GREAT PLACES SW Corridor

Portland • Sherwood • Tigard • Tualatin
Beaverton • Durham • King City
Washington County • ODOT • TriMet • Metro

Tunnel Alignments Report

May 2015

Overview of the Corridor

The Southwest Corridor Plan is a comprehensive approach to achieving community visions through integrated land use and transportation planning. The Southwest Corridor Plan incorporates high capacity transit (HCT) alternatives, roadway, bicycle and pedestrian projects and local land use visions, including Barbur Concept Plan, Tigard High Capacity Transit Land Use Plan, Linking Tualatin and Sherwood Town Center Plan. The Plan is exploring Bus Rapid Transit (BRT) and Light Rail Transit (LRT) alternatives for several alignments that connect the Portland Central City, Southwest Portland, Tigard, and Tualatin.

Many of high capacity transit BRT or LRT alignments being considered for the Southwest Corridor Plan follow roadways or other rights-of-way to connect the Southwest corridor communities, but there are several areas where tunnels are being considered.

Tunnel alignments currently being considered are:

- Marquam Hill -Hillsdale 2.4-mile bored light rail tunnel;
- Capitol Highway/Hillsdale Loop cut and-cover tunnel for light rail or bus rapid transit; and
- A light rail cut-and-cover tunnel to Portland Community College (PCC) Sylvania.

The plan's Steering Committee is scheduled to make a decision in July 2015 about whether the tunnel options should be further considered for the HCT element of the Preferred Package for the plan.

Transit Tunnels

Tunnels are most often used when major ridership areas cannot be served in another way. Compared to standard at-grade or elevated alignments, tunnels must surmount more design and technological challenges as well as construction risks, and this in turn causes them to carry substantially greater costs.

In major transit systems in the country, HCT tunnels have been considered when these factors are present:

- slopes are steep (more than 5 to 6 percent);
- large physical barriers such as hills or rivers to cross;
- right-of-way is inadequate for at-grade or elevated profiles;
- the density of homes and businesses is high; or
- there is high ridership and high train or bus frequencies that would make street-level transit operations impractical.

Tunnel construction is a major undertaking for technological as well as logistical reasons, and the scale of construction activities is high and complex. Digging a tunnel means removing large volumes of rock or soil (and often groundwater). Large amounts of materials must also be brought in to build the tunnel structures. Tunnels require complex equipment and machinery. Multi-acre sites must be dedicated to construction use for several years. Other critical tunnel construction factors can vary greatly, including geological conditions, the construction approach, how work is sequenced, the techniques for building the tunnel and stations, the equipment used, and local permit conditions and constraints. This in turn affects how long construction lasts, the kinds of impacts that occur in surrounding areas, and the overall costs for a project. At all stages of construction, a builder must safeguard against a wide range of potential risks in order to protect workers, nearby structures, the environment and the public.

The two most common tunnel construction methods are cut-and-cover, or boring with machines, although other mining techniques may also be used.

Cut-and-cover construction excavates the tunnel from the surface. The most typical method is to create a trench and then cover it up with fill as the tunnel structure is completed. Cut-and-cover techniques are commonly used for stations unless they are very deep. Temporary or permanent sections of lids can be used during construction if access across the excavation is needed, but it complicates the construction.

Bored (or mined) tunnels are constructed underground from portals with 3- to 5-acre construction staging areas nearby. Bored-tunnel stations can be either mined or cut-and-cover, but if they are more than 100 feet deep, they are usually mined. Even a mined station would still need excavation to reach the surface above to allow for access, ventilation, and emergency systems.

Common Features of Transit Tunnels

Tunnel Portals

These entrances to a tunnel transition the transitway from the surface to underground. They can be placed into a hillside, often surrounded by retaining walls, or they can gradually descend into a trench and then underground. During construction, portal areas are the focus of soil removal, water removal, construction staging, and materials delivery for the tunnel. After service starts, the approaches to portals are usually walled or fenced and are restricted areas.

Tunnel Structures

Depending on the type of tunnel construction method, tunnels are either hollow boxes or tube "linings" that house and support all transit system features and operations. Each tunnel is unique because it must be designed to withstand a wide array of loads and forces presented by localized geological conditions and pressures, as well as by forces generated by the structure itself and the operating transit system. When they are built in areas with variable soils, they often include ground stabilization measures and supports. Where groundwater is present, tunnel linings must be waterproofed.

Tunnel Stations

The box or cylinder structure for a tunnel station must address the same array of forces and loads as the tunnel structure, but they are often about 50 feet or more wide and several hundred feet long. They also house facilities needed to operate the system and they include structures for passengers to safely and efficiently access the transit line from the surface. Tunnel stations need at least two points of entry from the surface, with stairs, elevators, and, in some cases,

Tunnel portals in Seattle

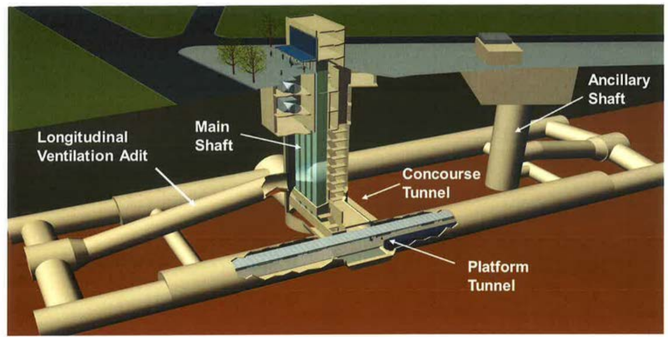


Diagram of deep tunnel station in Seattle

escalators. They need platforms large enough and long enough to handle peak passenger loads. They have systems that monitor and control ventilation, protect against flooding, and serve fire/life/safety functions, including those needed for emergency response or evacuation.

Ventilation Shafts and Structures

Most tunnels require vertical ventilation shafts with surface structures for emergency ventilation and climate control. These can be located at stations, but for longer tunnels with more widely spaced stations they can also be used for emergency access. The surface building for a shaft would include an exhaust and air intake system on its roof, a fan room, and space for electrical and communications equipment. Ventilation also is needed at the tunnel portals, where jet fans are used.

Construction Staging Areas

During tunnel construction, areas ranging from two to five acres are needed at the portals, and two to three acres are typically needed to construct stations. Larger staging areas at one of the portals may be needed if most of the construction hauling, equipment and materials storage is to be performed from a single access point. Additional areas are needed wherever other facilities reach the surface. For bored tunnels, construction staging areas are at the portals and at stations, while cut-and-cover tunnels can feature staging areas at various points along the trench. Since tunneling projects usually involve continuous construction, the staging areas are usually active 24-hours a day. They are the focus of the project's trucking for spoils hauling and materials and equipment delivery, as well as for storage, for equipment and materials staging, and for all other systems needed for tunnel construction.

Tunnel Options for the SW Corridor

Marquam Hill-Hillsdale Deep-Bored LRT Tunnel

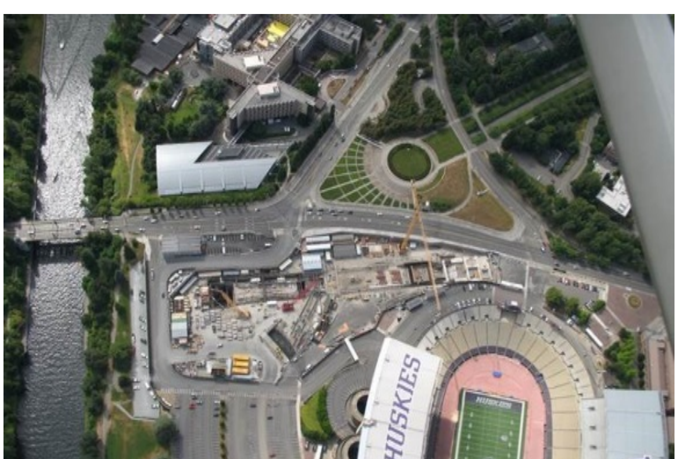
The tunnel alignment under Marquam Hill through to Hillsdale and Burlingame is about 2.4 miles long. Based on the concept design, the deepest part of the tunnel alignment is about 590 feet below the ground surface, but most other areas range from 100 to 350 feet below the surface. Large tunnel boring machines would be used due to the depth and length of the tunnel, and because they are best able to deal with the highly variable geological conditions involving basalt rock, various intermediate soils and layers, and the likelihood of high groundwater flows.

The option has two underground stations: one at the Oregon Health Sciences University (OHSU), about 200 feet deep, and another in the Hillsdale neighborhood, about 150 feet deep.

The north portal for the tunnel, where the tunnel boring machine would be launched and where it is likely most of the tunnel spoils removal and materials delivery activities would be based, would be off SW Barbur Boulevard near Duniway Park. The south portal would emerge at Burlingame, near SW Bertha Boulevard and Barbur.

Capitol Highway/Hillsdale Loop Cut-and-Cover LRT or BRT Tunnel

The Capitol Highway Hillsdale Loop option has a tunnel that is about 1/3 of a mile long, and the floor of the tunnel would be about 35 feet deep, based on the conceptual design currently being considered. An underground station is proposed near SW Capitol Highway and SW Sunset Boulevard, also about 35 feet deep. The tunnel and station would most likely be constructed using cut-and-cover techniques due to the shallow depths and soil conditions. The northeast portal to the tunnel would begin approaching Sunset Boulevard, and the southwest Portal would be near SW Vermont Street and SW Bertha Boulevard. Two options for the cut-and-cover tunnel alignment are being evaluated, including one along SW Capitol Highway and turning south at SW Bertha Boulevard, and the second crossing across an elementary school athletic field.



Tunnel and station construction staging in Seattle

Although the tunnel is relatively short, ventilation facilities on the surface would likely be needed for a Bus Rapid Transit tunnel to vent emissions from the buses.

PCC Cut-and-Cover LRT Tunnel

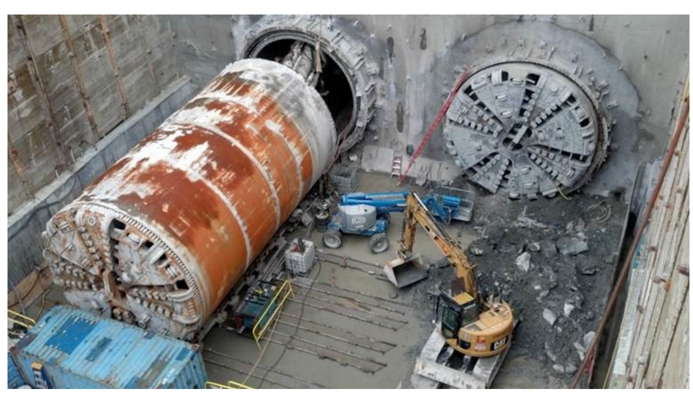
The PCC tunnel cut-and-cover is about ½ of a mile long, and up to 70 feet deep, based on the current concept design. One underground station is proposed at about 70 feet deep, in a parking area at the north side of the campus. The north end of the tunnel would begin near SW Barbur Boulevard and SW 53rd Avenue, proceed south to the campus before turning west for the station, and then continuing west to surface near SW Lesser Road before crossing over I-5.

Typical Tunnel Construction Activities

Bored Tunnel

Bored tunnels are used for longer, deeper tunnels, included those with highly varied geological conditions. The tunnels are built with special tunnel-boring machines (TBMs), or "moles." TriMet's Westside Light Rail project used a TBM for its tunnel. The machines are customized large multimillion-dollar pieces of equipment with cutting or excavating faces specifically designed or modified to handle the geological conditions of each specific tunnel. They can be designed to handle a wide array of ground types, from rock to partly rocky or mixed soils to areas with high amounts of groundwater. They automate the mining process from cutting to moving tunnel spoils out behind the machine, to helping support the emerging tunnel before other supports and parts of the permanent tunnel lining can be placed.

Even with a bored tunnel, some traditional excavation or mining may be needed with other equipment or the use of blasting. The construction of an access portal is often done by excavation. If a portal can be located on a hillside, it can be dug directly into the hillside by using excavation and structural support methods. In flatter areas, the tunnel can be excavated as a trench to a portal and then the tunnel continues to be dug to reach a depth



Tunnel boring machines emerging at a station in Seattle

where a tunnel boring machine can begin excavating earth.

Soils and muck are removed behind the tunnel boring machine and back through the tunnel to the portal, using conveyor belts or mining rail-cart systems. In areas where groundwater is present, a system for conveying the water out of the tunnel is needed. The large volumes of spoils that digging a tunnel generates, as well as the materials needed to build linings and supports as the tunnel progresses, are why multi-acre staging sites are needed in portal areas.

Portals are the hub of the construction activity for bored or mined tunnels, and trucking the materials in and out of the portal area often lasts for several years. While truck volumes depend on how quickly the tunnel is progressing, several hundred truck trips can occur daily to and from the staging areas at a portal, with 20 or more trucks an hour during high activity periods. This can create high levels of local congestion as well as congestion on haul routes, and this lasts for several years. Periodic road or lane closures or flagging are needed to allow trucks to enter and leave the staging site and onto the roadway network. Similar types of trucking, staging and hauling activities also occur in station areas, even with deep mined stations, although volumes are usually lower than at portals. Stations can generate up to 100 truck trips a day, or typically around 10 trips an hour.

Cut-and-cover Tunnels

Cut-and-cover excavation methods are used where tunnels are too short or shallow for boring, or where tunneling must avoid foundation elements of nearby buildings. They are also the most common method used for underground stations, even when the rest of the tunnel is bored, because it gives a contractor more flexibility in building the larger station structure.

The excavation method is also known as “sequential excavation mining” because it consists of smaller but defined steps to excavate a tunnel in sections. There are techniques that cut an open trench from the surface, as well as techniques that build a lidding structure first and then dig the tunnel underneath. These techniques can use conventional excavation and construction equipment, such as might be used to create a deep foundation for a tall building or underground parking garage, or it can feature a rapid excavation machine designed for more linear excavations. Sequential excavation can be slower and more expensive than using a boring machine, and it usually requires removing the existing surface features along the tunnel alignment and above the station.

Cut-and-cover construction for the downtown tunnel in Seattle (1980s)

Construction Issues for the Tunnel Options

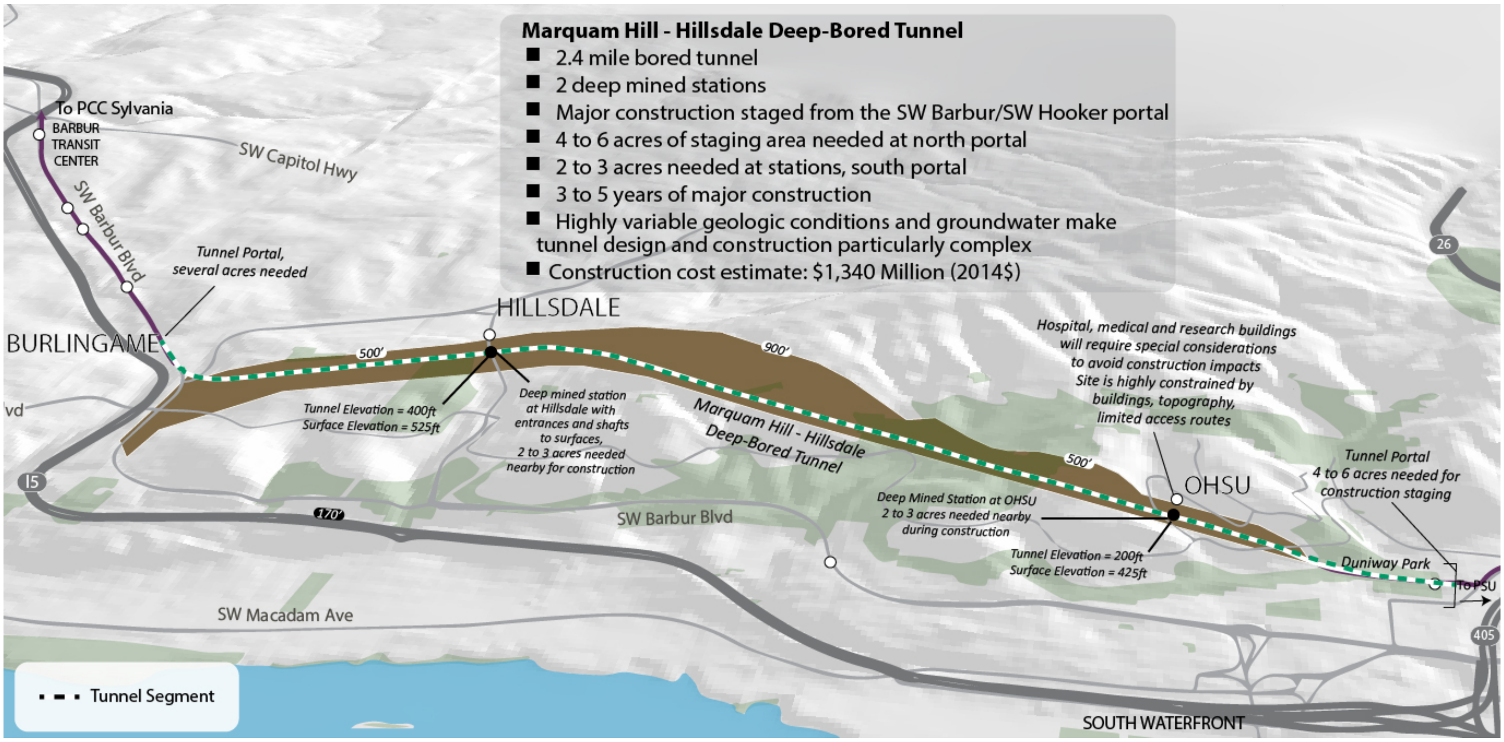
In developing the tunnel options, TriMet and Metro engaged a team of technical specialists with extensive experience designing and building transit tunnels and other types of tunnels in this region, as well as nationally and internationally. The team included geotechnical engineers, civil and structural engineers, construction managers, and environmental analysts, all with experience on successfully completed tunnel projects. Several of the team members worked on TriMet’s Westside Light Rail project tunnel or on Sound Transit’s tunnels and underground stations for the light rail system in Seattle.

The team reviewed the tunnel concepts, which are currently at a planning-level of design. They collected available information about geological conditions for the areas where the tunnel alignments are being considered, and they drafted a letter report on the geological conditions by area, focusing on elements that would likely affect tunnel design requirements, construction methods and issues, as well as factors affecting costs and general risks. They also advised TriMet and Metro on likely contractor needs for staging areas, both at portals and by station types, and outlined possible design or construction refinements that could be considered if the options were to move forward.

Marquam Hill-Hillsdale Deep-Bored Tunnel for LRT

Geological Conditions

The initial geotechnical review shows the alignment must cross through a complex series of basalt layers, with faults and variable transitions between layers and sections. Above the core of basalt are undifferentiated sedimentary soils with cobble- to boulder-sized blocks of intact rock, and silt and clay. The multiple layers of basalt, which were built up over time from volcanic flows, along with the presence of faults, indicates that the tunnel would move repeatedly through layers of rock and into fractured rock, sediments, and areas with loose or



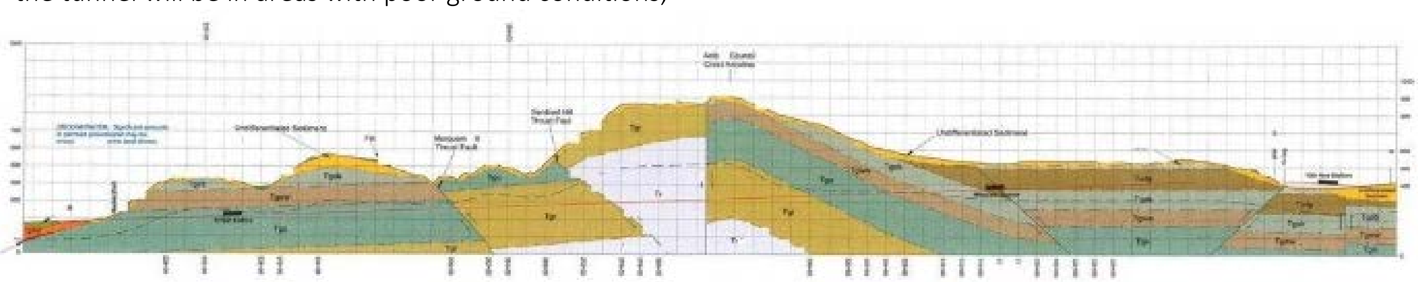
less stable soils. Groundwater will be present, and high flows are more likely wherever there is a fault or transitions between rock layers. About two-thirds of the tunnel alignment, including the OHSU Station, would be partially or completely beneath the groundwater table. Large quantities of water may need to be handled during tunnel construction, although flows could be reduced if a watertight concrete liner can be installed during excavation.

Likely Construction Techniques

Based on experience with similar tunnels (such as the Oregon Zoo tunnels and deep mined stations and shafts,) the tunnel would likely have twin 20-foot-diameter bored tunnels, with two deep mined stations connected to the surface through 30- to 50-foot-diameter shafts. An additional vent shaft would also likely be needed along the alignment between the stations. Because the area has highly variable ground conditions and high groundwater pressures, the design of the tunnel and the contractor's methods would need to address the potential for changes in how the tunneling is done as well as its structural elements, as the tunnel will be in areas with poor ground conditions, as well as high water inflows. A much higher level of geotechnical information will also be needed to support the detailed design and construction planning that would be needed for the tunnel.

Based on available information, the tunnel would repeatedly cross various zones of rock and soils, including many with higher potential for collapse during construction. A tunnel boring machine that is capable of handling a wide range of ground conditions would be needed. The contractor would likely need to install precast lining segments that would support the ground around the tunnel and allow a waterproofing liner as the boring progresses. A variety of ground-supporting techniques will also be needed for the shafts, stations, and crossover tunnels.

Blasting is likely to be needed at the portals, stations and cross passages for the tunnel. The north and south portals could also require excavating 100- to up to 300-foot-long approaches cut into the hillside. This would allow the full diameter of the tunnel boring machine to be placed within rock and with at least 10 feet of rock cover above before boring starts.



Cross-section of Marquam Hill shows highly variable underground conditions

Tunneling Issues

All of the surface construction areas are highly constrained. It would be difficult to locate large enough staging areas at the tunnel portals and the stations because the areas surrounding these surface features of the tunnel are largely developed. At the north portal, where the tunnel boring would most likely be launched, an area from 3 to 5 acres would be needed, but the adjacent areas are part of Duniway Park, and residences are nearby. There are federal laws that restrict transportation projects from impacting parks when other options are available.

While the stations and the south portal could have smaller staging areas than the north portal, they would still need several acres. The south portal area in particular lacks any sizable vacant land, is adjacent to residences, and property acquisitions appear unavoidable. Trucking needed for soils removal, trucking equipment transport, and materials delivery, including large or oversize loads, would occur at all the staging areas and would last for several years. The highest concentration of truck trips would likely be at the north portal near Duniway Park, where several hundred truck trips could occur on a daily basis.

The OHSU as well as the Hillsdale stations have other considerations to address during construction. The OHSU complex has limited roadway access, hilly topography, and limited areas that could be used for staging around the station site. Emergency access routes to the hospital would need to be maintained at all times. The OHSU complex is likely to be especially sensitive to the noise and vibration that tunneling activities would generate, including facilities using sensitive equipment, and where overnight patients reside. The impacts of trucks and heavy equipment getting to and from the site on Terwilliger Boulevard, one of the two routes to OHSU, is also an issue. The permits and agreements needed for construction in this sensitive area would likely place special conditions and constraints on a construction contractor.

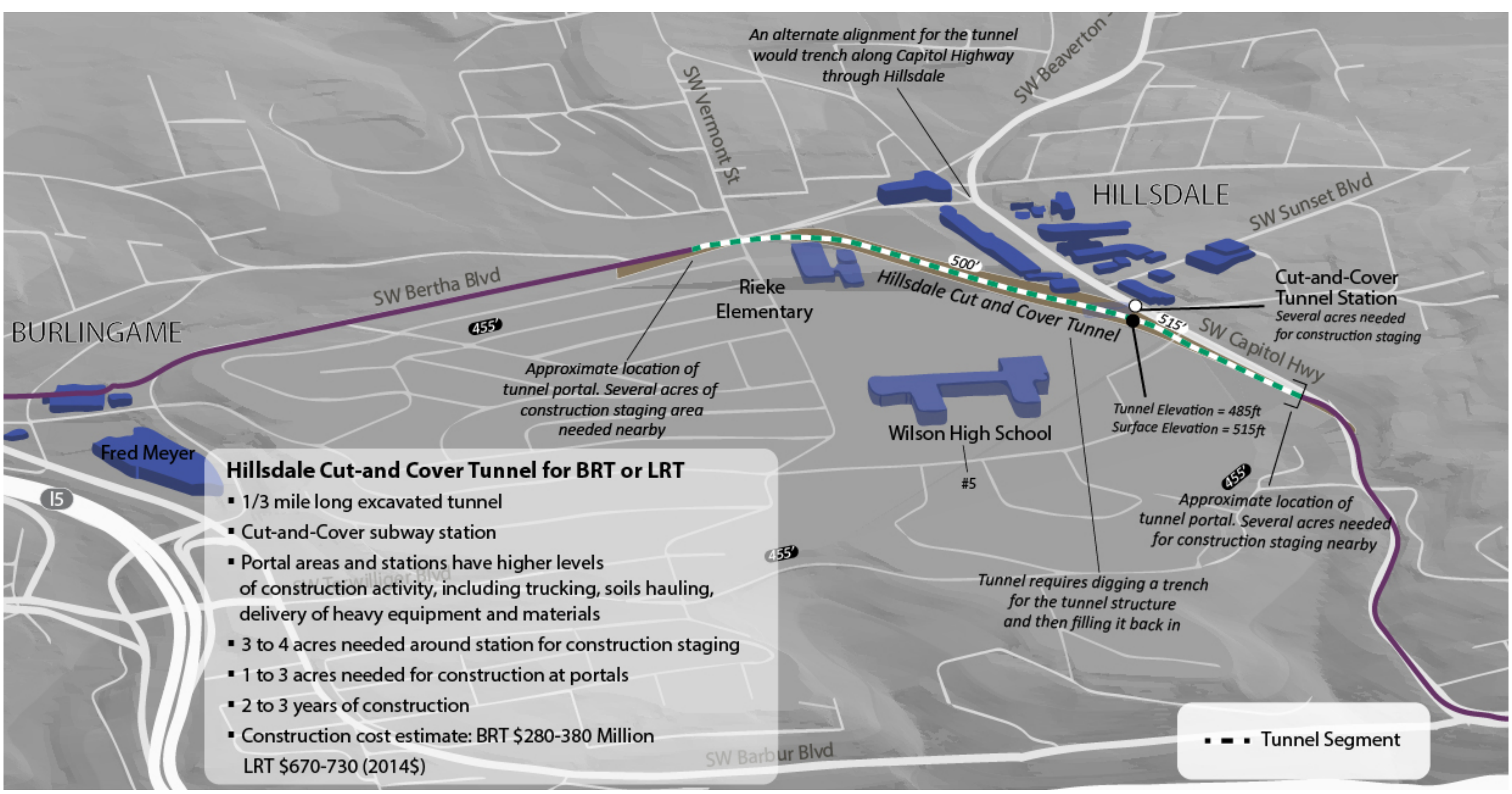
The Hillsdale station construction area is at a busy intersection of Capitol Highway, adjacent to two schools, residences and the commercial district. The staging area would likely displace existing properties, and the placement of the construction site, as well as the plan for construction itself would need to consider impacts to the schools, the neighborhood, businesses, and area transportation. These issues include congestion due to trucking to and from the site, noise, vibration, access, light and glare.

All of these factors, combined with the highly variable geological conditions for the tunnel itself, have a high potential to affect a contractor's schedule, efficiency, and costs for the tunnel.

Hillsdale Loop Cut-and-Cover Tunnel for LRT or BRT

Geological conditions

The tunnel alignment is in an area with basalt rock, overlain by about 15 to 40 feet of varied soils. In some spots, up to 30 feet of fill is in place. The alignment is



above an aquifer lying 300 feet below the surface, but groundwater has been measured at depths as shallow as 5 feet. Key geotechnical issues include the potential for rock excavation, perched groundwater, and supporting structures to avoid collapse of the soils exposed by the cut.

Likely Construction Techniques

The shallow depth of the alignment would involve excavating a trench for the tunnel and larger box for the station. The floor of the tunnel and station would be up to 40-feet deep, with widths of about 35 feet for the tunnels and 50 feet for the station. Rock excavation may be required, which could be done with machines but could also involve drilling and blasting. Perched groundwater may be encountered and would need to be managed and then disposed of to prevent groundwater flow into the excavation. The removed soils for the station and trench would likely need to be hauled away, and then new fill soils would be brought back to cover over the tunnel and underground station box. While the trench for the tunnel is being dug, vertical shoring walls will likely be needed to support the walls, and this could involve large equipment for drilling or potentially pile driving. Depending on a contractor's construction plans, portions of the cut for the station and the tunnel could be temporarily covered or lidded as construction progresses. However, streets or paths across the tunnel alignment would be closed or restricted during much of the construction period, and the areas along trench would be restricted as well.

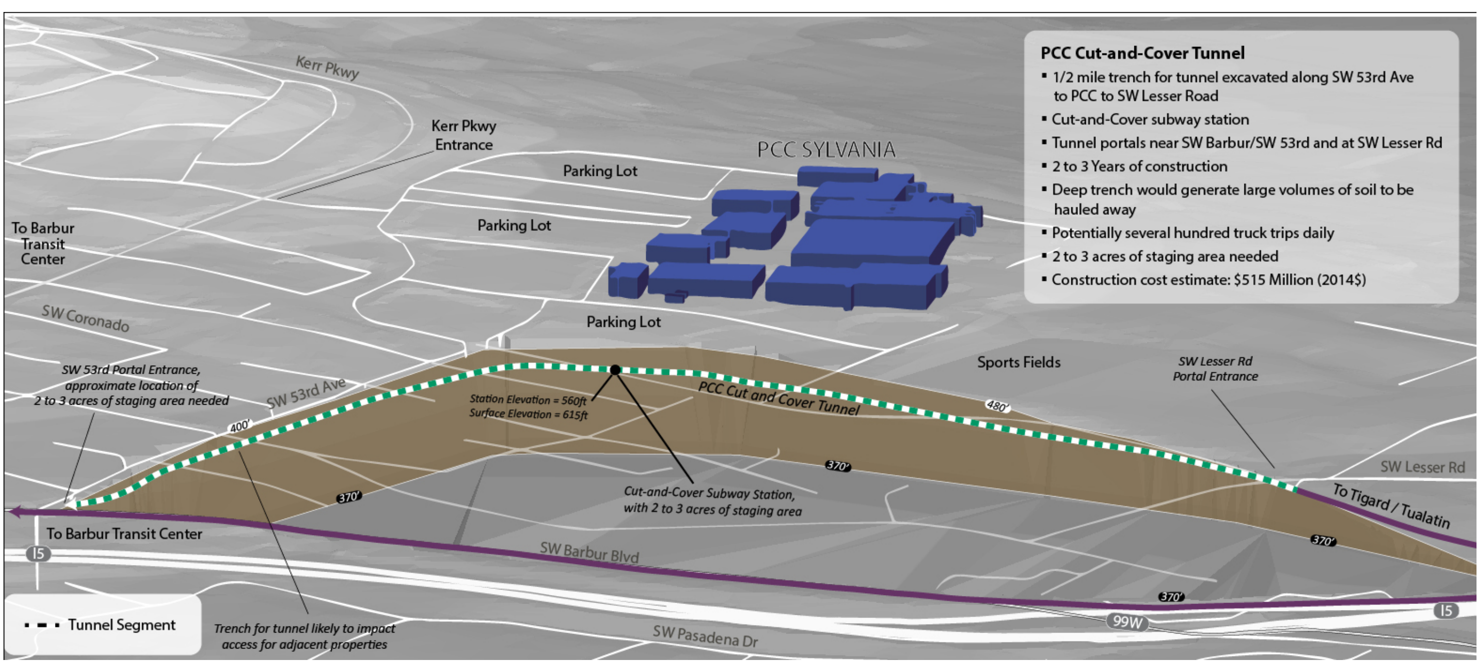
Tunneling Issues

The trench for the cut-and-cover tunnel and station would be constructed in areas that are mostly developed today. The site is adjacent to a major roadway, high school, elementary school, residential neighborhoods and a commercial district. The two to three acre area needed for station construction would need to be sited to maintain safe access to the nearby schools, and property impacts affecting several blocks appear unavoidable. While two routes for the tunnel have been outlined, one would involve crossing fields that are part of the elementary school, and the other would affect the commercial district along Capitol Highway. The presence of the schools is likely to require special measures and procedures to ensure the health and safety for students, and avoid disruptions to school operations or emergency access. Several years of construction would be needed, and the cut-and-cover tunnel and station sites would be restricted areas that would require alternative routes and detours, restricting movements in and through the Hillsdale area. As with any of the tunneling options, high levels of truck traffic would occur throughout much of the primary construction period, and congestion as well as roadway or lane closures would be involved. In addition to the traffic and property impacts, noise and vibration, light and glare would be other issues of concern for nearby residences and businesses.

PCC Cut-and-Cover Tunnel for LRT

Geological conditions

The alignment is on the flanks of an ancient volcano (Mount Sylvania), and has a core of basalt flows and volcanic cinders, with about 40 feet of silt, clay, some sand, gravel and cobbles up to the surface. The tunnel depths approach or intersect the transition between the upper soils and the underlying basalt rock layers. The conditions for the tunnel will be highly variable, and there



are boulders and blocks of rock in some locations in the upper soils.

While the tunnel is generally above the groundwater table, there are areas where pockets of water are likely to be encountered during construction.

Likely Construction Techniques

The fairly deep alignment poses challenges for cut-and-cover techniques, but the length and depth of the tunnel is also a challenge for other tunneling methods such as boring. The available right-of-way is narrow, and the alignment is up to 70 feet deep. To dig the trench for the tunnel, deep shoring walls or other measures will be needed to support in the soil and weathered rock, and the excavation will temporarily occupy and close an existing residential street. The soil over rock excavation conditions and the shallow depth are manageable but would pose other challenges for construction. Factors include groundwater and high variability in the rock surface and ground conditions. The contractor would likely need to use combination of soil excavation, soil treatments or ground condition, drill-and-blast rock excavation, and excavation support systems.

Some of these issues could be reduced if the alignment were deepened by 30 to 50 feet, potentially allowing a boring machine to be used. However, this would extend the length of the tunnel, and the station would likely need to be mined, which is a more costly method of construction.

Tunneling Issues

As the alignment is along a ¼ mile section of an existing residential street, access to the adjacent residences would be closed, and construction activities causing noise and vibration would also be present. The residences along the street would likely need to be purchased and the residents would be relocated. Houses along the street could also experience some settlement from the excavation, as well as potentially vibration-induced damage from blasting. Other areas needed for staging and construction appear to be available, although the high volume of trucks serving the construction area would affect surrounding areas.

Initial Capital Cost Estimates

TriMet has developed initial cost estimates for the tunnel alignments, based on the early conceptual designs alignments. These costs reflect projects of a similar type and scale, using recent TriMet project as well as other projects nationally. Costs were developed in year 2014 dollars (2014$), and do not include inflation of finance costs. Operational costs are also not included.

The cost estimates by option:

- Marquam-Hillsdale bored tunnel for light rail: $1,340 Million (2014$)
- Capitol Highway/Hillsdale Loop cut and-cover tunnel (with two alignments and two modes considered)
  - o light rail: $670 to $730 Million (2014$)
  - o bus rapid transit $280 to $380 Million (2014$)
- A light rail cut-and-cover tunnel to PCC Sylvania
  - o $515 Million (2014$)

This report prepared by Parametrix, 2015