Technical Report
South Lake Union Streetcar Project

Geology and Soils

March 24, 2005

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The City of Seattle Department of Transportation

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Chapter 1 Summary

This technical report addresses geology and soils at the South Lake Union Streetcar project site and their potential impact on the proposed project. The purpose of this report is to describe the subsurface environment within the project area, the environmental consequences of the proposed project, and potential mitigation measures that may be employed to lessen the environmental impacts.

The proposed streetcar line would require relatively little earthwork to complete construction. It is anticipated that most of the earthwork would consist of shallow excavations of 12 to 18 inches in depth along the alignment. Some excavation would also be required for construction of the maintenance facility, proposed stormwater detention structures, utility relocation, and the traction power substations. These excavations could extend up to approximately 15 feet below the surface. The construction of the detention structures may require the relocation of existing utilities and protective measures to reduce the potential for damage to existing improvements. The site is located in a seismically active zone where some soils may liquefy.

General findings, conclusions and recommendations provided in this report can be found in the following sections:

- Affected Environment: The affected environment is discussed in Chapter 4. Included in this chapter are sections describing the current topography and historical development, regional geology, alignment subsurface conditions, sensitive areas, seismic setting, and potential seismic hazards.
- Environmental Consequences: The environmental consequences associated with this project during construction and operation are discussed in Chapter 5. Included in this chapter are discussions on erosion and seismic hazards. The seismic hazards associated with the project include the potential for liquefaction and liquefaction-induced lateral spreading.
- Mitigation: The measures available to mitigate the environmental impacts of the project during construction and operation are discussed in Chapter 6.

Chapter 2 Project Description

The City of Seattle, in cooperation with the U.S Department of Transportation Federal Transit Administration (FTA), proposes to construct a new streetcar line to serve the downtown, Denny Triangle and South Lake Union areas of Seattle. This line would provide local transit service, connect to the regional transit system, accommodate economic development, and contribute to neighborhood vitality. The project elements and construction are discussed in detail in the *South Lake Union Streetcar Project Description Memo* (Parsons Brinckerhoff, March 2005).

The proposed South Lake Union Streetcar would begin in the vicinity of the intersection of Westlake Avenue and Olive Way/5th Avenue in downtown Seattle (see Figure 2-1). It would extend north through the Denny Triangle and South Lake Union neighborhoods and terminate in the vicinity of Fairview Avenue N. and Ward Street near the Fred Hutchinson Cancer Research Center. The line would connect these neighborhoods and destinations with the regional transit hub at Westlake Center, which will be a major connection point for light rail, buses and monorail. The length of the proposed streetcar line is approximately 1.3 miles in each direction (2.6 track miles total) and the tracks and stops would be constructed entirely within existing right-of-way. The project would include three new traffic signals.

The streetcar would share the street with automobile traffic. Initially, the streetcar is expected to operate for 15 hours per day (roughly 6 AM to 9 PM), with fifteen minutes between cars. Ultimately, the system is expected to operate for 18 hours per day (roughly 5 AM to 11 PM), with ten minutes between cars.

As shown in Figure 2-1, streetcar stops would typically be side-platform corner-curb bulbs located within the parking lane at the far side of an intersection. Two stops would be center platform configurations: one within Fairview Avenue N. at the Fred Hutchinson campus and one in the railbank north of Valley Street adjacent to South Lake Union Park.

Bi-directional, low-floor, single-car, articulated streetcars are proposed. They are typically 66 feet long, 11.5 feet high, and 8 feet wide and run on standard gauge tracks. The streetcar would be powered by an overhead electrical system similar to those used by streetcars in cities such as Tacoma, Washington and Portland, Oregon.

A maintenance facility at the southwest corner of Fairview Avenue N. and Valley Street is planned as part of this project. The maintenance facility building would be approximately 100 x 70 feet. Two additional yard storage tracks would also be provided. Daily vehicle maintenance and inspections and minor repairs would be completed at the facility.

In the typical construction method for the streetcar track system, the top 12 to 18 inches of pavement would be removed and replaced with rail-embedded reinforced concrete slabs within a trench approximately eight feet wide. This project would also involve upgrading the stormwater detention system, relocation of utilities, and installation of traction power substations.

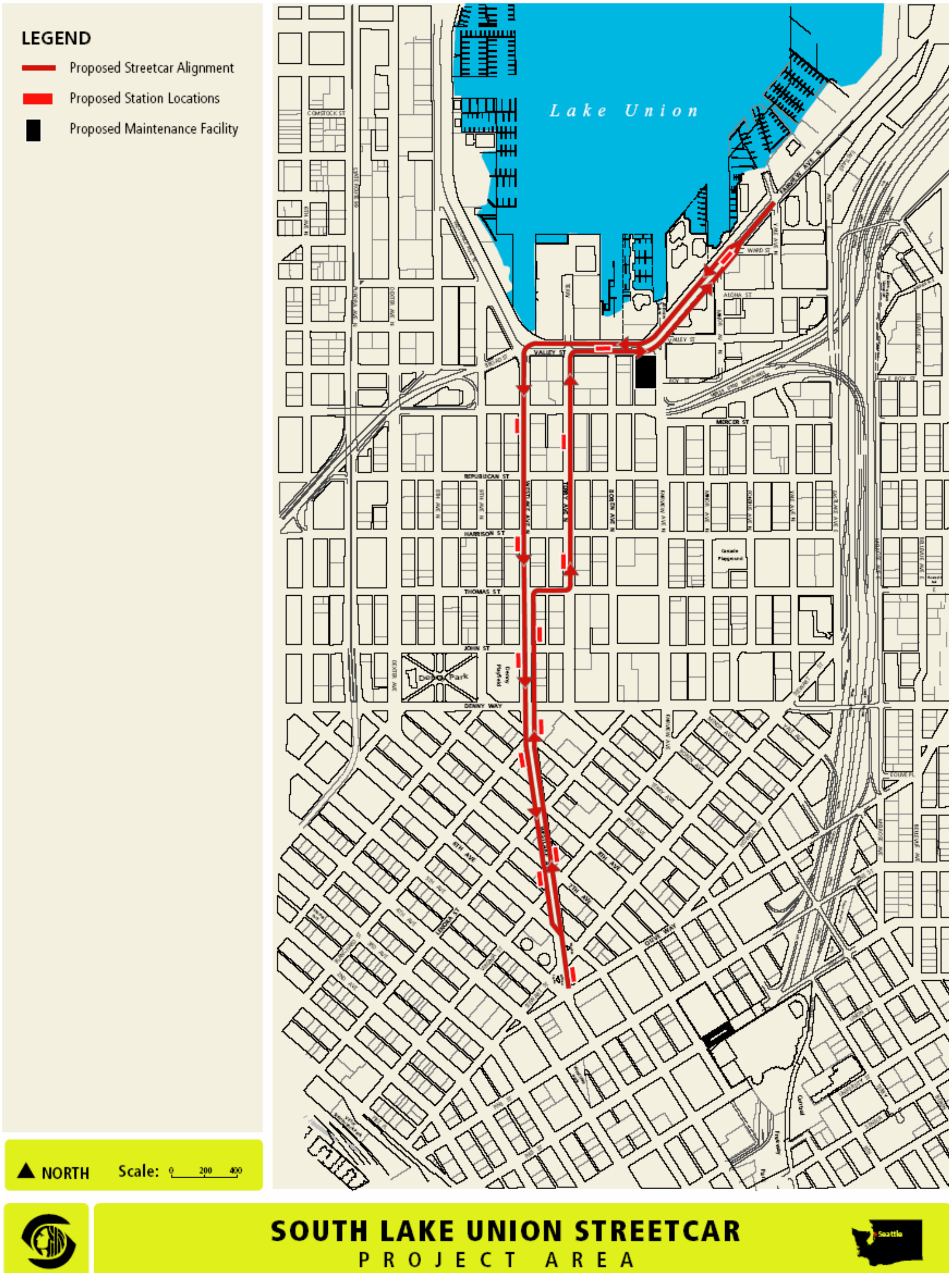


Figure 2-1: Project Area

Chapter 3 Methodology

Preparation of this technical report consisted of the following tasks:

- Reviewing preliminary design documents and drawings
- Reviewing available information within the project area
- Evaluating project area conditions
- Determining the project impacts
- Providing mitigation alternatives

The information reviewed during preparation of this technical report consisted of the following:

Published Maps and References

- Shimel, S. A., Booth, D. B., and Troost, K. G. (compilers). *Composite Geologic Map of the City of Seattle: University of Washington, Seattle-Area Geologic Mapping Project*, scale 1:31,250. This map is based on the original mapping from: Waldron, H.H., Liesch, B.A., Mullineaux, D.R., and Crandell, D.R., 1962, *Preliminary Geologic Map of Seattle and Vicinity, Washington: U.S. Geological Survey Miscellaneous Investigations Map I-354*, scale 1:31,250.
- The City of Seattle Department of Construction and Land Use, *Critical Areas Maps*, map series 9600, 1996.
- *Active Tectonics of the Seattle Fault and Central Puget Sound, Washington: Implications for Earthquake Hazards*, 1999, Johnson, S.Y., Dadisman, S.V., Childs, J.R., and Stanley, W.D.: GSA Bulletin, v. 111, no. 7, p. 1042-1053.
- *International Building Code*, 2003, International Code Council

SGMP Database

The Seattle-Area Geologic Mapping Project (SGMP) database was searched for existing subsurface soil and groundwater information within the project area. This project is a collaborative effort between local, state and federal agencies, the University of Washington, and local engineering consultants. The database is maintained by Pacific Northwest Center for Geologic Mapping Studies (GeoMapNW) at the University of Washington. The database is accessible on the World Wide Web at: *http://geomapnw.ess.washington.edu/index.php*

Geotechnical Reports

Several geotechnical soils reports were reviewed during preparation of this technical report. The most significant report was prepared by Hong West Associated for the Mercer Combined Sewer Overflow (CSO) project.

Chapter 4 Affected Environment

4.1 Current Topography and Historical Development

4.1.1 Topography

The topography within the project area generally slopes gently down from south to north. The topography within the project area ranges from approximately Elevation 110 feet at the south terminus to approximately Elevation 25 feet at the north terminus. The alignment does not include any steep slope areas.

4.1.2 Historical Development

The South Lake Union Streetcar project area is located between Lake Union and downtown Seattle. The majority of the project area is located within a predominantly commercial, retail and light industrial urban area. The project area located south of Denny Way is within the Denny Regrade area. The Denny Regrade project used hydraulic mining techniques to level what once was Denny Hill. The project area located north of Denny Way is known as the South Lake Union neighborhood. Prior to the area's development, the Westlake corridor was a natural drainage that drained into the south end of Lake Union. Early development included a narrow-gauge railroad to transport coal from the lake to the Seattle waterfront (constructed in 1872) and a saw mill on the south shore of the lake (constructed in 1882). Presently, the topography within the project area slopes gently down from south to north.

4.2 Regional Geology

Published geologic information for the project vicinity includes a U.S. Geological Survey Map titled "Geologic Map of Surficial Deposits in the Seattle 30' x 60' Quadrangle, Washington" (Yount, 1993). A more recent geologic map is titled "Seattle Composite Geologic Map" by Scott Shimel, Derek Booth, and Kathy Troost, Seattle-Area Geologic Mapping Project (SGMP), University of Washington, August 12, 2003. An excerpt of the project area taken from this map is shown in Figure 5-1.

The native soils in the vicinity of the project area are the result of glacial and post glacial processes. Landforms within the area are primarily the result of recent glaciation, erosion, sedimentation and modification by human activities. The glacial deposits are derived from several regional glaciations. The Vashon stade of the Frasier glaciation is the most recent, which occurred from about 13,500 to 15,000 years ago.

Deposits within the project vicinity associated with Vashon glaciation include the following deposits, listed in descending order from most recent to oldest: recessional outwash, glacial till, advance outwash, and transitional beds. These deposits are described in the following sections.

4.2.1 Recessional Outwash (Qvr)

Recessional outwash is deposited by meltwater streams in front of a receding glacier and typically consists of loose to dense, moderately well-sorted sands and gravels with a relatively low fine content.

4.2.2 Glacial Till (Qvt)

Glacial till typically consists of medium dense to very dense, non-stratified deposits of clay, silt, sand and gravel with occasional cobbles and boulders. The glacial till has been glacially overridden, but the upper 2 to 5 feet is often weathered and is typically medium-dense to dense. The glacial till grades to dense and very dense below the weathered zone.

4.2.3 Advance Outwash (Qva)

Advance outwash generally consists of moderately to well-sorted and well-stratified sand and gravel deposits with irregular lenses of fine gravel, silt and clay. The advance outwash was deposited by meltwater streams emanating from the advancing glacier, has been glacially overridden, and generally varies from dense to very dense.

4.2.4 Transitional Beds (Qtb)

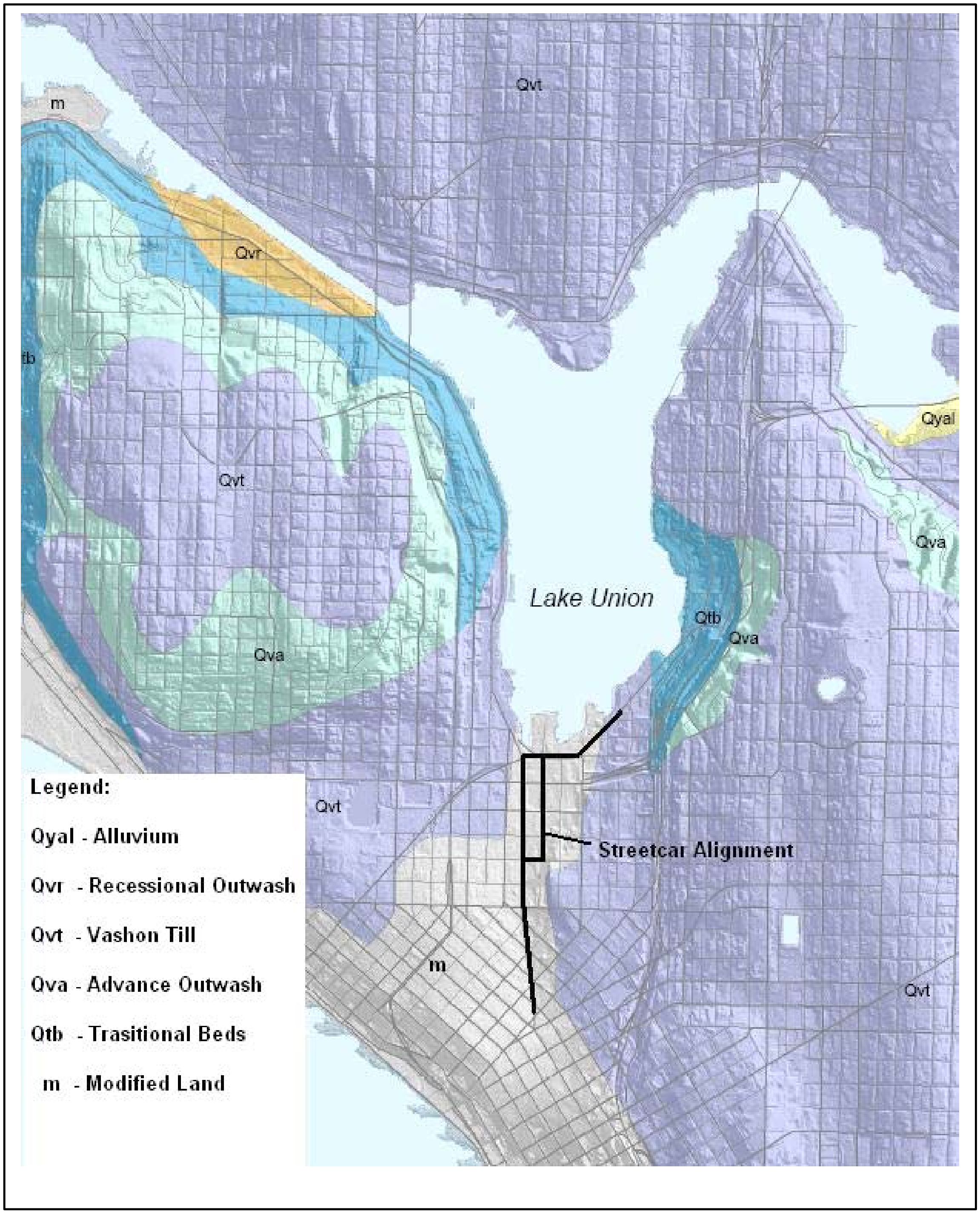
The transitional beds generally consist of stiff to hard silts and clays with interbedded sands and occasional gravels. These soils were deposited in pro-glacial lakes and have been glacially consolidated.

4.3 Alignment Subsurface Conditions

At this time, our understanding of subsurface soil conditions along the proposed project alignment is based on the existing subsurface information. This information includes soils reports prepared by GeoEngineers and other engineering firms in the area. Some of this information was acquired from the Pacific Northwest Center for Geologic Mapping Studies, which is a collaborative effort between the University of Washington and several local, state and federal agencies, including the City of Seattle. The following sections summarize the subsurface soil conditions within the project area. This information was compiled from these data sources. The sections are based on the streets along which the alignment would follow.

4.3.1 Westlake Avenue

Subsurface soils along Westlake Avenue consist of fill overlying glacial deposits. The fill thickness generally increases toward the north, ranging in thickness from approximately 3 feet near the south terminus to approximately 25 feet near the intersection of Westlake Avenue North and Valley Street. The fill generally consists of very loose to medium-dense sands and very soft to soft silts. Based on the available information, the fill appears to be less than approximately 5 feet thick south of John Street. North of John street, it begins to thicken considerably toward the north. The existing boring logs indicate that the fill north of Republican Street contains cinders, wood, brick, sawdust and other organics. It appears that north of Mercer Street, the fill was placed over organic soils that were once wetlands along the south shore of the lake.



Source: Seattle Composite Geologic Map by Scott Shimel, Derek Booth, and Kathy Troost, Seattle-Area Geologic Mapping Project (SGMP), University of Washington, August 12, 2003

Figure 4-1: Local Geologic Map

4.3.2 Terry Avenue North

Existing subsurface information along Terry Avenue North is limited, but it appears that subsurface conditions are similar to those along Westlake Avenue North, with a layer of fill that thickens toward the north. All of the available borings are located north of Republican Street. These borings indicate that the fill thickness ranges from approximately 20 to 35 feet. The fill is typical for this area, consisting of loose sands and soft silts with lenses of wood chips and occasional brick fragments.

4.3.3 Valley Street

The fill below Valley Street varies in thickness from approximately 5 feet at the intersection of Valley Street and Fairview Avenue to over 30 feet at the intersection of Valley Street and Westlake Avenue North. The fill typically consists of very loose to medium-dense sands and soft silts. The boring logs indicate that the fill contains wood chips, sawdust, slag, brick, and glass.

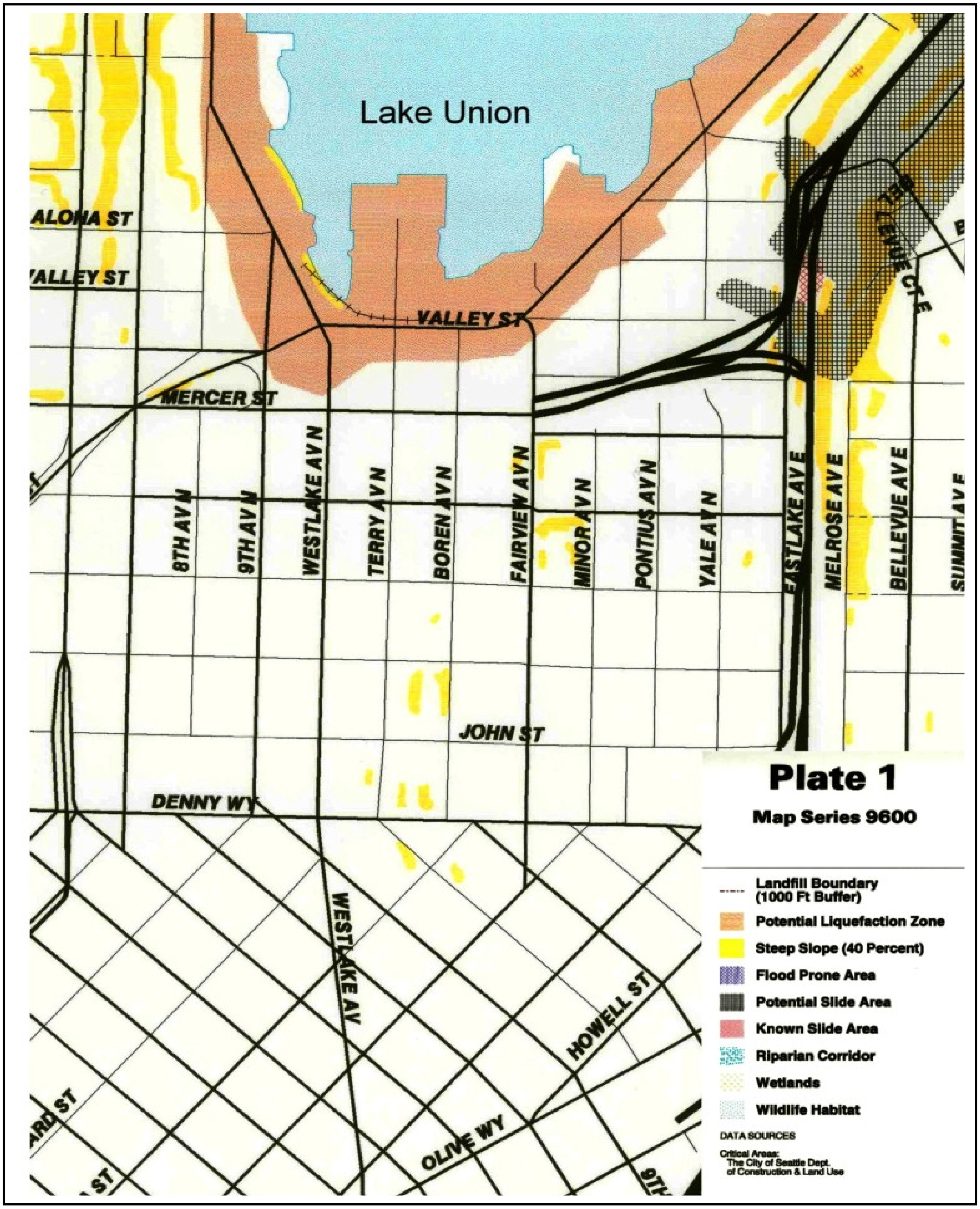
4.3.4 Fairview Avenue North

Subsurface soils along Fairview Avenue North generally consist of fill overlying glacial deposits. The available information indicates that fill is not present in some locations along Fairview Avenue. It appears that north of the centerline, the fill thickness increases significantly toward the lake. This is most likely associated with the development of the lake shore properties. The fill generally consists of loose to medium-dense sands. Wood chips, bark, and other organics have been observed in the fill.

4.4 City of Seattle Sensitive Areas

As part of the project site investigation, the available sensitive areas maps published by the City of Seattle were reviewed. Theses maps delineate environmentally sensitive (critical) areas within the City. These areas include areas at high risk of landslide, liquefaction, flood and erosion hazards.

This review of sensitive areas maps indicates that a portion of the project site is located within an area delineated as a liquefaction hazard. This liquefaction hazard area is located along Valley Street, Fairview Avenue, and Westlake Avenue North between Valley and Mercer streets, as shown in Figure 4-2.



Source: City of Seattle Department of Construction and Land Use (DCLU)

Figure 4-2: Sensitive Areas Map

4.5 Soft Ground Areas

Areas underlain by compressible fine-grained or organic soils may be considered soft ground areas. Units of compressible soils underlie the project area north of Harrison Street between Westlake Avenue North and Fairview Avenue North. These soils include very soft to medium-stiff silts, organic silts, and units of peat and wood chips.

4.6 Seismic Setting

Seismicity in the Puget Sound area is primarily driven by the Cascadia Subduction Zone, which is the zone where the westward advancing North American Plate is overriding the subducting Juan de Fuca Plate. Three potential seismic source zones are generally acknowledged for the Puget Sound area:

- Shallow crustal earthquakes associated with known and/or unknown faults;
- Cascadia Subduction Zone plate interface earthquakes, which occur along the boundary located between the Juan de Fuca and North American tectonic plates; and
- Cascadia Subduction Zone intraplate earthquakes, which occur within the subducting Juan de Fuca Plate.

The regional seismic source zones are discussed in the following sections. A schematic of these source zones is shown in Figure 4-3.

4.6.1 Shallow Crustal Source Zones

Shallow crustal earthquakes occur within the North American Plate to depths of up to 15 miles. Shallow earthquakes in the Puget Sound region are expected to have durations ranging up to 60 seconds. Four magnitude 7 or greater earthquakes are known to have occurred in the last 1,100 years in the Cascadia region. Two of these occurred on Vancouver Island and two in Western Washington.

The largest historic earthquake in Western Washington occurred in 1872 in the North Cascades and is estimated to have had a magnitude of 7.4. This earthquake is believed to have occurred at a depth of less than 10 miles. The other Western Washington earthquake with a 7+ magnitude occurred on the Seattle Fault approximately 1,100 years ago.

The most significant fault within the Puget Sound Lowland is the Seattle Fault Zone. The Seattle Fault Zone is a 4- to 7-kilometer-wide fault zone consisting of three or more thrust faults that roughly trend east-west. The Seattle Fault Zone extends approximately 77 kilometers from Hood Canal in the west to the Cascade foothills in the east. Researchers have estimated the slip rate of the Seattle Fault Zone to be between 0.2 to 1.0 mm per year. Researchers estimate that the last large earthquake to occur within the Seattle Fault Zone was approximately 1,100 years ago. Since the regional seismic network became operational in 1970, the two largest earthquakes associated with this fault zone had magnitudes of 5.0 and 4.9. Relatively little is known at this time concerning the magnitude or recurrence intervals for crustal earthquakes associated with the Seattle Fault Zone. The Seattle Fault Zone is characterized by researchers as being capable of generating earthquakes of magnitude 7.7.

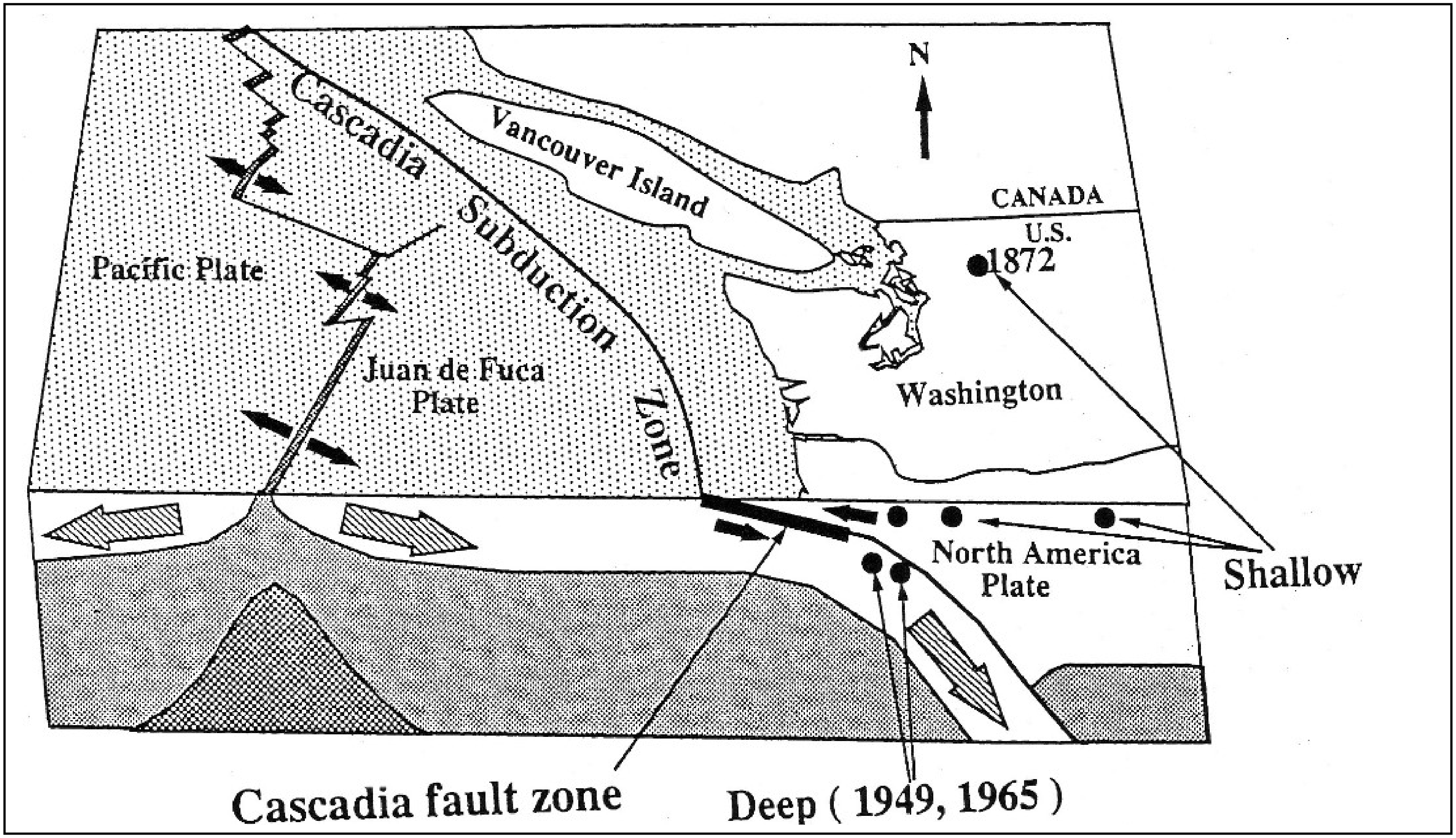


Figure 4-3: Regional Tectonic Setting

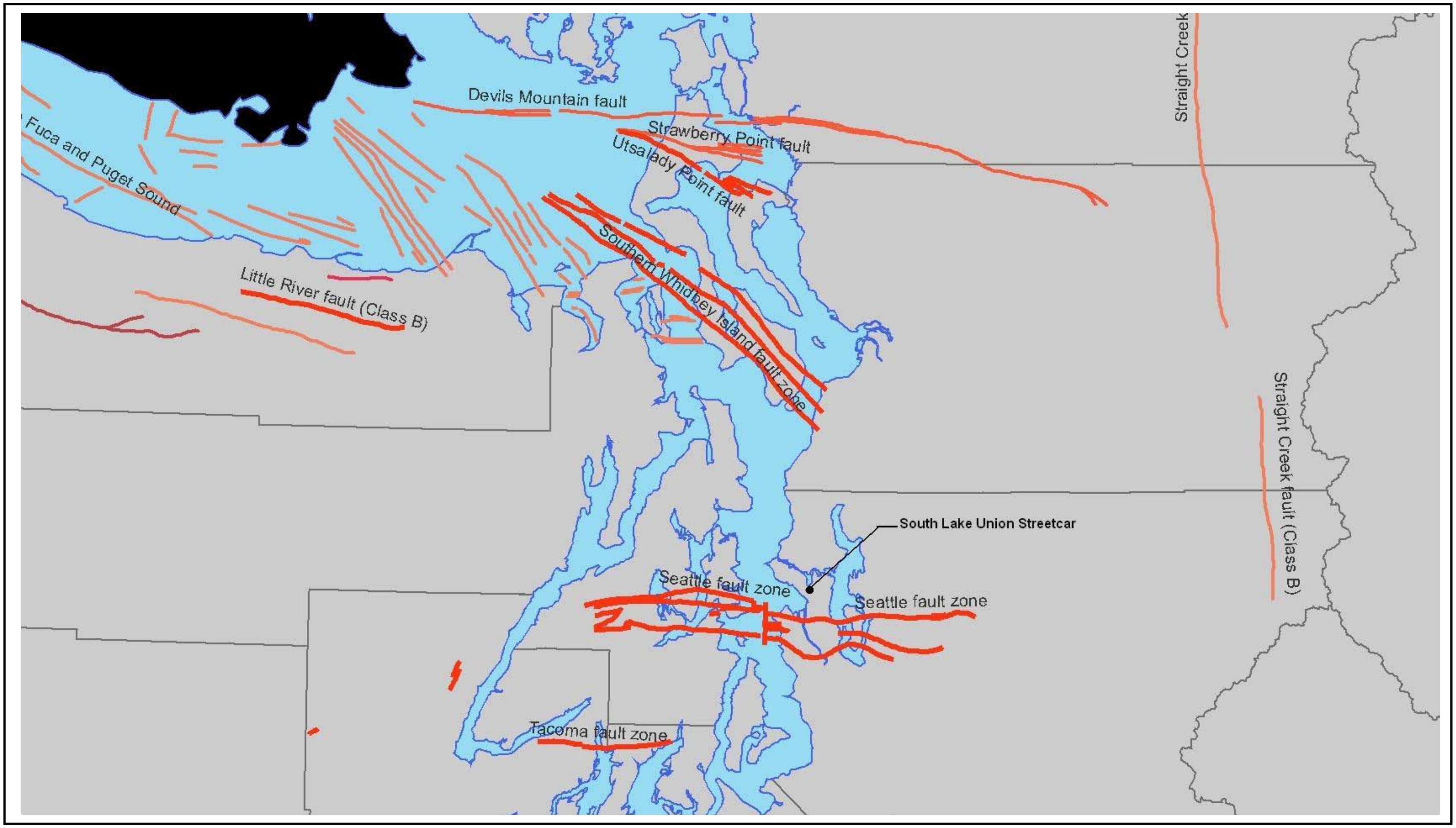


Figure 4-4: Quaternary Faults in the Puget Sound Region

4.6.2 Plate Interface Source Zones

Interface earthquakes occur on the boundary between the Juan de Fuca and North American tectonic plates. The Cascadia Subduction Zone extends from Vancouver Island to Northern California. Interface earthquakes on the Cascadia Subduction Zone are anticipated to have durations ranging up to four minutes.

Evidence of the occurrence of large (magnitude 8 to 9+) earthquakes occurring on the Cascadia Subduction Zone has recently been discovered. The last large interface earthquake is believed to have occurred in the year 1700. It is estimated that the recurrence interval for interface earthquakes on the Cascadia Subduction Zone is about 400 to 600 years, but the interval between earthquakes appears irregular.

4.6.3 Intraplate Source Zones

Cascadia Subduction Zone intraplate earthquakes occur within the subducting Juan de Fuca Plate at depths of 30 to 40 miles within the Puget Sound area. Intraplate earthquakes are expected to have durations ranging up to 30 seconds and magnitudes ranging up to 7.5. The Olympia 1949 (magnitude 7.1), Seattle 1965 (magnitude 6.5), and Nisqually 2001 (magnitude 6.8) earthquakes were intraplate earthquakes. Other earthquakes considered to be intraplate events occurred in 1882, 1909 and 1939.

4.7 Seismic Hazards

4.7.1 Ground Shaking/Design Earthquake Level

The key seismic design parameters are the peak acceleration and the magnitude of the earthquake. In general, a design earthquake is chosen based on a probability of exceedance (the probability that the design earthquake will be exceeded over a given time period). The design earthquake event for this project was determined by performing a seismic hazard deaggregation for all of the known seismic sources in the region.

For this study, a design earthquake associated with a probability of exceedance of 2 percent in a 50-year period was evaluated following IBC 2003 guidelines. An earthquake with a 2 percent probability of exceedance corresponds to an earthquake recurrence interval of 2500 years. The design earthquake event corresponding to this recurrence interval consists of an earthquake with a Richter magnitude of 7.0 and a peak horizontal ground acceleration of approximately 0.62g. The predominant hazard source for this event originates from the Seattle Fault Zone.

The peak horizontal ground acceleration corresponds to a IBC site class D soil profile which may not be applicable to all soil conditions within the project area. In order to more accurately determine the effect of damping and amplification, one or more site-specific ground response analyses would have to be completed.

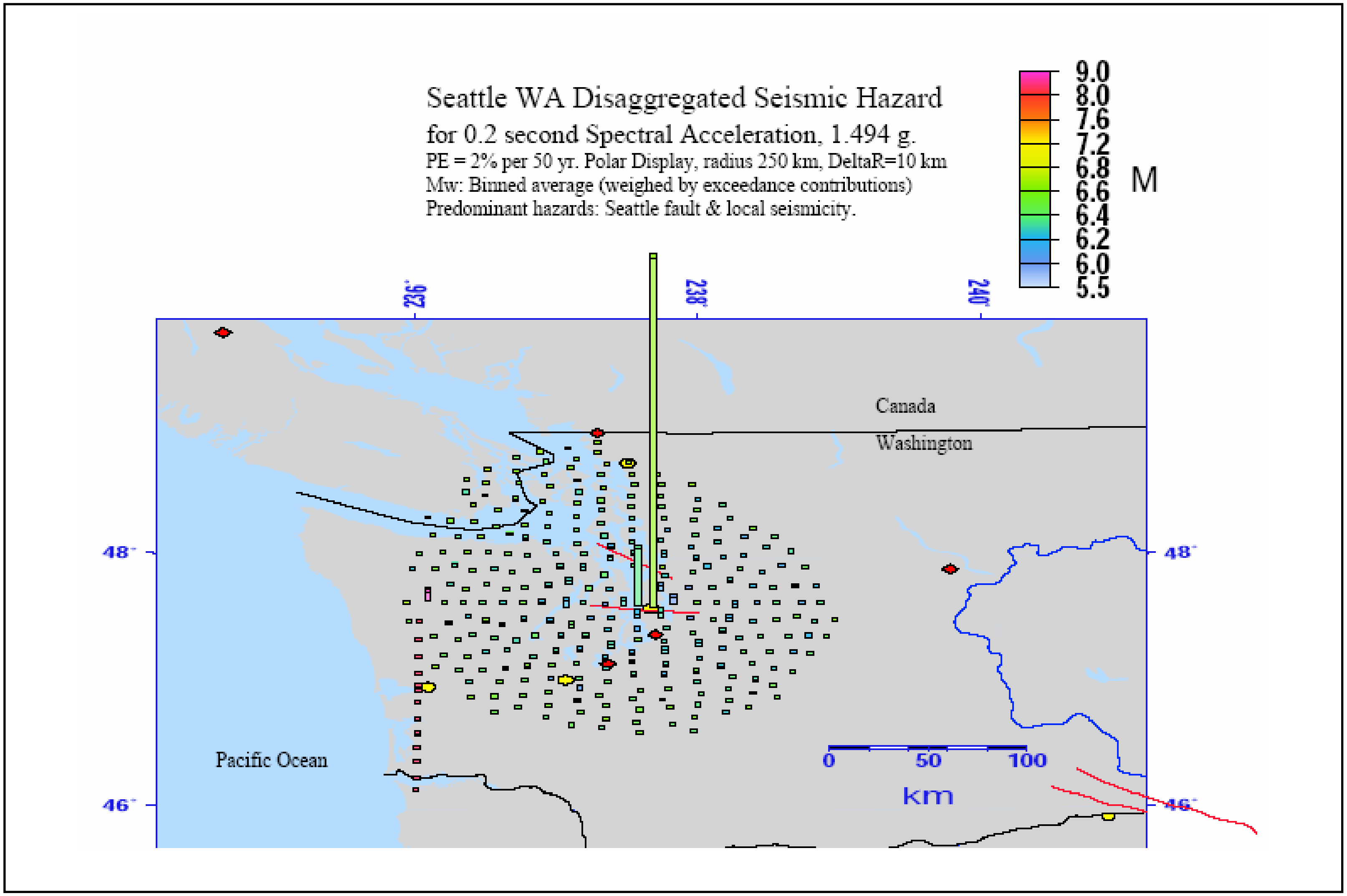


Figure 4-5: USGS Geographic Seismic Deaggregation

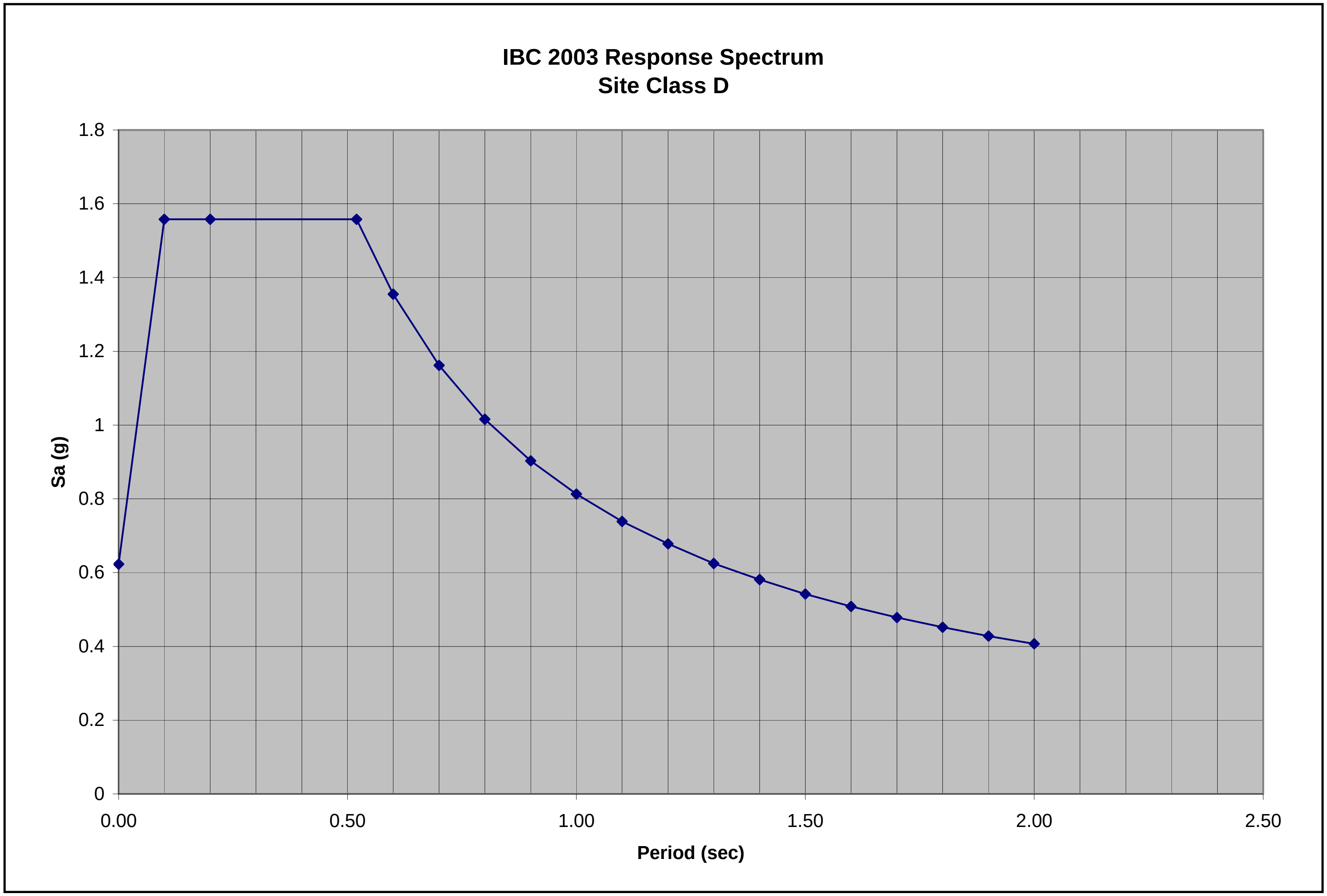


Figure 4-6: IBC 2003 Response Spectrum

4.7.2 Liquefaction Potential

Liquefaction is a phenomenon where soils experience a rapid loss of internal strength as a consequence of strong ground shaking. Ground settlement, lateral spreading and/or sand boils may result from soil liquefaction. Structures supported on liquefied soils could suffer foundation settlement or lateral movement that could cause structural damage.

Conditions favorable to liquefaction occur in loose to medium-dense, clean to moderately silty sand that is below the groundwater level. The evaluation of liquefaction potential is complex and depends on numerous site parameters including soil grain size, soil density, site geometry, static stresses and the magnitude and ground acceleration of the design earthquake.

Based on a review of the available subsurface information, the areas delineated as liquefaction hazard areas on the City of Seattle sensitive areas maps were determined to have a significant potential for liquefaction during a magnitude 7.0 design earthquake with a horizontal ground acceleration of 0.62g. The affected areas include Valley Street, Fairview Avenue, and Westlake Avenue North between Valley and Mercer streets. These areas are underlain by up to approximately 30 feet of fill consisting of loose to medium-dense granular soils. Liquefaction of these soils may result in ground settlement. Typically, this is manifested as hummocky features resulting from differential settlement along the ground surface. Ground loss due to sand boils is also likely in these materials. Although the engineering analysis is not yet complete, it appears that ground settlement could range from 2 to 8 inches during a design-level earthquake. Lateral spreading is discussed in the following section.

4.7.3 Lateral Spreading

Lateral spreading results when the shear strength of liquefied soil is incrementally exceeded by the inertial forces induced during an earthquake. The result of lateral spreading is typically horizontal movement of non-liquefied soils located above liquefied soils, in addition to movement of the liquefied soils themselves. Liquefaction-induced lateral spreading generally occurs on gently sloping sites or where sites are located near a free face such as a steep slope, channel, or shoreline. The effects of lateral spreading are typically located within 200 to 300 feet from a free face.

Based on the potential for liquefaction along the south shore of Lake Union, the potential for lateral spreading would be significant during a design-level earthquake for the few areas located within about 300 feet of the shoreline. These include the intersection of Westlake Avenue North and Valley Street, the intersection of Fairview Avenue North and Valley Street, and along Fairview Avenue North near Ward Street.

The extent of the lateral displacements associated with this process is not easily determined and have not been analyzed for this project. A more in-depth study would be required to quantify the lateral displacements caused by liquefaction-induced lateral spreading within the project area. However, based on observations following the Nisqually and Kobe earthquakes, it is estimated that lateral spreading may result in horizontal cracking of approximately 2 to 6 inches in the affected areas.

Chapter 5 Environmental Consequences

The proposed South Lake Union Streetcar Project could affect and be affected by the local geologic and soil conditions. This chapter discusses the operational and construction impacts associated with the project. Chapter 6 discusses the related mitigation alternatives.

5.1 Operation

5.1.1 Erosion

The proposed design would not increase the area of impervious surfaces to any significant degree, and therefore would not increase surface water runoff volumes. Proper design and construction practices, including the design, construction and maintenance of permanent erosion measures, would reduce the potential for erosion during the projected life of the project.

5.1.2 Earthwork

There would be no earthwork during operation and thus no impacts.

5.1.3 Ground Shaking

The proposed elements of the South Lake Union Streetcar project may be subject to significant ground shaking during the project's projected lifetime. The typical design earthquake event used for design is an event that has a 2 percent probability of exceedence over a 50-year period. This corresponds to an earthquake with a 2,500-year return interval. Ground shaking during an earthquake event of this magnitude can cause damage to structures, pavements, and utilities. This damage may impede rescue and relief efforts after the earthquake. The resulting damage may consist of ruptured/severed utilities, ground rupture, differential settlement of rails and structures, cracking of concrete and loss of structural integrity, and other effects.

Buildings would be designed for life safety and egress by designing to current building code standards (2003 IBC). For rails and pavements, the current standard of practice is not to mitigate the risk of seismic-induced damage but to repair the damage after an earthquake occurs. Life safety during ground shaking is typically not an issue for streetcar rails that are on-grade. However, the design for the rail foundations would incorporate methods to reduce this impact on the streetcar performance. This is discussed in Section 6.

5.1.4 Liquefaction

Based on a review of the available subsurface information, the areas delineated as liquefaction hazard areas on the City of Seattle sensitive areas maps do have a significant potential for liquefaction during a magnitude 7.0 design earthquake with a horizontal ground acceleration of 0.62g. The affected areas include Valley Street, Fairview Avenue, and Westlake Avenue North between Valley and Mercer Streets. These areas are underlain by up to approximately 30 feet of fill consisting of loose to medium-dense granular soils. Liquefaction occurs in saturated granular soils below the groundwater table. Within the liquefaction hazard area, the groundwater table ranges from 10 to 30 feet below the existing ground surface. The elevation of the groundwater table will fluctuate as a function of time, weather, the elevation of Lake Union, and other factors, which will in turn affect the thickness and extent of the potentially liquefiable soils.

The project elements potentially impacted by liquefaction include the track alignment along Valley Street and Fairview Avenue, and the proposed maintenance facility located at the southwest corner of Fairview Avenue and Valley Street. Impacts to the rail line would be limited to differential rail settlement and possible derailment of the streetcars that are in operation at the time of the earthquake. However, because all tracks would be at grade, this would not be considered to be a life safety issue. Power failure during an earthquake is also a potential hazard. This would result in stoppage of street car travel, but damage from a power failure would be negligible. Liquefaction also could occur in the area of the proposed streetcar maintenance facility.

5.1.5 Lateral Spreading

Based on the potential for liquefaction along the south shore of Lake Union, lateral spreading could be significant in a few areas nearest the shoreline during a design-level earthquake. It is expected that the lateral spreading would be limited to a few locations where the alignment is within 200 to 300 feet of Lake Union. These areas include the alignment along Valley Street and Fairview Avenue and the proposed maintenance facility site.

The potential impacts due to lateral spreading are lateral displacements that could render the rail tracks unusable. The maintenance building is expected to be sufficiently far away from the shoreline to limit potential damage from lateral spreading to a small amount. The extent of the lateral displacements associated with this process has not been determined for this project. Based on experience with past earthquakes in similar conditions, it is estimated that lateral spreading in the affected areas may result in horizontal cracking of the pavement that is approximately 2 to 6 inches wide. Differential rail movement may also be within this same range where the rails are supported on conventional ties along Valley Street. This level of rail movement would stop streetcar travel but is repairable. Lateral spreading also could affect the proposed streetcar maintenance facility.

5.2 Construction

5.2.1 Erosion

Erosion is a process where the earth’s surface is worn away by mass wasting and movement by wind, water and/or ice. Vegetation and existing improvements serve to protect the underlying soils, effectively slowing the rate of erosion. The rate of erosion is often accelerated by human activities, especially during construction when the vegetation and existing improvements are cleared or removed. Underlying soils are then directly exposed to erosional processes. The process of erosion increases surface water runoff volumes and velocities. The increased runoff carries sediment downslope to low-gradient areas and receiving waters where the sediment is deposited. Turbid surface water runoff reduces the water quality of receiving waters and the resulting deposition can adversely affect aquatic habitat.

Potential sources or causes of erosion and sedimentation depend on construction methods, slope length and gradient, the amount of soil exposed and/or disturbed, soil type, construction sequencing, and weather. Effects of erosion during construction of the streetcar project will be mitigated through the use of Best Management Practices (BMPs) as required by City of Seattle Standard Specifications Section 1-07.15. Appropriate spill response measures would also be implemented to control any loss of fuel or oil by construction equipment.

5.2.2 Earthwork

Limited earthwork would be required for construction of the railbed, maintenance facility, stormwater detention facilities, and other required structures. The earthwork activities anticipated during construction of the railbed and streetcar stations would include removal of existing pavements and preparation of the subgrade soils for proper support. This may require the over-excavation and replacement of unsuitable soils. Over-excavation depths may range from 2 to 3 feet. Construction of the maintenance facility would include demolition of existing structures, removal of existing pavements, temporary excavations, site grading, and potentially the installation of a deep foundation system. The stormwater detention structures will require temporary excavations up to 15 feet in depth. Traction power sub-stations, if placed underground, would also require excavation to similar depths as the stormwater detention structures.

Construction along the alignment would likely require the export of unsuitable soils and import of structural fill quality soils that would impact traffic flow, traffic safety, noise, dust, and mud. On-site earthwork activities will meet the requirements of City of Seattle Standard Specifications Sections 2-01 through 2-12. It will result in temporary cut slopes, noise, dust, vibration, soil disturbance and other impacts related to the operation of heavy equipment. The underground utility improvements including the relocation of existing utilities and construction of the detention structures will require temporary excavation support to protect existing improvements in the vicinity. These effects are typical of any pavement and/or utility construction project and would not be significant.

5.2.3 Liquefaction and Lateral Spreading

No mitigation of potential liquefaction hazards such as ground settlement and lateral spreading would be accomplished during construction. If such events do occur during construction, the plan would be to assess the damage, repair the damaged areas as required, and continue with construction.

Chapter 6 Mitigation

This chapter discusses mitigation techniques and alternatives for the potential environmental impacts associated with the proposed streetcar project.

6.1 Operation

6.1.1 Erosion

The proposed design includes a drainage control system that includes construction of up to five stormwater detention structures along the project alignment. The drainage control system will be designed in accordance with The City of Seattle Stormwater, Grading and Drainage Control Code (Seattle Municipal Code 22.800-22.808) and the following associated Director's Rules:

- DR 17-2000, Volume 1, Source Control Technical Requirements Manual
- DR 26-2000, Volume 3, Flow Control Technical Requirements Manual
- DR 27-2000, Volume 4, Stormwater Treatment Technical Requirements Manual

6.1.2 Ground Shaking

The proposed structures to be constructed as part of this project should be designed in accordance with applicable seismic codes for a design-level earthquake of magnitude 7.0 and a peak ground acceleration of 0.62g. Proper seismic design practices that follow current design codes (IBC 2003) are planned for this project, which will increase the likelihood of satisfactory performance during a design-level earthquake.

6.1.3 Liquefaction

The mitigation of liquefaction hazards would require extreme measures such as grouting or densifying the entire mass of soil in the potential affected areas. Because of the high expense of these measures, mitigation of liquefaction is typically not accomplished for low-risk projects such as this streetcar project. However, some mitigation is included in the planned design for the rail support. The rails would be embedded in a reinforced concrete slab for the majority of the alignment with only the short section of track along Valley Street supported on conventional railroad ties. Where the rails are embedded in concrete, the increased the stability and integrity of the rail foundations reduces the potential for differential settlement during an earthquake. Any structural damage that does occur during an earthquake would be repaired after the damage is properly assessed.

The mitigation of liquefaction hazards for buildings would include supporting settlement-sensitive structures on deep foundation systems such as driven or drilled piles and drilled shafts. The deep foundation elements are designed to transfer the structure's load to the non-liquefiable soils below the liquefiable zone.

6.1.4 Lateral Spreading

Because lateral spreading is a result of liquefaction, the mitigation of lateral spreading includes the same measures discussed in Section 6.1.3. A rigid pavement foundation would reduce lateral spread effects on the rails. A deep foundation system would reduce the risk of excessive settlements and lateral spreading of buildings.

6.2 Construction

6.2.1 Erosion

The stormwater pollution prevention plan will incorporate Temporary Erosion and Sediment Control (TESC) measures. Please refer to the South Lake Union Streetcar Project Stormwater Technical Report (Parsons Brinckerhoff, March 2005) for additional discussion of these measures.

6.2.2 Earthwork

On-site earthwork activities would meet the requirements of City of Seattle Standard Specifications Sections 2-01 through 2-12. Typical construction practices to control dust, noise, traffic disruptions would be used for this project. Dust control would be accomplished by wetting exposed soil surfaces and by regular street cleaning. The contractor would develop and implement a traffic control plan. Construction would be accomplished during normal daylight work hours and is not expected to contribute significantly to noise in the area. Spill response plans would be developed and implemented by the contractor. Temporary shoring will be utilized during utility relocation and installation to protect existing improvements in the vicinity. The soil and groundwater conditions where the deeper excavations will be located are favorable for common shoring techniques such as trench boxes and trench shields.