4.11 Geology and Soils

4.11.1 Introduction to Resources and Regulatory Requirements

Geology and soil considerations important to the East Link Project include topography, geology, soil characteristics, groundwater conditions, and geologic hazards. These considerations affect the type of construction methods used for the project and, if not adequately considered during project design, could affect the long-term operations and safety of the light rail system. Regional geology and seismicity would not change as a result of the project, but they would have an important influence on how the project is designed and constructed. While the conditions of the general area are described for the entire project corridor, specific impacts were determined by looking within a study area of 100 feet from the proposed alternatives.

Washington State's Growth Management Act (GMA) (Revised Code of Washington [RCW] Chapter 36.70A) requires all cities and counties to identify critical areas within their jurisdictions and to formulate development regulations for their protection. Among the critical areas designated by the GMA are Geologically Hazardous Areas, which are areas susceptible to erosion, sliding, earthquake, or other geologic events. These hazards could affect the design, construction, and operation of the project and, if not considered appropriately, could pose a risk to public safety.

Geology and soils considerations are closely related to groundwater conditions. While this section includes general information on groundwater within segments, more detailed information about groundwater along the alternative routes is discussed in Section 4.9, Water Resources. Locations of possible contaminated soils and contaminated groundwater are identified and discussed in Section 4.12, Hazardous Materials.

4.11.2 Affected Environment

Geologic units and soil characteristics along each alternative were assessed within the study area to establish the affected environment for geology and soils. The study area for geology and soils is defined as the area within 100 feet of either side of each alternative and associated facilities.

Sound Transit assessed geologic units and soil characteristics using maps—including topographic maps, surficial soils maps, geologic maps, and geologic hazard maps—published by governmental agencies, including the U.S. Department of Agriculture and U.S. Geological Survey. Sound Transit also assessed available site-specific geotechnical information for each alternative based on geotechnical explorations conducted as part of other projects along the alternative routes. This information includes data from over 450 soil test holes that were drilled within the study area (Exhibit F4.11-7 in Appendix F4.11).

As part of the East Link Project, eight additional borings were drilled in Segment C in March and April 2007 to augment the available subsurface soil and groundwater information along tunnel alternatives. Further information about these borings is available in *Sound Transit East Corridor HCT Summary Geotechnical Report for Preliminary Route Selection* (Jacobs, 2007).

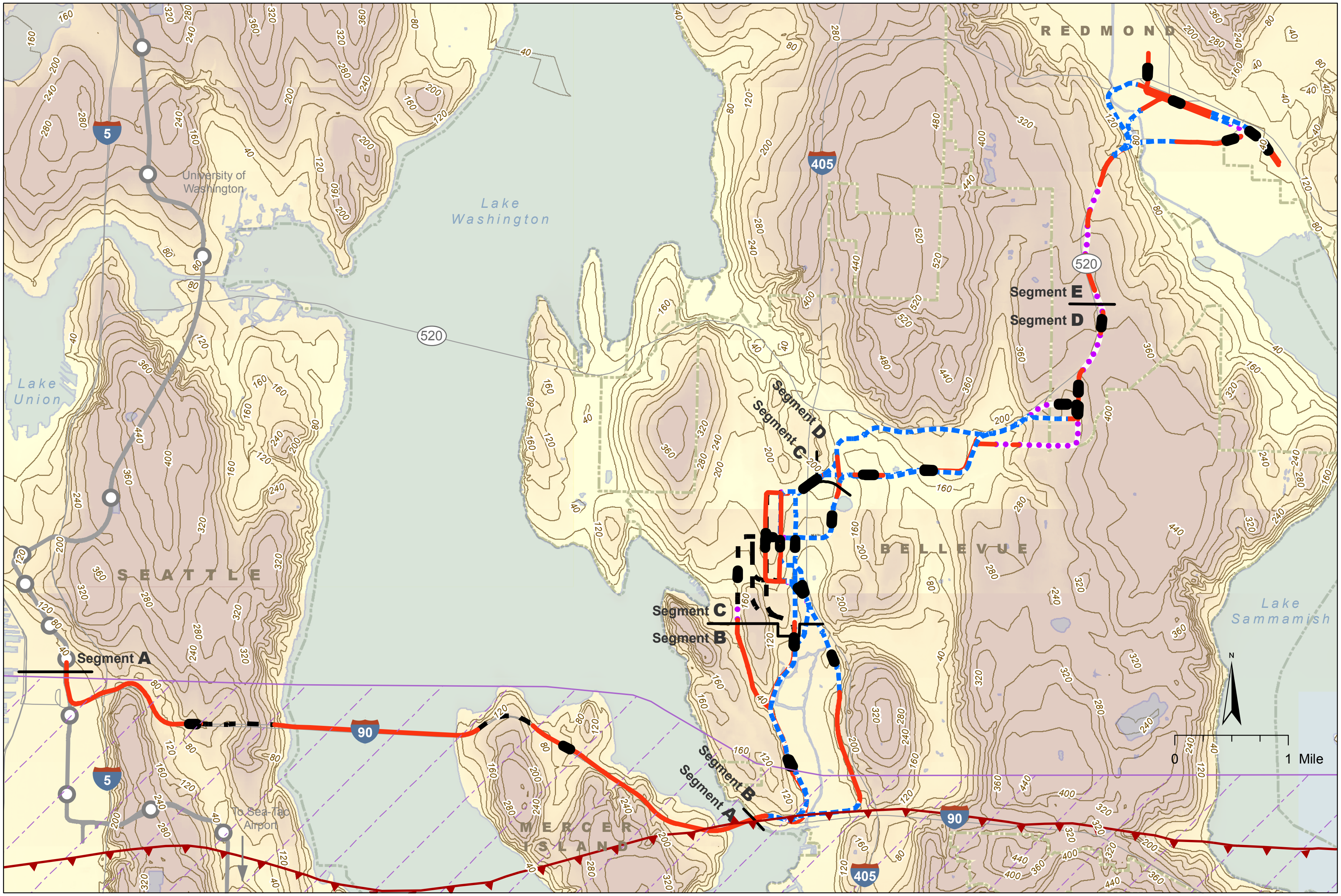
4.11.2.1 Topography, Regional Geology, and Seismicity

The East Link Project is located in the central portion of the Puget Sound Basin, an elongated, north-south trending depression situated in western Washington between the Olympic Mountain Range to the west and the Cascade Mountain Range to the east. The regional topography consists of a series of north-south trending ridges separated by deep troughs. The troughs are now occupied by streams, lakes, and waterways, including Puget Sound, Elliott Bay, Lake Washington, and Lake Sammamish. Land elevations range from about 15 to 360 feet (National Geodetic Vertical Datum 29) across the East Link Project corridor (Exhibit 4.11-1).

This regional topography was shaped mainly by glaciations that moved back and forth across the region thousands of years ago. Soils that were over-ridden by glaciers that were sometimes several thousand feet thick are generally very hard or compact as a result of the weight of the glaciers. More recently, erosional processes and landform changes made by human development of the area have modified the regional topography.

Geology in the region generally includes recent, surficial soils over a thick sequence of glacially consolidated soils and then bedrock. Appendix F4.11 shows the surficial geology of the area (Exhibits F4.11-1 to F4.11-4) and provides descriptions for each of the geologic units and a summary of their engineering properties (Table F4.11-1).

Another important consideration related to geology and soils is seismicity, which is well documented within the study area. The project vicinity has been subject to earthquakes in the historic past and will undoubtedly undergo shaking again in the future.



Source: Data digitized from GeomapNW at the University of Washington (2005 and 2006), data from U.S. Geological Survey (2007), King County (2006), and Sound Transit (2007).

40-Foot Contour (Vertical Datum NGVD 29)
Seattle Fault Strand [a]
Seattle Fault Zone [b]
At-Grade Route
Elevated Route
Retained-Cut Route
Tunnel Route
Proposed Station
Central Link Alignment and Station

Note:
[a] USGS (2007)
[B] Troost et. al. (2005) and Troost and Wisher (2006)

Exhibit 4.11-1
Regional Terrain
Segments A,B,C,D, and E
East Link Project

Earthquakes in the Puget Sound region result from any one of three sources: the Cascadia subduction zone off the coast of Washington, the deep intraslab subduction zone located approximately 20 to 40 miles below the Puget Sound area, or shallow crustal faults. The closest active crustal source is the Seattle Fault Zone. The southern portion of the study area is mapped within the Seattle Fault Zone, and the northern portion of the study area is mapped within 6.5 miles of the Seattle Fault Zone (USGS, 2007) (as shown in Exhibit 4.11-1).

Geology and Soils Definitions

Subduction zone is the place where two lithospheric plates (the crust and the uppermost mantle of the earth) come together, one riding over the other.

Interslab subduction zone is the zone between the earth's crustal plates. This zone is the source of large earthquakes off the coast of Washington.

Liquefaction is a loss of strength in loose sands and non-plastic (i.e., with little or no cohesion) silts located below the water table.

Lateral spreading is the lateral movement of level or near-level ground associated with liquefaction of soil during an earthquake.

Surface faulting is displacement of the land surface by movement along the fault.

Tsunamis are sea waves resulting from seafloor movement during an earthquake.

Seiches are periodic oscillations in an enclosed body of water during an earthquake.

4.11.2.2 Geologic Hazards

An important consideration for the construction and operation of the East Link project would be the potential for geologic hazards, including steep slopes, erosion, landslides, seismicity, and soft soils. The seismic category includes secondary effects such as liquefaction and settlement. Table F4.11-1 identifies the type of geologic hazard areas within or adjacent to each segment. Landslide and liquefaction hazard areas that occur along the alternatives are shown in Appendix F4.11, Exhibits F4-11-5 and 6.

The geologic hazard potential identified in Table 4.11-1 was established following Washington state and local regulatory requirements involving steep slopes, erosion, landslides, seismic hazards, and soft soils. The geologic hazard potentials are defined as follows:

- Steep slope hazards are areas where slopes are steeper than 15 to 40 percent. These areas are considered hazards because they are prone to landslides, either during periods of wet weather or during large seismic events.
- Erosion hazards occur where soils may experience severe to very severe erosion from construction activities. Certain types of soil, such as silts, are more prone to erosion hazards. The potential for erosion also increases as the slope steepness increases. Surficial soils and topographic maps can be used to identify areas that are particularly susceptible to erosion.
- Landslide hazard areas are mapped where there is evidence of past landslides, where the slope is 15 percent to 40 percent and the soils are underlain by silt or clay that can perch groundwater, or where the slope is steeper than 40 percent, regardless of soil type. This type of hazard is closely associated with the steep slope hazard.
- Seismic hazard areas are subject to potential risk from earthquake-induced ground shaking and fault displacement. The ground shaking can result in slope failure, settlement, soil liquefaction, tsunamis, or seiches —all of which pose a risk to the public.
- Liquefaction is of particular concern because it has often been the cause of damage to structures during past earthquakes. Liquefaction occurs where soils are primarily loose and granular in consistency and located below the water table. The consequences of liquefaction include loss in the strength and settlement of the soil. The loss of strength can result in lateral spreading, bearing failures, or flotation of buried vaults and pipes.

TABLE 4.11-1
Potential Geologic Hazards within or Adjacent to Each Segment

Geologic Hazard Potential	Segment				
	A	B	C	D	E
Steep Slopes	✔	✔	✔	✔	✔
Erosion	✔	✔	✔	✔	
Landslide	✔	✔			✔
Seismic (Distance from Seattle Fault Zone)	0 – 2 miles	0 – 2 miles	2 – 3.5 miles	3.5 – 5 miles	5 – 6.5 miles
Liquefaction Potential	Moderate to High	Moderate to High	Low to Moderate	Low to Moderate	Low to Moderate
Soft Soils	✔	✔	✔	✔	✔

Examples of liquefiable soils located in the study area include:

- Some artificial fill
- Tideflat deposits
- Mass wastage deposits
- Lake deposits
- Recessional outwash deposits

- Tsunamis or seiches are possible secondary effect from seismic events. Both mechanisms involve water waves that are created by an earthquake. In general, the East Link alternatives are located either too far from Elliott Bay and Lake Sammamish or too high above Lake Washington for tsunami or seiche inundation to be a concern.
- Soft soil conditions can also be a form of geologic hazard. Soft soils have low strengths and are compressible. Without appropriate design consideration, soft soil can lead to embankment failures during construction or long-term settlement and would add to the maintenance requirements for the project.

4.11.2.3 Site Geology

This section summarizes geotechnical characteristics and groundwater conditions for each segment of the study area based on existing geologic maps and boring logs. Table F4.11-1 in Appendix F4.11 provides a summary of general geologic unit descriptions, and the *Sound Transit East Corridor HCT Summary Geotechnical Report for Preliminary Route Selection*, available from Sound Transit, provides more detail about specific soils and geologic units.

Segment A

The construction of Interstate 90 (I-90) and adjacent land development has modified the terrain within Segment A, changing the original topography and sometimes altering the type of exposed soil or the distance to groundwater.

Geotechnical Characteristics. The geotechnical characteristics of soils in this segment range from loose sands, which could be unstable if they were to liquefy, to glacially consolidated sands and gravels, which generally provide good bearing support and little settlement.

Groundwater Conditions. The groundwater elevation varies along the Segment A alternative. Groundwater in the Rainier Valley was typically found at around 20 feet deep and was not encountered in many borings on the hillsides. Some borings encountered groundwater at about 40 feet deep in the upland areas.

Constructibility of Soil Types

Fill: Highly variable.

Peat: Poor soil for construction.

Tideflat deposits: Poor soil for construction.

Alluvium: Properties range from poor to excellent. May be good soils for construction, but depends on groundwater level and type of soil.

Reworked glacial deposits: Variable, may be suitable for construction.

Glacially consolidated soils: Compressed by glaciers, very dense and strong.

Recessional outwash: Usually suitable for construction, but depends on groundwater level.

Glacial till: Good soils for supporting structures, can be difficult to excavate.

Advance outwash: Glacially compressed. Good support characteristics.

Bedrock: Good foundation support but often hard to excavate.

Soft silt: Poor soil for construction.

Medium stiff to hard silt: Can be suitable soil to for construction, water sensitive.

Loose sand: Poor soil for construction. Liquefiable if below water.

Medium-dense to very dense sand: Good soil for construction.

Segment B

Much of the land along the Segment B corridor has been developed with residential and light commercial structures. There are two areas that remain relatively undeveloped: the Mercer Slough Nature Park, which is a large wetland, and the area between the slough and I-405.

Geotechnical Characteristics. Soil conditions include soft, compressible materials, which are low in strength and prone to settlement in and around Mercer Slough. Further away from Mercer Slough, glacially consolidated soils that would be very stable during construction and long-term operations are present. Peat, which is particularly low in strength and compressible, occurs in Mercer Slough to depths greater than 60 feet in some areas. Steep slopes are present in areas along the west side of Bellevue Way and along the east side of the BNSF Railway.

Groundwater Conditions. Groundwater depth varies with topography and the season. Kelsey Creek, to the northeast of Mercer Slough, has a shallow unconfined aquifer, which primarily discharges into Mercer Slough. Groundwater is at or near the surface at the Mercer Slough wetlands, and also is present and highly pressurized in a sand unit at approximately 100 to 125 feet deep.

Segment C

Segment C is dominated by Downtown Bellevue and includes an extensive amount of underground development for parking garages, building foundations, and utilities. Most of the land in Segment C has been modified by human development.

Geotechnical Characteristics. Soils consist of fill, underlain by deposits of glacial till composed of silt, sand, and gravel. The tills are generally compact and stable, providing good bearing support and posing limited risk of settlement. Fill areas in the downtown core, however, are highly variable and range in soil type and consistency. The variability of this fill makes it less dependable for construction, and it can be prone to settlement and/or liquefaction. Table 4.11-2 described specific conditions in each potential tunnel corridor.

Groundwater Conditions. The groundwater elevation varies with topography and season in Segment C. A groundwater table is typically encountered at depths between 40 and 120 feet. In some locations of Downtown Bellevue, there is artesian groundwater pressure, which results in excess groundwater pressures that would have to be considered for tunnel and elevated structure excavation and foundations during the design phase. Dewatering wells have been used to lower groundwater during excavations for new high-rise buildings in some parts of Downtown Bellevue. Dewatering during construction can also increase the potential for settlement where soils are soft or loose and heavily saturated. The extent of dewatering would need to be monitored closely in areas where soils are prone to settlements induced by dewatering. Previous excavation experience in Downtown Bellevue indicates that loose or soft soils would probably not be encountered. However, a more thorough evaluation of soil conditions would be performed during the preliminary design phase.

TABLE 4.11-2
Geological Conditions for Tunnel Alternatives

Alternative	Geotechnical Characteristics	Groundwater Conditions	Types of Tunnels Proposed	Depth of Expected Excavation
C1T, Bellevue Way Tunnel	10 to 15 feet of medium dense fill underlain by very dense glacial till and advance outwash.	Depth to groundwater varies between 65 feet and 90 feet.	Cut and cover, SEM under Bellevue Arts Museum[a]	South of NE 6th Street: up to 80 feet East of Bellevue Way: up to 55 feet
C2T, 106th NE Tunnel	Conditions unknown south of Main Street. North of Main Street there is minimal fill until NE 6th Street, which is up to 17 feet of medium dense advance outwash underlain by very dense advance outwash. Along NE 6th Street, there is up to 15 feet of medium dense fill underlain by very dense glacial till and stiff to hard glaciolacustrine deposits.	Depth to groundwater is approximately 50 feet south of NE 6th Street. At the Bellevue Transit Center Station, no groundwater was encountered in borings up to 90 feet deep. Groundwater depth unknown north of NE 6th Street.	Cut and cover, bored tunnel	Up to 55 feet
C3T, 108th NE Tunnel	Conditions unknown south of Main Street. North of Main Street is very dense glacial till, advance outwash, and very stiff silt. At the Bellevue Transit Center Station and north to NE 10th Street, there is up to 16 feet of very loose to medium dense fill underlain by dense glacial till and advance outwash and stiff to very stiff glaciolacustrine deposits. North of NE 10th Street, there is up to 15 feet of loose to medium dense fill underlain by very dense glacial till consisting of sand with silt and silty gravel.	Depth to groundwater is approximately 47 feet south of NE 6th Street. At the Bellevue Transit Center Station, no groundwater was encountered in borings up to 90 feet in depth. Groundwater depth unknown north of NE 6th Street.	Bored, except for cut and cover at tunnel portals and stations	Between 80 and 110 feet for bored sections Up to 65 feet for cut and cover tunnels, and 110 feet at cut and cover Bellevue Transit Center Station.

[a] SEM = sequential excavation mining

Segment D

Land within Segment D is relatively level upland areas located within a trough. Several streams travel through the area toward Lake Washington.

Geotechnical Characteristics. Soil conditions consist primarily of layered sand and gravel. In some localized areas, sands and gravels are of loose or medium density, making these soils potentially prone to liquefaction during a large seismic event. Other areas of glacial till are heavily overconsolidated from the weight of past glaciations, resulting in very high bearing strengths and little potential for settlement or liquefaction. There are steep slopes in areas on the south side of State Route 520 (SR 520).

Groundwater Conditions. The groundwater elevation in the area from NE 12th Street to Northup Way is close to the ground surface, as indicated by the water level in Lake Bellevue. In other areas along the alternative, groundwater was typically encountered between the surface and 15 feet deep or at greater depths, between about 45 and 60 feet. In some locations, there was highly pressurized groundwater.

Segment E

The area within Segment E transitions from a higher ridge to the Sammamish River Valley. Lake Sammamish and the Sammamish River have influenced the geology and soils of this area.

Geotechnical Characteristics. Soil conditions vary between the upland areas and the valley areas. In upland areas, geological conditions are similar to those in Segment D. In the valley, soils consist of an upper layer of fill, underlain by sand and gravel and layers of soft, compressible peat and clay up to 25 feet deep. These soils are less suitable for construction and some are prone to liquefaction. Dense glacially consolidated soils are located beneath the fill and surface soil deposits. There are steep slopes in areas along the west side of West Lake Sammamish Parkway.

Groundwater Conditions. The groundwater elevation varies. In upland areas, zones of groundwater are encountered from the surface to 20 feet deep or more. Adjacent to the Sammamish River, groundwater is within 3 feet of the ground surface in natural areas and deeper in areas where fill has been placed. In the valley area, away from the Sammamish River and Bear Creek, groundwater is encountered at about 20 feet deep.

Maintenance Facility Surroundings

Four potential locations have been identified for siting a maintenance facility. Three of these are located in Segment D and one is located in Segment E. The surface geology and soil conditions at the ground surface in those locations have been modified by human development. Geotechnical characteristics and groundwater conditions are generally as described above for Segments D and E.

4.11.3 Environmental Impacts

This section summarizes the impacts that could result from the East Link Project and the No Build Alternative. For the project, the discussion of impacts covers the general impacts that are common to all segments, and then the key impacts for each segment are discussed.

4.11.3.1 No Build Alternative

Under the No Build Alternative, construction of East Link would not take place. The existing geology and soils environment would essentially remain unchanged. The existing risk from seismic hazards would still exist.

4.11.3.2 Impacts During Operation

Impacts Common to All Build Alternatives

Operational impacts would result from new slopes and new earth fills resulting from new light rail facilities. Other impacts would be related to geologic hazards that already exist. For example, there would be a risk of seismic events during the period of operation, and this risk could result in other related geologic hazards, such as liquefaction and seismic-induced slope failures.

Following is a list of potential long-term operational impacts associated with geology and soils that are common to each of the segments:

Slope Stability and Landslides. Insufficient long-term stability of earth slopes and retaining wall structures could endanger on-site and off-site properties. This risk would be greater if a large seismic event were to occur.

The overall risk of impacts from slope instability and landslide would be low for all alternatives. Slope stability would be considered during the design phases of the project and various minimization measures could be implemented to stabilize areas of potential risk.

Seismic Hazards. The project would be within a seismically active area. The consequences of a seismic event during operations would be strong ground shaking, which could lead to liquefaction of loose, saturated, cohesionless soils, settlement from densification of loose soils, instability of steep slopes, or increased earth pressures on retaining walls. These effects could damage the constructed light rail facilities.

The elevated light rail support systems and earth-retaining structures, including retained fills or cuts, would be designed for the seismic hazards that are known to exist. The tunnel alternatives should perform well during a large earthquake based on the performance of tunnels around the world during past earthquakes when appropriate designs were applied.

The East Link Project would meet seismic design standards to minimize the long-term risks to the system. Methods that could help minimize seismic hazards in areas with liquefiable soils include, but are not limited to, the following:

- Stone columns, which are 3-foot-diameter columns of compacted gravel spaced at approximately 7 to 10 feet to improve unstable ground
- Grouted columns of cement and soil that range in diameter from 2 to 3 feet to improve unstable ground
- Excavation and replacement with non-liquefiable soil

Groundwater Flow Alterations. Groundwater flow paths could be altered by foundations, tunnels, or ground improvements included in the project design. The volume of earth affected by foundations and ground improvement by itself would be limited relative to groundwater flow regimes in the area.

Although the potential impact to groundwater flow is considered low for all segments, the potential effects of barriers to groundwater flow, such as sheet pile walls or subsurface tunnels and stations, would be considered during final design to confirm that effects to any nearby soils or structures supported on or within the soils would be negligible.

Long-Term Settlement from Retained Fills. Retained fill would be used in some areas to meet track-grade requirements. Walls would typically be used to retain the fill, thereby minimizing the area covered by fill. Construction would involve placing imported fill soil between two retaining walls. The fill would cause new earth loads on the existing soil, which could lead to settlement of soft soil.

Settlement of compressible soils beneath proposed retaining structures and fill areas could require periodic maintenance of the new infrastructure and/or poor ride quality when maintenance is not performed. Utilities or other structures located adjacent to the new facilities could also settle as a result of increased loads. Over much of the project corridor, the existing soils would provide excellent bearing support, and the potential for long-term settlement would be negligible. In areas where settlement-prone soils exist, minimization measures would be used to avoid the detrimental effects of settlements.

In summary, the degree of the impacts described above in each segment would depend on the specific site conditions, development plans, and final design. In all cases, the severity or frequency of the hazard or impact could be avoided or minimized using conventional design and construction methods. Where impacts are found to be moderate to high, more effort would be required during design to evaluate the severity of the impact and identify an adequate avoidance or minimization method.

The most important geologic hazard for operations would result from seismic ground shaking, which would affect all segments, although the hazard would be slightly higher in Segments A and B because of their proximity to the Seattle Fault Zone where the risks from fault movement and ground shaking are higher. In other segments, the primary seismic hazard would be associated with ground shaking and secondary effects of ground shaking, such as liquefaction, slope failures, and ground settlement.

Most segments present a low risk from geologic hazards. While impacts are generally similar between alternatives within each segment, the observations in following subsections were made relative to the alternatives. These geologic issues would be addressed during final design. With the implementation of appropriate design, potential adverse impacts would be avoided and/or minimized.

Segment A

This segment would offer overall stable geology and soil conditions during operation. Operational geologic hazards to this alternative during operation would be from seismic-related ground-shaking and from fault displacement, if the Seattle Fault were to rupture.

Segment A includes the use of the I-90 existing structures, which were designed during the 1970s and mid 1980s. These structures were designed to meet the seismic requirements at the time of construction in the early 1980s. WSDOT recently adopted a new seismic retrofit policy for bridges, including portions of I-90 where the light rail would be located. Placing light rail on the I-90 structures would not change their seismic vulnerability. However, Sound Transit commits to funding improvements to improve the earthquake resistance of the structures in the corridor used by light rail. Structures assumed to be retrofitted include the columns, bridge seats, and restrainers for the light rail portions of the D2 Roadway, Rainier Avenue Overcrossing, approach spans to the floating bridge, and the East Channel Bridge, using the currently known Federal Highway Administration (FHWA)/ American Association of State Highway and Transportation Officials (AASHTO) policies, consistent with WSDOT's own practices for retrofitting existing structures. The floating bridge is generally not vulnerable to seismic events due to the dampening effect of the lake water.

Segment B

This segment would include at-grade and elevated alternatives located in south Bellevue. Within Segment B, at-grade alternatives adjacent to the north end of Mercer Slough (112th SE At-Grade [B2A] and 112th SE Bypass [B3] alternatives) would potentially involve more maintenance issues because of long-term settlement of soft clays and peats and would be at a higher risk for liquefaction in saturated sands than the other alternatives.

The slopes along Bellevue Way SE and 112th Avenue SE would require the use of retaining walls to accommodate the roadway widening for the rail system. Heights of the walls are generally limited and can be designed to provide long-term stability, even where slopes are located above the walls. The 112th SE Elevated Alternative (B2E) would generally involve fewer cuts into existing slopes than alternatives that involve at-grade sections (B1, B2A, and B3) and therefore would involve less risk for long-term landslide or slope instabilities. The grade changes along 112th Avenue SE (B2A, B3) are lower than along Bellevue Way (B1), suggesting that the 112th Avenue SE alternative would involve less risk from a sloping ground standpoint.

The BNSF Alternative (B7) would also include an elevated structure across Mercer Slough, which would be at greater risk during a seismic event than other alternatives. The steep slopes along B7 between Mercer Slough and I-405 would be a higher risk during operations than they would be for other Segment B alternatives.

Segment C

The geology and soil conditions within Segment C would be generally stable for all alternatives and would not differ substantially for at-grade, elevated, and tunnel profiles. Because the downtown area includes extensive underground development for parking garages, building foundations and utilities, the soils generally consist of fill, which are underlain by deposits of glacial till, silt and sand and gravel. These soils are generally compact and pose little risk of settlement.

Retained fill profiles, which are required for elevated structures, would result in new earth loads, which could lead to minor long-term settlement and increased maintenance requirements. However, in most locations, the existing soils are relatively incompressible because they are glacial till and can support the loads without detrimental settlement. Tunnel alternatives are generally designed to avoid other underground developments and take advantage of the stabile glacial till geologic layers. The at-grade Couplet (C4A), the 112th NE Elevated (C7E), and the 110th NE Elevated (C8E) alternatives would have the lowest risk for long-term settlement during operations because of the good bearing characteristics of the soil along these alternatives.

Segment D

The Segment D alternatives would be at-grade, within retained cuts, on retained fills, or elevated. Sections of the alternatives could also involve localized areas with steep slopes. The good bearing characteristics of the soil along Segment D would limit the long-term impacts from any of these types of construction.

Sections of the NE 16th At-Grade (D2A) and the NE 20th (D3) alternatives that require additional fill to meet grade would have more risk for long-term settlements than the NE 16th Elevated Alternative (D2E) and sections of all alternatives already at grade. Retained cuts would also be required in some areas and for a substantial portion of D3, and there would be some chance of settlement behind these cuts. As with other segments, seismic events would be a minor risk during the operation of the light rail systems, and the effects of a seismic event would need to be carefully considered during design.

Areas with steep slopes would need to be evaluated for long-term stability, and the potential effects of seismic events would have to be established. The seismic loading effects could include areas of localized liquefaction, seismic-induced settlement, or slope failures.

Segment E

No clear distinctions could be made between Segment E alternatives because of similar geology and soil conditions, but all Segment E alternatives would be located in areas that have a high potential for seismic hazards due to sand and silt layers in the Sammamish Valley and a moderate potential for slope instability and landslides from steep slopes heading into the valley. Areas within the valley could also be prone to settlement of peat deposits.

Overall, conditions are such that the types of hazards are relatively easy to address and are not expected to result in substantial long-term operational risk.

Maintenance Facility

The 116th (MF1), BNSF (MF2), and SR 520 (MF3) maintenance facility locations in Segment D appear to have lower potential impacts, due to fewer settlement issues, than the SE Redmond Maintenance Facility (MF5), which would be located in Segment E where soils are more compressible and prone to liquefaction.

4.11.3.3 Impacts During Construction

Impacts Common to All Build Alternatives

Impacts during construction are associated with the equipment used to perform the construction, as well as the direct and indirect impacts of the construction activities. Construction activities have the potential to cause a number of short-term impacts on the environment related to geology and soils, including the following:

Erosion Hazards. Clearing of protective vegetation, fill placement, and spoils removal or stockpiling during construction allows rainfall and runoff to erode soil particles. The severity of potential erosion is a function of the quantity of vegetation removed, site topography, rainfall, types of soils, and the volume and configuration of soils stockpiled. Best management practices (BMPs) that could help minimize erosion hazards include, but are not limited to, the following:

- Maintaining vegetative growth and providing adequate surface water runoff systems
- Constructing silt fences downslope of all exposed soil and using plastic covers over exposed earth
- Using temporary erosion control blankets and mulching to minimize erosion prior to vegetation establishment

Slope Instability and Landslide Hazards. Construction of the proposed infrastructure would involve grade changes, cuts and fills, and/or installation of bridge and retaining wall structures that have the potential to cause landsliding or slumping of hillsides. Overall risk of impacts due to constructing in landslide hazard areas would be limited for all alternatives due to the limited number of existing landslides along the proposed alternatives.

During final design, detailed slope stability evaluations would be conducted, and where appropriate, methods of stabilization developed. Methods that could help minimize landslide hazards include, but are not limited to, the following:

- Use of retaining structures that are designed for the loads from moving soils
- Use of mechanical slope reinforcement such as soil nailing
- Construction specifications and quality assurance programs that prohibit oversteepened slopes

Seismic Hazards. An earthquake could occur during construction, resulting in embankment slope failures, liquefaction, or ground settlement. The risk of seismic hazards to construction is considered low because there is a low probability that an earthquake would occur during the actual construction period.

If a large earthquake were to occur, the major risk would be to the ongoing construction activities. Work schedules would likely be delayed as efforts are made to repair damaged components of the work. Some disruption could also occur to utilities or nearby structures from the damage to exposed cuts or fills.

Construction-Induced Vibrations. The use of heavy equipment during construction causes ground vibrations. The level of vibrations depends on the type of heavy equipment, distance from the source, and ability of the soil to transmit vibrations. The main concern for construction vibration is potential damage to structures and most construction processes do not generate high enough vibration levels to approach damage criteria. The major sources of construction vibration include impact pile driving, augered piling, vibratory rollers, and tunnel boring machines, including associated muck trains. The only activity with potential to cause building damage is impact pile driving at locations within 25 feet of structures. Section 4.7, Noise and Vibration, provides a detailed review of these potential impacts.

Settlements From New Earth Loads. Retained fill would be used along some sections of the light rail route to meet track grade requirements. These retained fills could be 20 feet or more in height, causing higher earth loads on the soil than occur at present. These loads could cause settlement of the existing ground. Most of these settlements would occur during construction; however, for some soil types, the settlements could also occur during operation.

Settlements from new earth loads would be of primary concern in areas that have soft surface soils. Although settlement-prone soils could occur anywhere along the alternatives, the areas of primary concern are near Mercer Slough and in the Sammamish River valley where soft, compressible soils have been identified. Where glacially consolidated soils occur at the ground surface, the potential for settlements from new earth loads would be minimal because these soils have already been compressed by the weight of ancient glaciers.

The new earth loads would cause compression of soft soils below and adjacent to the new construction. The extent of compression beyond the footprint of the new earth load can extend 20 feet or more from the load. The impacts on adjacent areas could include the following:

- Settlement of buildings or residential structures
- Damage to roadways and sidewalks, resulting in additional maintenance work
- Damage to buried utilities located next to new fill

Design studies would be focused on identifying the location of these soft soils, and where found, they would either be removed and replaced, or ground improvement techniques would be used to prevent long term settlement.

Excavations for Foundations and Removal of Unsuitable Material. Excavations for structure foundations and relocation of utilities, if not supported correctly, could result in failure and collapse of the ground next to the excavations, causing damage to buried utilities and to structures or roadways located adjacent to the excavations. The impact to utilities and buried structures is considered low during construction. Methods that could help minimize utility and buried structure impacts include, but are not limited to, the following:

- Relocation or protection of utilities where ground settlement cannot be avoided
- Constructing a pile-supported embankment to transfer earth loads to incompressible layers
- Modifying tunneling methods (such as use of soil conditioners and/or higher face pressures) or using replacement grouting to limit settlement above the tunnels

Existing soils excavated during construction that cannot be used as structural fill or for landscape material would require removal from the project footprint and disposal elsewhere. Disposal of the material at off-site locations would result in additional truck traffic, dust, and other construction-related impacts. Table 4.11-3 shows potential soil excavation volumes and number of truck trips. These estimates include all excavation, not just unsuitable soils.

Dewatering. Dewatering of excavations located below the groundwater table during construction could result in settlement of nearby structures, if proper

TABLE 4.11-3
Estimated Excavation Volumes

Alternative	Waste (cubic yards)	Total Truck Trips
Segment A		
A1, I-90 Alternative	20,000	1,350
Segment B		
B1, Bellevue Way Alternative	153,000	10,200
B2A, 112th SE At-Grade Alternative	127,000	8,470
B2E, 112th SE Elevated Alternative	76,500	5,100
B3,112th SE Bypass Alternative	107,500	7,200
B7, BNSF Alternative	142,000	9,500
Segment C		
C1T, Bellevue Way Tunnel Alternative	1,035,000	69,000
C2T, 106th NE Tunnel Alternative	796,500	53,100
C3T, 108th NE Tunnel Alternative	635,000	42,350
C4A, Couplet Alternative	127,000	8,500
C7E, 112th NE Elevated Alternative	102,500	6,850
C8E, 110th NE Elevated Alternative	123,000	8,200
Segment D		
D2A, NE 16th At-Grade Alternative	204,500	13,650
D2E, NE 16th Elevated Alternative	185,000	12,350
D3, NE 20th Alternative	397,000	26,500
D5, SR 520 Alternative	170,000	11,350
Segment E		
E1, Redmond Way Alternative	364,000	24,300
E2, Marymoor Alternative	399,000	26,600
E4, Leary Way Alternative	345,500	23,050
Maintenance Facilities		
MF1, 116th Maintenance Facility	840,500	56,050
MF2, BNSF Maintenance Facility	250,500	16,700
MF3, SR 520 Maintenance Facility	370,000	24,700
MF5, SE Redmond Maintenance Facility	120,000	8,000

Note: Quantities assume all excavation would be wasted. Amount that could be used on site would be defined as design proceeds. Number of truck trips based on an average of 15 cubic yards per truck. Actual numbers would vary depending on the types of equipment used by contractor and the amount of material that would be re-used on site.

consideration is not given to the effects of water level changes. This impact would most likely be associated with Segment C for the bored or cut-and-cover tunnel alternatives. Underground construction for the tunnel or stations could require dewatering if the combination of permeable soils and high groundwater elevation occurs at, for example, a station location.

The impact of dewatering is considered low if proper avoidance and minimization measures are used. Methods that could help minimize soil settlement include, but are not limited to, the following:

- Controlling the changes in groundwater elevation near critical structures through the use of localized dewatering and groundwater injection methods
- Using sheetpile barrier systems to control the horizontal extent of groundwater withdrawal
- Installing deep foundations systems that would support the structure during settlement

In summary, the severity or frequency of the hazard or impact could be avoided or minimized using conventional design and construction methods. Where impacts are identified as being moderate to high, more effort would be required during design to evaluate the severity of the impact and identify an adequate avoidance and minimization method.

The most important geologic hazard during construction would be erosion control, which would need to be appropriately addressed in all segments. Alternatives with steep slopes would require more consideration than relatively flat areas. Some common methods of erosion control include silt fences, sedimentation ponds, and limiting amounts of exposed earth during wet winter months.

Although impacts would be generally similar among alternatives within each segment, the following observations were made regarding impacts from certain alternatives. In addition, each impact can be avoided or minimized using commonly accepted procedures and design considerations.

Segment A

As stated under Operational Impacts, Sound Transit anticipates seismic retrofits for some I-90 structures that would be used by light rail. This may include in-water work in Lake Washington to reinforce the existing structures. No other geologic issues would be a concern for the existing I-90 structure in Segment A during construction.

Segment B

The alternatives associated with 112th Avenue SE in Segment B, including the 112th SE At-Grade (B2A), 112th SE Elevated (B2E), and 112th SE Bypass (B3) alternatives, have flatter slopes and would be expected to have fewer erosion and landslide issues during construction than the Bellevue Way Alternative (B1), where some steep slopes exist. However, the soils along 112th Avenue SE are generally softer than soils along Bellevue Way, and these softer soils are more susceptible to construction-related issues in areas where fills are placed or where foundations for elevated structures must be constructed. The potential slope and erosion issues along Bellevue Way would be easier to address than soft soil conditions along 112th Avenue SE.

The BNSF Alternative (B7) crosses the Mercer Slough Nature Park, which is an area with a history of soil settlement from Washington State Department of Transportation (WSDOT) projects, such as I-90. These soil conditions would require the use of deep foundations for new supporting structures that are not supported. Special methods would also be required for protecting wetlands during construction. The steep slopes along the BNSF corridor also would require additional engineering efforts compared to the other Segment B alternatives.

Segment C

Tunnel construction methodology is described in Chapter 2, subsection 2.4.5. Tunneling alternatives within Segment C could result in settlement of the ground above or adjacent to the tunneling work. Because of the nature of the glacial till along the tunnel alternatives, settlement is expected to occur during construction. During construction, adjacent structures and surface areas would be monitored for settlement. Following construction, Sound Transit would conduct inspections, and although no damage to structures is anticipated, any damage that occurs would be repaired.

Geotechnical engineering evaluations would be conducted during design to identify the major differences in soil and groundwater conditions for each alternative within Segment C. Information from these explorations would be used to select tunnel construction methods that control the potential for ground settlement. The risk of tunnel-related settlements would include the following:

- Damage to roadways and utilities
- Damage to residential structures where tunneling results in settlement beneath the structures
- Damage to buildings where the tunnel location is near building foundations and walls

Where groundwater is present, tunneling and excavation could require some localized dewatering, which also has the potential to result in subsidence or settlement in soft or loose soils. The potential for settlement is higher when soils are loose, tunnels are shallower, excavations for stations are deeper, and adjacent buildings foundations are shallow. Where soil is settlement-prone, measures can be implemented to limit the settlement to tolerable levels. The magnitude of acceptable settlement depends on the type and dimension of the structure but is generally in the order of 1 inch or less. The settlement is greatest above the tunnel centerline and decreases outward. Typically, the settlement extends horizontally from the tunnel centerline no more than three times the tunnel diameter, which would be approximately 75 to 85 feet. In areas where retained cuts would be used for access to tunnel sections of the alternative, the potential for settlement behind the retaining walls would exist. This potential risk can be minimized by implementing standard design methods and industry best practices.

The three alternatives that involve tunneling, the Bellevue Way (C1T), 106th NE (C2T), or 108th NE (C3T) alternatives, would be constructed by a combination of boring, sequential excavation mining (SEM), and cut-and-cover methods. The alternative with the greatest potential for settlement that could cause damage to existing structures is C1T because of the use of SEM under the Bellevue Arts Museum and the combination of excavation depth for cut-and-cover construction, location of groundwater table, and soil types. With good engineering practices, settlements of up to approximately 2 inches are anticipated directly next to a cut-and-cover excavation and should reduce to zero beyond a horizontal distance of about 2 to 3 times the excavation depth. Outside of this area, settlement is expected to be less than 1 inch, although tight control of ground movement during construction would be required adjacent to existing buildings. Walls of the excavation would be supported by one of several flexible support systems that are commonly used in the Puget Sound region, including sheetpiles, soldier pile and lagging, and soil nail wall systems. In addition, supplemental ground support would be used to support the structure, as well as other nearby buildings.

The 106th NE Tunnel Alternative (C2T) is cut-and-cover construction north of Main Street, and settlement is expected to be minimal because of very dense material adjacent to the alternative. When connecting the 112th SE At-Grade Alternative (B2A) from Segment B, settlement potential is greater where the bored tunnel is shallow (less than 50 feet) south of Main Street. This shallow depth only occurs under Surrey Downs Park, and the tunnel would be deeper under residences in this area. The remaining bored sections would be located from 50 to 150 feet below the ground surface, which would minimize settlements at the ground surface.

The magnitude of settlement could be kept within acceptable levels by using appropriate tunneling methods and equipment and keeping the volume loss (see text box) to less than about 0.5 percent based on preliminary calculations. Volume loss would also be further minimized by using appropriate ground improvement methods such as grouting. The need for ground improvement, however, would be evaluated during future design phases using additional geotechnical information. In areas of cut-and-cover construction, walls of the excavation would be supported by one of several flexible support systems that are commonly used in the Puget Sound region, including sheetpiles, soldier pile and lagging, and soil nail wall systems.

Volume Loss

Volume loss is the amount of excavated soil in excess of the calculated geometry of the tunnel. If a greater volume of material is excavated than is displaced by the tunnel, then this material was lost from around the tunnel, which could create adverse impacts.

Because the 108th NE Tunnel Alternative (C3T) would be entirely bored tunnel construction except at the Bellevue Transit Center Station, settlement in this area is expected to be limited to less than 1 inch by limiting the volume loss to less than 1 percent. As discussed above, the need for ground improvement would be evaluated during future design phases. For cut-and-cover construction at the Bellevue Transit Center Station, where excavation would reach depths of 110 feet, a rigid excavation system, such as a secant or tangent pile wall system (i.e., wall system that uses concrete-filled boreholes), may be required to minimize ground movement and groundwater inflow into the excavation. This would minimize changes in the groundwater table that could induce settlements in loose or soft soils, although this is not anticipated in this area based on previous excavation. North of the Bellevue Transit Center Station, excavation for the bored tunnel would be up to 65 feet, with potential for settlement of up to 1 inch at the edge of excavation, reducing to zero beyond a horizontal distance of about 2 to 3 times the excavation depth.

For all tunnel alternatives, the tunnels would be fully lined, typically with bolted and gasketed precast concrete segments. Inflows through the segments would be small and result in little or no drawdown of water levels. Seepage and potential groundwater drawdowns would also likely be small at cast-in-place, concrete-lined stations designed to resist hydrostatic pressure (i.e., pressure from groundwater) and associated settlement potential. Also, use of waterproof lining in tunnels would minimize potential for groundwater drawdowns.

For the Couplet Alternative (C4A), relatively standard construction methods would be used because it would be mostly at grade, and no geologic concerns exist.

The 112th NE Elevated (C7E) and the 110th NE Elevated (C8E) alternatives both would be elevated systems with at-grade and retained-fill components. Standard construction techniques of retaining walls and compaction methods would be used to address settlement impacts from new earth loads.

Segment D

The SR 520 Alternative (D5) would appear to have the least amount of risk of the Segment D alternatives for all impact categories, except for the soils along D5, which would have a somewhat higher erosion potential along the south side of SR 520.

Segment E

No differences were identified for the alternatives within Segment E. Each alternative would have low potential for liquefaction and settlement.

Maintenance Facility

The SR 520 Maintenance Facility (MF3) would appear to have the low potential to result in soil erosion or liquidfaction. 116th Maintenance Facility (MF1) has the highest potential for erosion due to the deep cut design and soil conditions. The BNSF Maintenance Facility (MF2) has a lower potential for erosion due to the reduced amount of cut and fill required over that of MF1, but only slightly lower. The SE Redmond Maintenance Facility (MF5) would have more foundation engineering design and construction issues than MF1, MF2, and MF3 because of the soils that occur at this site are prone to liquidfaction.

4.11.4 Potential Mitigation Measures

Detailed study during final design would confirm the degree of geologic risk. At sites where geologic conditions are not suitable, appropriate design and construction measures would be implemented to avoid potential effects and geologic risks during operations.

Engineering design standards and best management practices would be used to avoid and minimize potential construction impacts. Based on the review of potential impacts, the design and construction process would address seismic hazards, soft soils, settlement, landslide hazards, erosion and sediment control, vibrations, and groundwater.