Section 3.1

Soils/Geology

This chapter describes the affected environment for soils/geology conditions and presents the analysis completed to compare and contrast the alternatives. Mitigation measures for identified impacts and any significant unavoidable adverse impacts are also summarized. The study area for Soils/Geology is defined as the area that could be directly or indirectly affected by the construction activities or land uses that result from implementation of the industrial and maritime strategy.

Impacts of the alternatives on soils/geology conditions are considered significant if they result in:

- Erosion that could not be contained on future development sites.
- Exposure of people to risk of injury or substantial damage to structures and infrastructure due to the creation or acceleration of a geologic hazard, such as slope failure, liquefaction, settlement.

3.1.1 Affected Environment

Data & Methods

The project team collected data from the following sources to support analysis of existing soils and geologic conditions and potential effects of the project alternatives:

- Seattle Department of Construction & Inspections GIS (Seattle, City of 2021)
- Geology of Seattle, Washington (Galster and Laprade 1991)
- Quaternary geology of Seattle (Troost et al. 2003)
- Geologic Map of Seattle (Troost et al. 2005)
- Geology of Seattle and the Seattle area, Washington (Troost and Booth 2008)

Current Policy & Regulatory Frameworks

Geologic hazard areas and historical landfills that can impact site development are defined in the City's environmentally critical areas code (Seattle Municipal Code (SMC) 25.09.012 and include:

- Seismic hazard areas (include liquefaction-prone areas, areas subject to ground shaking from seismic hazards addressed by Building and Construction Codes under Title 22, the Seattle Fault Zone, shorelines that could be impacted by Tsunamis, and waterbodies that could be impacted by a seiche [a standing wave oscillating in a body of water])
- Sleep slopes (areas with an incline of 40% or more within a vertical elevation change of at least 10 feet).
- Landslide-prone areas (areas with indications of past landslide activity, and areas with signs of potential landsliding).

- Liquefaction-prone areas (areas typically underlain by cohesionless soils of low density, usually in association with a shallow groundwater table, which lose substantial strength during earthquakes)
- Peat-settlement-prone areas (sites containing peat and organic soils that may settle when the area is developed, or the water table is lowered)
- Historical landfills (includes areas with buried solid waste identified by the Seattle-King County Health Department, and areas within 1,000 feet of methane-producing landfills [Seattle-King County Department of Public Health. 1984])
- Seattle Municipal Code 25.09.220 (Environmentally Critical Areas Code) indicates that development on historical landfills is subject to Seattle-King County Health Department requirements. The code also specifies methane barriers or appropriate ventilation per Title 22, Subtitle I, Building Code, and the Seattle King County Health Department regulations.
- The Title 10 King County Board of Health Solid Waste Regulation governs construction standards and methane controls on historical landfills. Authority is established under RCW Chapter 70.05 and Washington State Administrative Code WAC 173-304, Minimal Functional Standards for Solid Waste Handling, and WAC 173-351, Criteria for Municipal Solid Waste Landfills.

Current Conditions

Geology

Seattle is located within the southwestern portion of the Puget Sound Lowland physiographic region, a basin located between the Olympic Mountains to the west and the Cascade Range to the east (Troost et al., 2003; Troost and Booth, 2008). Seattle's geology has been shaped by multiple processes with movement of materials caused by glaciers, rivers, volcanoes, earthquakes, landslides, coastal deposition and erosion, and human activities. A high degree of geological complexity and variation is frequently encountered on development projects within Seattle and subsurface conditions often change significantly and unpredictably over short distances. These conditions cause challenges for project planners who must consider multiple geological concerns for a single project.

At least seven glaciations have impacted the Seattle area within the last 2.4 million years (Troost and Booth, 2008). Near-surface geology in Seattle is dominated by sediments associated with the advance and retreat of Vashon Glaciation, the most recent icesheet that reshaped our region's topography around 15,000 to 13,500 years ago (Galster and Laprade 1991). As this icesheet advanced and retreated over the Puget Sound Lowland, it left behind a complex mix of geologic materials including advance outwash deposits (silt, sand, and gravel); dense glacial till (a random mixture of clay, silt, sand, and gravel); and recessional outwash (stratified deposits of sand and gravel).

The Ballard Subarea includes areas with Vashon till, recessional outwash, and artificial fill overlying the till, recessional outwash, and alluvium deposits. The Interbay Dravus Subarea includes Pre-Fraser glacial deposits of firm interbedded sand, gravel, and silt on the north; alluvium deposits along the ship canal on the northeast, and large areas of artificial fill overlying tideflat deposits in the central part of the subarea. The Interbay Smith Cove Subarea is dominated almost entirely by artificial fill overlying tideflat deposits, with very small areas of Vashon till, recessional outwash, or other geologic units. The SODO/Stadium Subarea is similarly dominated by artificial fill overlying tideflat deposits, peat, and alluvium. The Georgetown/South Park Subarea is dominated by artificial fill overlying alluvium deposits, including younger alluvium containing peat lenses.

All of the subareas contain areas dominated by or with some history of artificial fill. These areas tend to contain alluvial or sandy soil conditions that could be subject to greater movement and/or liquefaction during major earthquake events.

Geologic Hazards or Limitations

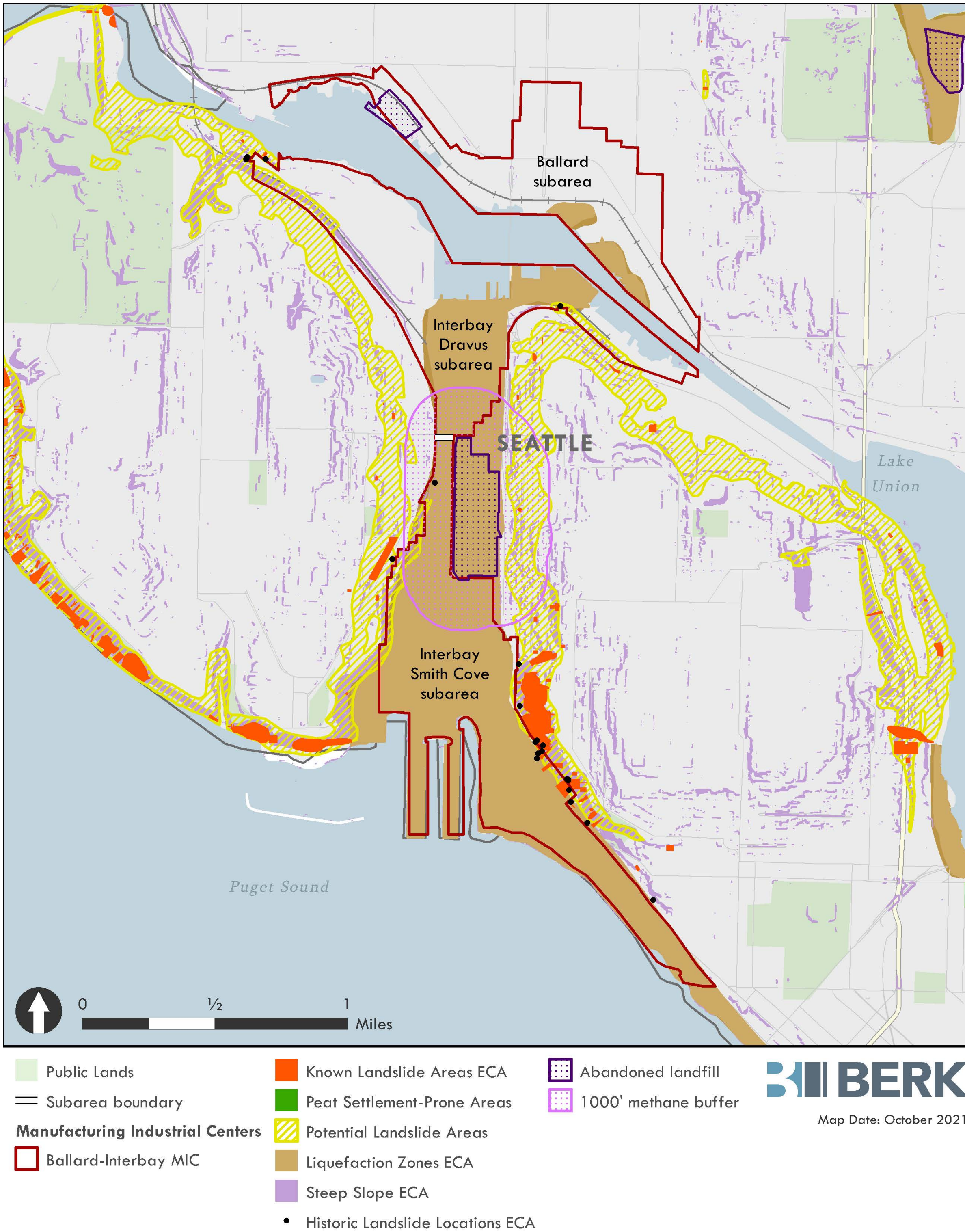
Geologic hazards defined under **Current Policy & Regulatory Frameworks** above are found in each of the subareas as summarized in **Exhibit 3.1-1**. Maps of the BINMIC and Greater Duwamish MIC and geologic hazards are shown in **Exhibit 3.1-2** and **Exhibit 3.1-3**. Descriptions of the hazards follow the table and maps.

Exhibit 3.1-1 Summary of Geologic Hazards Mapped in the BINMIC and Greater Duwamish MIC by Subarea

Subarea	Geologic Hazards or Limitations
Ballard	▪ Short steep slope area along Shilshole Avenue NW ▪ Known areas of historical artificial fill ▪ A small liquefaction-prone area south of Leary Way NW ▪ One historical landfill located just south of Shilshole Avenue NW (no methane buffer)
Interbay Dravus	▪ Several steep slopes and landslide-prone-areas along the east and west edges of the study area ▪ Known areas of historical artificial fill ▪ Nearly all of the study area is prone to liquefaction ▪ The Interbay Landfill located adjacent to the MIC at Interbay Golf Course, with 1,000-foot methane buffer extending into the MIC
Interbay Smith Cove	▪ Several steep slopes and landslide-prone-areas along the east and west edges of the study area ▪ Known areas of historical artificial fill ▪ Nearly all of the study area is prone to liquefaction ▪ The Interbay Landfill located adjacent to the MIC at Interbay Golf Course, with 1,000-foot methane buffer extending into the MIC
SODO/Stadium	▪ A few steep slopes along the west side of Harbor Island ▪ Known areas of historical artificial fill ▪ Nearly all of the study area is prone to liquefaction ▪ Two historical landfills: the West Seattle Landfill along Harbor Avenue SW (with 1,000-foot methane buffer), and a second unnamed landfill that straddles 6th Avenue South.
Georgetown/ South Park	▪ Several steep slopes and landslide-prone areas along the east and west edges of the study area ▪ Known areas of historical artificial fill ▪ Nearly all of the study area is prone to liquefaction ▪ One peat-settlement-prone area near the far southeast corner, just west of State Route 99 ▪ The South Park Landfill located south of the South Transfer Station with 1,000-foot methane buffer

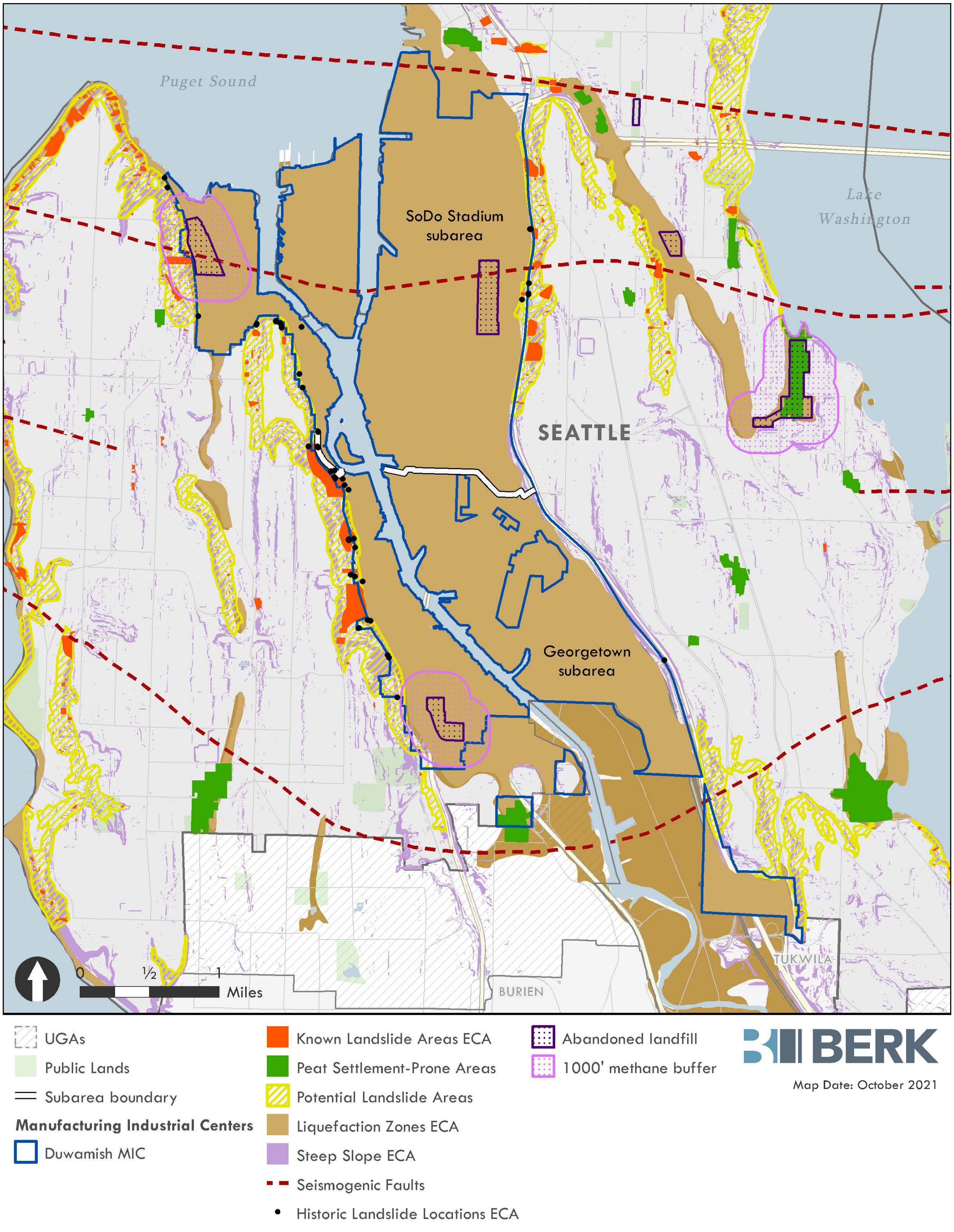
Source: Herrera, 2021.

Exhibit 3.1-2 Geologic Hazards Mapped in the BINMIC



Source: Seattle, City of 2021.

Exhibit 3.1-3 Geologic Hazards Mapped in the Greater Duwamish MIC



Source: Seattle, City of 2021.

Seismic Hazards

Seismic hazards exist within the study area. Seattle and the surrounding region are located in a seismically active region and Seattle sits atop the Seattle Fault Zone (SFZ), a major east-west trending fault zone (WDNR 2020a; USGS 2014). The SFZ consists of a series of closely spaced east-west faults with the exact locations unknown because few clear surface features are visible. The SFZ runs roughly parallel to Interstate 90 from southern Bainbridge Island, through south Seattle, across Lake Washington, and into the Bellevue area and beyond (**Exhibit 3.1-2** and **Exhibit 3.1-3**).

Earthquake recurrence in the Puget Lowland is also influenced by the Cascadia Subduction Zone (CSZ), where the ocean crust off the Pacific Coast is sinking beneath the North American continental plate approximately 70–100 miles off the shoreline. The CSZ has four segments, with the Juan de Fuca plate off the coasts of Washington and Oregon being the segment located closest to CHRLF. The magnitude of an earthquake located along the CSZ varies depending on how many sections of the plate boundary fault are involved, the depth and location of the earthquake epicenter, and the amount of seismic displacement (Rogers 1988; WGCEP 2003).

Steep Slopes

Steep slopes are mapped in several places along the east and west edges of the Interbay Dravus and Interbay Smith Cove subareas (i.e., along the edges of Southeast Magnolia, North Queen Anne, and West Queen Anne). Steep slopes are mapped only in a few small areas in the Ballard Subarea along Shilshole Avenue NW. A few steep slopes are mapped along the west side of Harbor Island in the SODO/Stadium Subarea, and several steep slopes are mapped along the east and west edges of the Georgetown/South Park Subarea above Airport Way South and West Marginal Way, respectively.

Landslide-Prone-Areas

Landslide-prone-areas overlap closely with the steep slope areas described above except for Harbor Island, but they are more extensive in the north-south extents where they present hazards to development.

Liquefaction-Prone Areas

Mapped liquefaction-prone areas include a small portion of the Ballard Subarea south of Leary Way NW, and nearly all of the Interbay Dravus, Interbay Smith Cove, SODO/Stadium, and Georgetown/South Park subareas.

Peat-Settlement-Prone Areas

Only one peat-settlement-prone area is mapped near the far southeast corner of the Georgetown/South Park Subarea, just west of State Route 99.

Historical Landfills

Five historical landfills are mapped within or directly adjacent to the subareas. An unnamed landfill is located in the Ballard Subarea just south of Shilshole Avenue NW and does not include a 1,000-foot methane buffer. The Interbay Landfill is located beneath Interbay Golf Course and includes a 1,000-foot methane buffer that extends into the Interbay Dravus and Interbay Smith Cove subareas. The West Seattle Landfill and an unnamed landfill are located in the SODO/Stadium Subarea along Harbor Avenue SW and straddling 6th Avenue South, respectively. The West Seattle Landfill has a 1,000-foot methane buffer, while the unnamed landfill beneath 6th Avenue South does not. And finally, the South Park Landfill is located along West Marginal Way and 5th Avenue South in the Georgetown/South Park Subarea.

The methane buffer is meant to allow for methane gas monitoring/mitigation. Landfills and other areas containing solid waste, refuse, or artificial fill soils, or lands substantially modified by humans can be challenging to develop due to poor or unpredictable soil characteristics. The construction potential of artificial fill areas depends on construction techniques and material type of the fill. Fill material unsuitable for construction may need to be removed or remediated to prevent problems such as settlement or expansion. Landfills may be unable to support the weight of buildings or structures and methane mitigation and monitoring may be required on and within 1,000 feet of landfills.

3.1.2 Impacts

Impacts Common to All Alternatives

None of the alternatives would accelerate or create geologic hazards; future development would need to be designed to respond to potential hazards consistent with adopted building codes to reduce risk of damage or injury. The study area is located within the Puget Sound Region, an area susceptible to moderately high seismic activity. During a seismic event, the study area might be subjected to high-level ground motions. Areas with steep slopes might experience seismic slope stability problems.

Portions of the Ballard and Interbay Dravus subareas, and all of the Interbay Smith Cove, SODO/Stadium and Georgetown/South Park subareas are susceptible to liquefaction. During an earthquake, vertical and lateral displacements of structures, embankments, and paved areas might occur due to seismic liquefaction hazard. The liquefaction potential of mapped liquefaction hazard areas would be confirmed during the design stage of proposed development, regardless of the alternative.

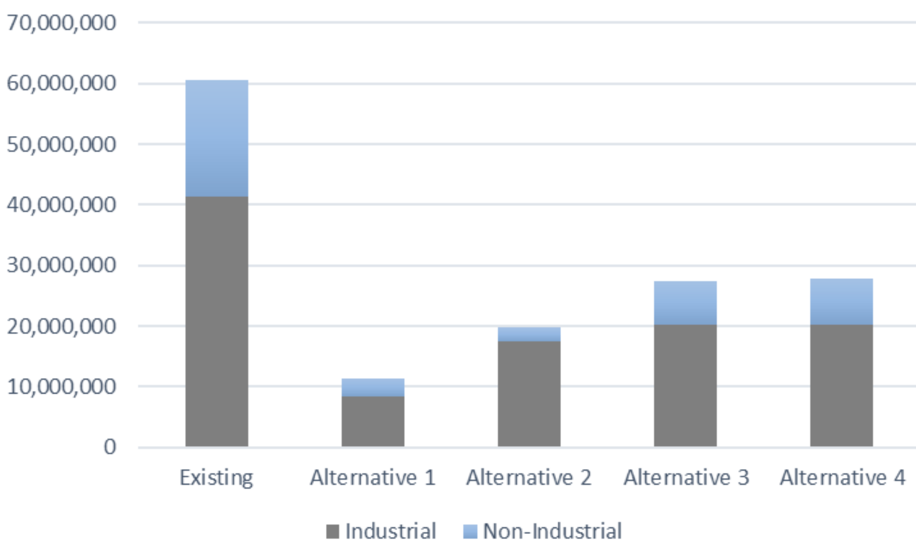
Development on or adjacent to any of the five historical landfills located within the study areas would require special planning and design. This could include installing methane barriers or appropriate ventilation per Title 22 of the Seattle Municipal Code 25.09.220 and the Seattle King County Health Department regulations. In addition, geotechnical studies would be completed to inform the design of structures and account for poor or unpredictable soil characteristics that could cause settling. These structural features can include the use of pile-supported or floating foundations, depending on the building type.

A peat settlement-prone area in the southwest portion of the Georgetown/South Park Subarea could limit the possibility of development and maintenance of existing structures with any of the alternatives. In this area, compressible soils might need to be excavated and replaced, or planned structures, embankments, and pathways might need to be supported on deep foundations.

All alternatives would allow development that could disturb soils, but erosion would be minimized using erosion control measures per suggested BMPs prescribed in Construction Stormwater Pollution Prevention Plans prepared for each development project.

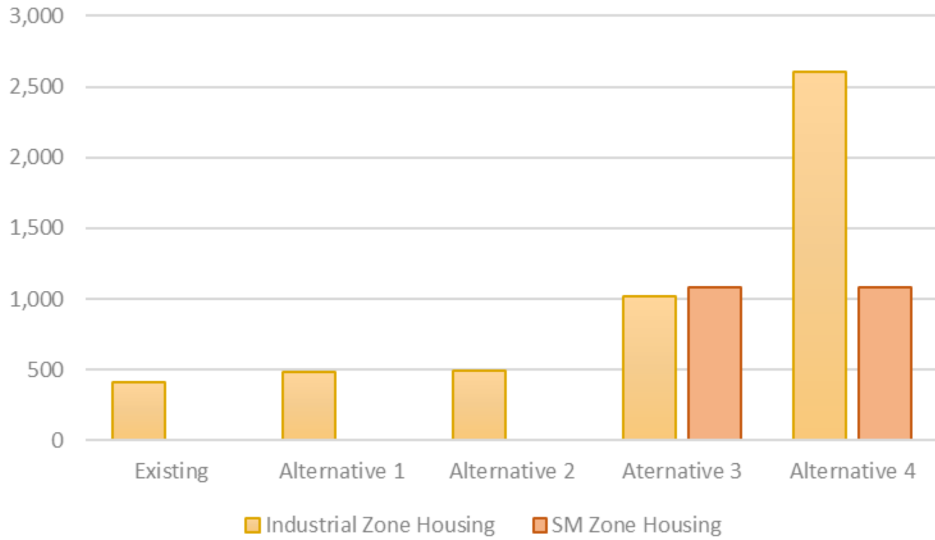
Alternative 1 would allow the least new jobs and housing and Alternative 4 the most in each subarea and across the whole subarea. See **Exhibit 3.1-4** and **Exhibit 3.1-5**.

Exhibit 3.1-4 Existing and Net Employment Building Space by Alternative



Note: Existing based on Assessor Records. Alternatives assume 700 square feet per industrial employee and 250 square feet per non-industrial employee similar to buildable lands assumptions.
Source: City of Seattle, 2021; BERK, 2021.

Exhibit 3.1-5 Total Housing in Study Area by Alternative



Source: City of Seattle, 2021; BERK, 2021.

Ballard

The Ballard Subarea would have the lowest growth under the Alternative 1 No Action and greatest under Alternative 4. This subarea has a small area prone to liquefaction and an historical landfill. The risk of erosion that could not be contained, or risk of damage to structures or injury from landslides, settlement, or seismic events is considered significant but avoidable with mitigation.

Interbay Dravus

The Interbay Dravus Subarea would have the lowest growth under Alternative 1 No Action and the most under Alternative 4. Approximately half of this subarea is prone to liquefaction and there are two areas with steep slopes and one area with potential landslide hazards. The southern portion of this subarea also lies within the 1,000-foot methane buffer of the Interbay Landfill. The risk of erosion that could not be contained, or risk of damage to structures or injury from landslides, settlement, or seismic events is considered significant but avoidable with mitigation.

Interbay Smith Cove

The Interbay Smith Cove Subarea would have the lowest growth under Alternative 1 No Action and the most under Alternative 4. All of this subarea is prone to liquefaction and potential landslide areas are located along the east and west edges. The Interbay Landfill and a large portion of the associated 1,000-foot methane buffer is located in the northern part of this subarea. The risk of erosion that could not be contained, or risk of damage to structures or injury from landslides, settlement, or seismic events is considered significant but avoidable with mitigation.

SODO/Stadium

The SODO/Stadium Subarea would have the lowest growth under Alternative 1 No Action and the most under Alternative 4. All of this subarea is prone to liquefaction and both known and potential landslide areas are located along the east and west edges. Two landfills are located within this subarea; the West Seattle Landfill has a 1,000-foot methane buffer, while the unnamed landfill beneath 6th Avenue South does not. The risk of erosion that could not be contained, or risk of damage to structures or injury from landslides, settlement, or seismic events is considered significant but avoidable with mitigation.

Georgetown/South Park

The Georgetown/South Park Subarea would have the lowest growth under Alternative 1 and the greatest under Alternative 4. All of this subarea is prone to liquefaction. Known and potential landslide areas are located along the east and west edges, and steep slopes are located along the west edge. The South Park landfill with 1,000-foot methane buffer, and a peat settlement-prone area are both located within this subarea. The risk of erosion that could not be contained, or risk of damage to structures or injury from landslides, settlement, or seismic events is considered significant but avoidable with mitigation.

Equity & Environmental Justice Considerations

The population in the BINMIC portion of the study area are less disadvantaged than the population in the Greater Duwamish MIC which has the highest and middle disadvantage per the Seattle Racial and Social Equity Index. See **Exhibit 1.7-7**.

Under any of the Action Alternatives, the primary equity and environmental justice concern for the proposal would be if development on lands subject to geologic hazards carries the risk of injury or damage to structures due to seismic activity. Although the proposal would allow development at sites in areas prone to landslides, liquefaction, or similar geologic hazards, modern building codes mitigate the risk of injury or economic losses for vulnerable communities.

Under Alternative 1 No Action, humans and animals could potentially feel the greatest impacts from geologic hazards in all subareas due to potentially less redevelopment of aging buildings and infrastructure not built to modern building codes to withstand seismic events compared to Action Alternatives.

The Ballard Subarea is less susceptible to seismic impacts than other subareas given nature of the geology that includes deposits of Vashon till, recessional outwash, and artificial fill overlying the till, recessional outwash, and alluvium deposits. The other four subareas are more susceptible to seismic impacts such as liquefaction given the prevalence of large areas of artificial fill overlying tideflat deposits and alluvium deposits, including younger alluvium containing peat lenses.

The Action Alternatives would generally have positive long-term benefits. The greatest benefits would be associated with Alternative 4 because it would result in the most sites developed to international building code standards.

Impacts of Alternative 1 No Action

Under Alternative 1 No Action, there would be similar building forms as found today with gradual densification in parts of all subareas. A total of 8,330,000 square feet (SF) of industrial space and 2,900,000 SF of non-industrial space would be developed. Existing dwellings would increase slightly from 413 to 488, or 75 net new units.

Due to the least amount of planned growth and development under the Alternative 1 No Action, there would be the least amount of soil disturbance but also the least number of structures built to modern building codes. The risk of damage or injury would be less in new buildings developed to international building code standards, but fewer buildings would be constructed to the latest standards compared to alternatives 2, 3, and 4.

Impacts of Alternative 2

The impacts of Alternative 2 are similar to those described under Impacts Common to All Alternatives. The total square feet of industrial space developed within the subareas would more than double, from 8,330,000 SF under the No Action Alternative to 17,430,000 SF under Alternative 2; there would be less non-industrial space of 2,375,000 SF under Alternative 2 compared to 2,900,000 SF with Alternative 1 No Action. In addition, the total housing units would increase from 488 under Alternative 1 No Action to 493 under Alternative 2 (80 above existing units, 5 more than Alternative 1 No Action).

This would mean more workers in industrial spaces and slightly more residents living in housing in the subareas. However, there should be less risk of injury or structural damage from geologic hazards than Alternative 1 No Action because structures would be designed to minimize risks consistent with building and construction standards.

Compared to Alternative 1 No Action, Alternative 2 could create more cut material to be hauled due to taller buildings that might require deeper foundations and potential increase in underground parking needs due to larger buildings. Cut materials in the area are potentially contaminated which would require special handling, storage, transportation, and off-site hauling. The cut materials in the region are known to be moisture sensitive (meaning difficult to compact if they are allowed by become wet) and therefore if not contaminated, cut material should be kept covered to facilitate reuse.

All these impacts together are considered significant but avoidable with mitigation.

Impacts of Alternative 3

The impacts of Alternative 3 are similar to those described under Impacts Common to All Alternatives and under Impacts of Alternative 2. Zoning would change to allow more development of residential properties and non-industrial mixed-use properties. Another 2,870,000 SF of industrial space, 4,725,000 SF of non-industrial space above Alternative 2 (total new 20,300,000 SF industrial and 7,100,000 SF non-industrial).

As well, 2,101 housing units would be developed within the subareas (610 new caretakers' quarters/makers' studios and 1,078 new units in mixed-use in areas removed from the MIC).

This would mean more workers in industrial spaces and more residents living in housing, and more structures that could be exposed to geologic hazards than Alternative 1 No Action, but structures would be designed to minimize risks consistent with building and construction standards.

All these impacts together are considered significant but avoidable with mitigation.

Impacts of Alternative 4

The impacts of Alternative 4 are similar as those described above under Impacts Common to All Alternatives and under Impacts of Alternative 3. The total square footage of industrial space would decrease slightly compared to Alternative 3, but an additional 500,000 SF of non-industrial space is possible (total new 20,160,000 SF of industrial space and 7,600,000 SF of non-industrial space). Additionally, 3,273 new housing units would be developed within the subareas (2,195 new caretakers' quarters/makers' studios and 1,078 new units in mixed-use in areas removed from the MIC).

Under Alternative 4, the greatest level of development could be subject to geologic hazards, compared to Alternative 1 No Action, but structures would be designed to minimize risks consistent with building and construction standards.

All these impacts together are considered significant but avoidable with mitigation.

3.1.3 Mitigation Measures

Incorporated Plan Features

There are no incorporated plan features related to geology and soils.

Regulations and Commitments

Building and Construction Codes under Title 22 contains construction code standards, including the International Building Code, which ensure buildings are designed to meet seismic safety standards.

Seattle Municipal Code 25.09.220 (Environmentally Critical Areas Code) indicates that development on historical landfills is subject to Seattle-King County Health Department requirements. The code also specifies methane barriers or appropriate ventilation per Title 22, Subtitle I, Building Code, and the Seattle King County Health Department regulations.

The Title 10 King County Board of Health Solid Waste Regulation governs construction standards and methane controls on historical landfills. Authority is established under RCW Chapter 70.05 and Washington State Administrative Code WAC 173-304, Minimal Functional Standards for Solid Waste Handling, and WAC 173-351, Criteria for Municipal Solid Waste Landfills.

Other Potential Mitigation Measures

Geotechnical investigations are required as part of the design phase for new development, especially for those buildings with greater heights or in close proximity to artificially created slopes. Specific recommendations for liquefaction mitigation, subgrade preparation, roadway embankment, cut and fill, slope stability, foundation design, retaining structures, and dewatering measures would be prepared prior to construction. Appropriate waste sites for unsuitable excavated soils would be identified prior to construction.

Potential impacts of soil liquefaction could be mitigated by removing and replacing the loose materials with compacted fill materials, by densifying or reinforcing the in-situ soils, or by supporting the proposed facilities on deep foundations or piles. The need for liquefaction mitigation would be evaluated on a case-by-case basis for the individual structural elements potentially impacted.

Potential impacts of vapor intrusion from historical landfills within the study area would be investigated by performing site-specific vapor intrusion assessments and/or by installing passive or active methane mitigation systems in structures developed on historical landfills, or within the 1,000-foot methane buffer.

3.1.4 Significant Unavoidable Adverse Impacts

Development in the study area, as with most locations in Central Puget Sound, would expose population and structures to geologic hazards, and would disturb soils. These impacts can be mitigated to a less than significant level by designing development to the City’s adopted construction codes and applying any site-specific conditions (e.g., methane mitigation systems for buildings built near historical landfills) required by the City during permit review.