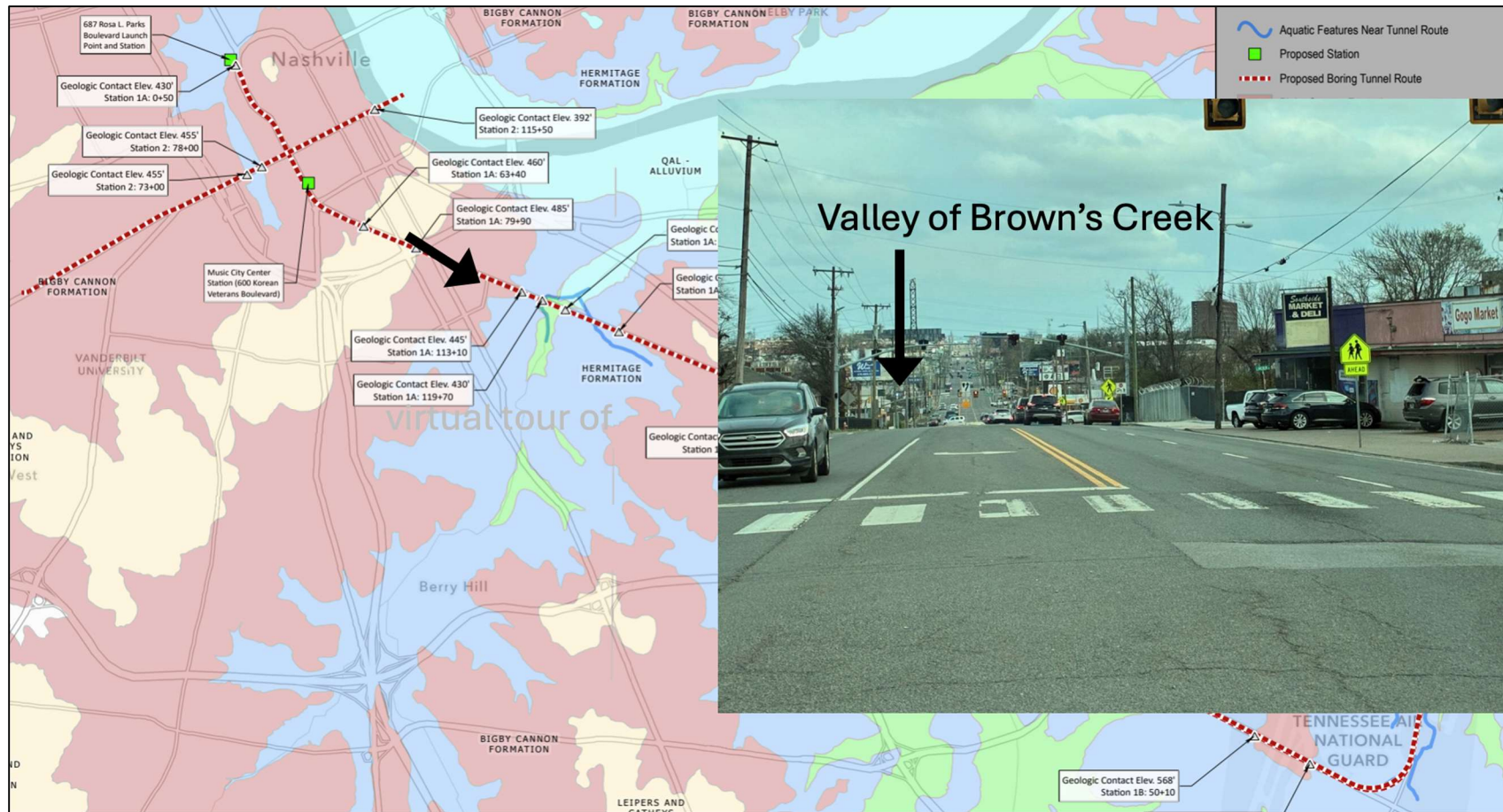


Figure 25. Cresting the hill capped with the Leipers-Catheys Formation, one drives into the valley of Browns Creek, which has cut down through the Bigby-Cannon and Hermitage Limestones into the top of the Carters Limestone. As you continue down Murfreesboro Pike, you will climb back out of Browns Creek Valley and crest the hill in the far distance of this picture, and then drop down into the valley of Mill Creek.



Figure 26. Crossing over Browns Creek which has cut its valley all the way down into the Carters Limestone (photo CG). Due to both well-developed karst in the Carters Limestone and saturated conditions beneath the water table, tunneling beneath Browns Creek will be challenging.

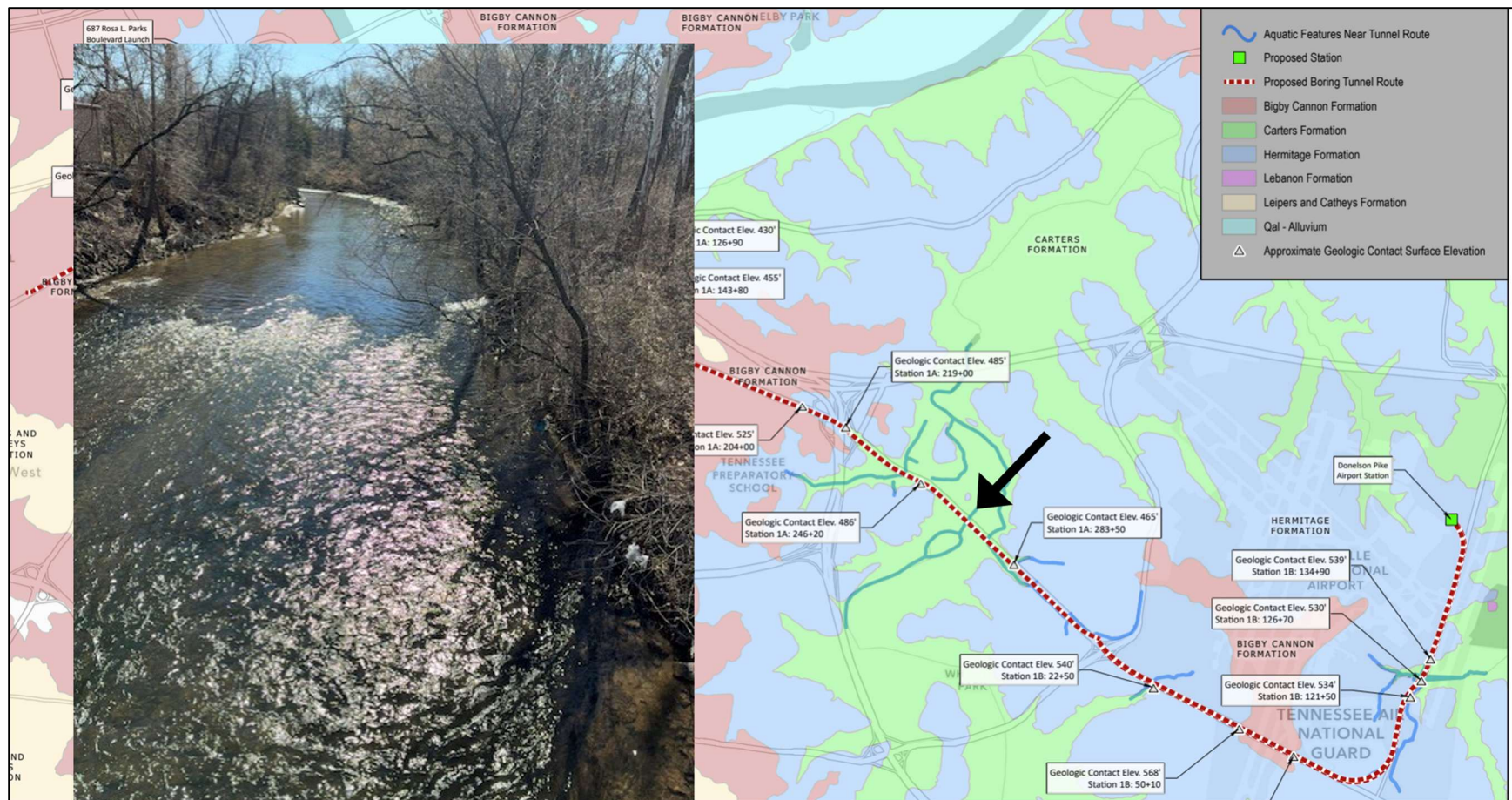


Figure 27. Driving southeast on Murfreesboro Road from Browns Creek, the route again climbs over the crest of a hill and then back down to the valley of Mill Creek, which has also removed the Hermitage Limestone and cut down into the green Carters (photo CG). Due to both well-developed karst in the Carters Limestone and saturated conditions beneath the water table, tunneling beneath Mill Creek will be challenging.