**Chapter 4**

# Worst-Case Earthquake Scenarios Assumed in the Impacts Analysis



**DRAFT SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT**

**Brightwater Regional Wastewater Treatment System**

# Chapter 4
# Worst-Case Earthquake Scenarios Assumed in the Impacts Analysis

Three earthquake scenarios are considered for analysis in this Supplemental EIS to address the possibility that an earthquake fault could rupture on the Route 9 site for the proposed Brightwater Treatment Plant. None of the three hypothetical scenarios is likely to occur during the design life of the Brightwater Treatment Plant. Nevertheless, each scenario was developed to allow consideration of the worst-case impacts that could result if an earthquake were, in fact, to damage treatment facilities.

This chapter describes those scenarios and the assumptions that served as the basis for analyzing resulting environmental impacts. The chapter also provides information about the performance of other treatment plants during past earthquakes and explains how King County would respond following an earthquake at the Brightwater Treatment Plant.

The worst possible environmental impacts that could result from damaged facilities and reasonable mitigation measures to address those impacts are discussed in Chapter 5. The assumed damage to facilities, resulting impacts, and reasonable mitigation measures are summarized in the Scenario Tables at the end of this document.

## 4.1 What Is Assumed About a “Worst-Case” Earthquake?

The three hypothetical worst-case scenarios, from the least unlikely to most unlikely to occur, are Scenarios A, B, and C:

- Scenario A assumes a ground surface rupture on Lineament 4 and very strong shaking on the site. The shaking would cause limited damage to treatment plant facilities.
- Scenario B assumes a ground surface rupture on Lineament X and very strong shaking on the site. The surface rupture and shaking would cause a break in the combined tunnel at the south end of the site and some limited damage to treatment plant facilities.
- Scenario C assumes a ground surface rupture on an unknown and hypothetical fault between Lineaments 4 and X on the site accompanied by very strong shaking. The surface rupture and shaking would cause extensive damage to portions of the new treatment plant facilities.

All of the hypothetical scenarios are very unlikely to occur during the design life of the Brightwater Treatment Plant. Of the three hypothetical scenarios considered, the least unlikely to occur would be Scenario A because researchers recently have determined that Lineament 4 at the north end of the Route 9 site is an active fault. Scenario B is considered to be less likely to occur than Scenario A because there is no direct evidence indicating that Lineament X at the south end of the site is an active fault. Scenario C is considered to be the most unlikely scenario to occur because there is no evidence similar to that for Lineament 4 or Lineament X indicating that any fault exists on the Route 9 site between these lineaments. See Chapter 2 for a discussion of the Southern Whidbey Island Fault (SWIF), Lineament 4, and Lineament X.

Results of recent trenching work suggest that, on average, movement along Lineament 4 at the north end of the Route 9 site could occur once every 9,000 to 4,000 years. Over the 50-year design life of the treatment plant, the probability of occurrence of fault rupture on Lineament 4 is about 1 percent or less. While no similar statistics can be provided for the probability of occurrence of fault rupture on Lineament X (Scenario B) or on a hypothetical and unknown fault between Lineaments 4 and X (Scenario C), it would be reasonable to assume that movement on Lineament X is less likely to occur than movement on Lineament 4 and that the probability of movement on a hypothetical unknown fault between Lineaments 4 and X is an order of magnitude lower. The best available information about the SWIF system also indicates that a simultaneous occurrence of surface ruptures in Scenarios A, B, and C would produce the same level of strong shaking at the site as a surface rupture in any one of the scenarios, but the amount of surface rupture would be distributed among all fault traces so that the impact on any one trace probably would be diminished.

While there is no direct evidence of a fault on Lineament X on the Route 9 site and no information about a hypothetical fault on the site between Lineaments 4 and X, the worst-case analysis of environmental impacts in Chapter 5 of this Supplemental EIS assumes that these faults do exist and that any of the three scenarios could occur. The analysis of impacts also assumes that if a rupture were to occur as described below for Scenarios B and C, the amount of deformation, ground warping, or faulting would be similar to that in Scenario A, which is based on interpretations of the trenching studies on Lineament 4 at the north end of the site.

The hypothetical worst-case scenarios also assume that maximum flow conditions (very heavy rainfall) would be occurring at the same time that an earthquake occurred, which would be very unlikely to happen. The combination of unlikely earthquake occurrence and infrequent maximum flow conditions means that the actual risk of occurrence at the levels evaluated in this Supplemental EIS is extremely remote. Simply stated, this Supplemental EIS makes the most conservative assumptions that reasonably could be made about the type and potential volume of liquids that could be released during an earthquake.

### 4.1.1 Scenario A – Surface Rupture on Lineament 4 Resulting in Very Strong Ground Shaking on the Site

Under hypothetical worst-case Scenario A, a surface rupture would occur on Lineament 4 at the north end of the Route 9 site and would cause displacement of 3 to 6 feet, both horizontally and vertically over a deformation zone approximately 30 to 50 feet wide. The amount of ground displacement outside the 30 to 50-foot wide zone would be negligible, thus the ground surface would not rupture beneath any newly constructed treatment plant structures or beneath the combined conveyance tunnel located at the south end of the site. This is because a significant buffer would exist between the zone of deformation associated with Lineament 4 and the newly constructed wastewater treatment facilities. However, the existing StockPot Building at the north end of the site would be damaged from surface rupture under the northern portion of the building and from the ground shaking.

It was assumed that the rupture also would cause very strong ground shaking throughout the rest of the treatment plant site. The level of ground shaking that could occur on the Route 9 site if an earthquake were to occur on the SWIF was determined in the probabilistic seismic hazard analysis (PSHA) completed for the Brightwater project (see Chapter 3 and Appendix B). In order to develop Scenario A, King County used the PSHA to also estimate the level of ground shaking that would be associated specifically with a rupture on Lineament 4. The estimate was made taking into consideration the fault length, its location relative to the Route 9 site, and the extent of vertical and horizontal ground displacement that could be expected from a fault rupture. The level of ground shaking that would be associated with a rupture on Lineament 4 was found to be comparable to the level of ground shaking estimated in the PSHA and to the level that is being used for design of the proposed treatment plant facilities (see Chapter 3).

The level of ground shaking from a rupture on Lineament 4 would be great—more than the shaking experienced in any large earthquake reported in the Puget Sound area in the past 160 years. However, Brightwater facilities are being designed to withstand this level of shaking without collapse or damage that could not be repaired (see Chapter 3). To put the expected level of ground shaking into perspective, it is comparable to the level assumed in the design of new hospitals, schools, bridges, and other critical structures in the Puget Sound area, and it exceeds the level used to design similar structures as recently as 10 years ago. While damage would be repairable under this scenario, it may be more economical to replace a damaged piece of equipment or portion of a building than to repair it. A decision on repair or replacement would be made after evaluation of the nature of damage and the cost of repairs.

### 4.1.2 Scenario B – Surface Rupture on Lineament X Resulting in a Break in the Combined Tunnel and Very Strong Ground Shaking on the Site

Under hypothetical worst-case Scenario B, a surface rupture would occur on Lineament X at the south end of the Route 9 site. Not withstanding the absence of any direct evidence that Lineament X is an active fault, this analysis makes the very conservative worst-case assumption that the amount of deformation, ground warping, or faulting that could occur in this scenario would be the same as it would be on Lineament 4 in Scenario A. That is, it would be 3 to 6 feet, both horizontally and vertically, and the deformation would be confined to a zone 30 to 50 feet wide. The ground deformation would occur around the combined conveyance tunnel on the treatment plant site and would cause stress in the tunnel and piping systems within the tunnel. Cracks and possibly breaks could occur in the tunnel and piping systems, and this worst-case analysis assumes that the tunnel does, in fact, break. It also is assumed that the rupture would cause strong ground shaking throughout the rest of the site at a level comparable to that in Scenario A.

### 4.1.3 Scenario C – Surface Rupture Between Lineaments 4 and X Resulting in Damage to Treatment Facilities and Very Strong Ground Shaking on the Site

Under hypothetical worst-case Scenario C, a surface rupture would occur on an unknown and hypothetical fault beneath one of the proposed new treatment facilities between Lineaments 4 and X on the Route 9 site. The amount of deformation, ground warping, or faulting that could occur in this scenario is assumed to be the same as it would be on Lineament 4 in Scenario A. That is, the deformation would be 3 to 6 feet, both horizontally and vertically, in a zone 30 to 50 feet wide. The vertical and horizontal ground movement beneath a structure would result in major damage to treatment facilities located directly above the area of surface rupture. It also is assumed that the surface rupture would cause strong ground shaking throughout the rest of the site at a level comparable to that in Scenario A.

There is no information to suggest that a fault exists between Lineaments 4 and X. It is unknown where, if anywhere, in this area a surface rupture could occur; however, the worst-case analysis assumes that a single fault does exist somewhere in this area and that the ground surface ruptures during an earthquake on the hypothetical fault. If this were to occur, the environmental impacts would vary depending on where on site the rupture occurred and which treatment facilities were affected.

## 4.2 What Is Assumed About Conditions at the Brightwater Treatment Plant Just Prior to a Major Earthquake?

The evaluation of environmental impacts in this Supplemental EIS assumes that just prior to an earthquake the plant is operating at 54 mgd average wet-weather flow (AWWF)—the full capacity after year 2040. (Treatment plants are rated for capacity based on AWWF. See the Glossary for a definition of AWWF.) It also assumes that all plant facilities, such as basins and tanks, are operating at full capacity and that no systems are off line and drained for maintenance or other reasons just prior to the earthquake. These assumptions result in the maximum possible volume of wastewater (treated and untreated) onsite within the facility when an earthquake occurs. However, the analysis of impacts in Chapter 5 considers the amount of storage available in the offsite system. The amount of storage may vary depending on weather conditions at the time of the earthquake; this, in turn, could affect the volume, location, and duration of any offsite overflows that would occur.

Flow to wastewater treatment plants typically increases over time as development occurs in the service area and customers are added to the system. The Brightwater Treatment Plant is designed for construction and operation in two phases: Phase 1 (initial phase) would provide an AWWF capacity of 36 mgd beginning in year 2010; Phase 2 (expansion phase) is expected to come online in year 2040 and increase the AWWF capacity to 54 mgd. The maximum design life of the plant is considered to be 50 years. After this period, a full upgrade or possible replacement of the plant would be expected; however, it is possible that only portions of the treatment plant would be upgraded or replaced, thus allowing the plant to remain operational for a longer period of time.

Although treatment plant capacity typically is expressed by AWWF, design and sizing of the plant are dictated by the maximum monthly flow and the amount of human waste and other organic waste in the wastewater stream that must be treated. As indicated in Table 4-1, the rate of flow to the treatment plant would vary from a minimum of 9 mgd during Phase 1 to a peak of 170 mgd during Phase 2.

### Table 4-1. Brightwater Treatment Plant Design Flows (mgd)

| Flow Condition | Phase 1 | Phase 2 |
|---|---|---|
| Minimum diurnal | 9 | 18 |
| Average dry weather | 27 | 40 |
| Average Wet Weather (AWWF) | 36 | 54 |
| Maximum monthly | 51 | 76 |
| Peak hourly | 130 | 170 |

In addition to increased flow due to growth in the Brightwater Service Area, flow would vary seasonally and would depend on weather conditions; there would be more flow during wet winter months than there would be during dry summer months. This is due to infiltration and inflow (I/I). (Infiltration refers to stormwater and groundwater that enter the wastewater system through cracked pipes and leaky joints. Inflow refers to stormwater that enters the system directly through manhole covers or through downspouts that have been improperly connected to the wastewater system.)

Three of the flow conditions in Table 4-1 are considered in the evaluation of impacts in Chapter 5 of this Supplemental EIS:

- **Average Dry-Weather Flow (April 1 through October 31).** The Puget Sound region is relatively dry during the summer months. Smaller amounts of I/I enter the collection system during this time than during the wet season, and therefore less flow is conveyed to the treatment plant for processing.
- **Maximum Monthly Flow (November 1 through March 31).** During the wet weather months in the Puget Sound region, increased rainfall and groundwater result in more I/I to the collection system; the increased flow is conveyed to the treatment plant for processing along with the wastewater. Maximum monthly flow refers to the maximum average daily flow projected to occur over a 30-day period.
- **Peak Hourly Flow (all year).** During a large rainstorm, large amounts of flow enter the collection system through I/I. Large storms are most common during the wet winter months, but they can occur at any time of year. The peak hourly flow condition is projected to have a 1-hour peak flow rate of 170 mgd.

Flow also varies during the day; the lowest flows occur during nighttime hours, and greater flows occur during morning and evening hours when there is more activity within homes. Thus, the flow rate to the treatment plant site when an earthquake occurred likely would be greater if the earthquake were to occur during morning or evening hours than the flow rate would be if an earthquake were to occur during the night.

Flow during an earthquake also would vary depending on whether the earthquake were to occur in the early years of treatment plant operation or whether it were to occur at buildout. Over the first 30 years of operation, flows to the treatment plant would be roughly two-thirds of those used for the evaluation of environmental impacts in Chapter 5 of this document (i.e., 36 mgd rather than 54 mgd). If an earthquake were to occur in the first 30 years of operation, there would be proportionally less volume of wastewater contained onsite and a lesser volume of potential releases from damaged facilities. Even when the plant is operating at 54 mgd, there would be times of the year when the average volume of wastewater in the system would be less than the maximum assumed. During these times, the volume of potential releases would be less than used in this analysis; however, this analysis makes the conservative assumption that all tanks are full year-round.

## 4.3 What Is Assumed About Availability of Regional Services Following a Major Earthquake on the Southern Whidbey Island Fault?

If any one of the three worst-case scenarios were to occur, the earthquake would damage facilities and services throughout the Puget Sound region. The availability or lack of facilities and services such as transportation systems, communications systems, and water supply resulting from this regional damage would affect the ability and time needed to repair any damaged facilities at the Brightwater Treatment Plant.

Following is a discussion of the potential impacts of Scenarios A, B, and C on regional services and the potential effect on the ability to repair and operate the proposed Brightwater Treatment Plant. The discussion relies in part on the results of a recent analysis of impacts to regional services if an earthquake were to occur on the Seattle Fault (EERI, in press).

### 4.3.1 Roads and Bridges

For all scenarios, the road system would be the limiting factor for delivery of offsite public services and recovery equipment and materials. Even if other public services survived the catastrophic earthquake or were quickly repaired, equipment, materials, and personnel would have to use the highway system to reach the Brightwater Treatment Plant site. Helicopters could be used to deliver some materials and personnel to the site, depending on their availability and the urgency of the situation.

Under any of the scenarios evaluated for the proposed Brightwater Treatment Plant site, seismic activity along the SWIF would likely cause damage to the regional transportation system (Figure 4-1). Because of the northwest trend of the fault strands, the at-grade portions of north-oriented routes, such as I-5, SR-99, SR-522, and SR-9, would likely be damaged as the result of grade changes and embankment failure and would experience at least one collapsed bridge span. Highway I-405 would not be subject to surface rupture along the SWIF, but bridges and slopes along the route could suffer damage due to very strong ground shaking. A potential for liquefaction also exists in some areas along SR-522 and SR-9; however, damage from liquefaction can normally be repaired within a short period of time.

The availability of heavy equipment, construction materials, spare parts, and recovery personnel needed for repairs at the treatment plant would be inhibited both because roads and bridges would be damaged and because heavy equipment, such as excavators, bulldozers, and cranes, and their operators would be needed for emergency life-saving activities and for repair of the transportation system. Once roads had been repaired or alternative travel routes had been developed to avoid damaged bridges and/or road segments, the needed equipment would be available for treatment plant repairs.

Significant disruption of the roadway network could last for many months. Alternative routes or helicopters, if they were available, could be used for delivery of repair equipment and materials. Alternative routes to the site could include southerly approaches along I-405, if operational, or a more likely approach would be along SR-522 between Woodinville and Seattle. Because SR-522 contains no large bridges and does not intersect the SWIF until it reaches the southern end of the Brightwater site, SR-522 would be a prime road access to the treatment plant.

Roadway transportation from the east along I-90 could possibly be routed to the site along East Lake Sammamish Parkway and then through the Sammamish River Valley to Woodinville.

### 4.3.2 Air Transportation

Under any of the scenarios, seismic activity along the SWIF could result in damage to Paine Field in Everett, limiting the importation of repair and replacement equipment from that location. However, SeaTac, Renton, and King County (Boeing Field) airports to the south would likely still be either functional because of their greater distance from the SWIF or quickly repaired because of the limited amount of damage. A potential for liquefaction exists at both King County and Renton airports; however, as discussed previously for roadways, damage from liquefaction can normally be repaired within a short period of time.

Because heavy equipment would need to be transported to the site, its delivery via ground transportation could be limited by the functioning of the roads and bridges between airports and the SR-9 site. If available, helicopters could deliver personnel and light equipment and materials to the site.

### 4.3.3 Ports and Ferries

The Port of Everett would likely sustain damage in a strong earthquake on the SWIF because of the port’s proximity to the fault; however, equipment imported by ship could be offloaded at the Ports of Seattle or Tacoma, approximately 18 and 38 miles south of the Route 9 site, respectively. Ground shaking from one of the three scenarios would be expected to cause only minor damage at the Port of Tacoma and some localized damage at the Port of Seattle because of the greater distance from the SWIF to these port facilities. Because equipment imported by ship would need to be transported to the site by truck, its delivery would be limited by the functioning of the roads and bridges between those ports and the Route 9 site, as described above.

The Washington State ferries at Mukilteo and Edmonds would likely sustain some damage and be out of service for a period of time. There would be little to no effect from this interruption of service on the recovery and operation of the wastewater treatment plant, other than hampering the transportation of personnel who may live on Puget Sound islands or on the Olympic Peninsula.

### 4.3.4 Railroads

Railroads are one of the major means for importation of heavy equipment and materials to the Greater Seattle area. The Union Pacific Railroad (UPRR) and the Burlington Northern Santa Fe Railroad (BNSF) both approach downtown Seattle from the south. Limited interruption of that portion of the route would be expected by an earthquake on the SWIF, because of the distance between downtown Seattle and the postulated earthquake source. However, a BNSF spur line that serves the Woodinville area is located less than 100 feet to the east of the Brightwater site. That spur line would likely sustain damage from the same earthquake that would damage the treatment plant, and it likely would not be operational for several days to weeks after the event.

In addition, the BNSF mainline between Everett and Seattle is located on a narrow embankment between the Puget Sound shoreline and steep, historically unstable slopes. This portion of the route is anticipated to be vulnerable to damage from an earthquake along the SWIF. It is estimated that this mainline could be out of service for about a week, and train transportation would be slow for about 2 months following an earthquake on the SWIF. Once repairs were made to the Port of Everett, equipment and materials could be offloaded in Everett if the rail yard were operational.

### 4.3.5 Electrical Service

It is estimated that 50 to 60 percent of the electrical system in the Puget Sound area could be out of service after a large earthquake, but most power could be restored within about 72 hours (EERI, in press). Electrical power would be provided to the Brightwater Treatment Plant by the Snohomish County Public Utility District (see Final EIS, Chapter 8, and the discussion later in this chapter). There would be some short-term loss of power if both of the power feeds to the plant site were out of service.

The power generators located on the plant site or portable units brought to the site would be operational or repairable within a short period of time to provide sufficient electricity to power the plant control system, life and safety features, and equipment required to provide limited treatment and discharge to Puget Sound. The availability of the portable generation equipment and the time required to repair the permanent electrical system would depend on the ability of electricians and repair materials to reach the treatment plant site on the road system.

Power at the influent pump station would not be affected by a power failure on the treatment plant site because primary power to the pump station is provided by another utility, Puget Sound Energy, which is separate from the power feed to the treatment plant. In addition, backup emergency power generation equipment would be provided on the pump station site for operating the pump station at full capacity.

### 4.3.6 Communications

The 2001 Nisqually Earthquake (EERI, 2001b) demonstrated that telephone and cell phone service is unreliable during a large earthquake because of damage to communications centers and jamming of the existing network. This unreliable service could cause difficulties in reaching the technicians and engineers who would be needed to evaluate damage at the Brightwater Treatment Plant and order equipment and materials for repair work. To address this problem, King County participates in a statewide disaster communication system. King County has been granted three channels in a regional 800-MHz radio communication system. During a disaster, this system has the capability of reaching throughout King County’s tri-county wastewater service area.

### 4.3.7 Water Supply

The effects of an earthquake on the regional water supply would be similar for Scenarios A, B, and C. These effects would include loss of water supply for periods of 72 hours or more because of damage to pipelines and water reservoirs. This loss in water supply would have direct impacts to the Brightwater Treatment Plant, and these impacts would differ for each scenario.

Brightwater would need about 20 gallons per minute (gpm) of potable water plus 600 gpm of reclaimed water for operation; however, the plant could operate with as little as 2 gpm of potable water for short periods of time. Water would come to the proposed Route 9 site from two directions. Groundwater from wells would be supplied by the Cross Valley Water District through lines coming from the plateau northeast of the site. Water also would be supplied to the Brightwater site by a line from the Alderwood Water District coming from the west.

During an earthquake, the wells and both of the potable water supply lines could be damaged. The type of damage that could occur under each scenario would be similar, but the source of the damage may differ:

- Some Cross Valley Water District wells and some water supply lines from both the Cross Valley Water District and the Alderwood Water District are located in areas of weak alluvial soils in the Bear Creek Valley. These wells and lines could be damaged by strong ground shaking in any of the three scenarios described.
- The Cross Valley Water District water supply line would cross Lineament 4 as it enters the Route 9 site from the northeast; Lineament 4 has been recognized as an active fault (Chapter 2). The line also would cross other portions of the Route 9 site where an unknown fault is hypothesized in Scenario C. The Cross Valley water supply line could be damaged if a surface rupture were to occur on Lineament 4, as described in Scenario A, or if a surface rupture were to occur under treatment facilities, as described in Scenario C.
- The water supply line from the Alderwood Water District would cross Lineament X offsite as the line enters the Route 9 site from the west; Lineament X is assumed to be an active fault in Scenario B. The line also would cross other portions of the Route 9 site where an unknown fault is hypothesized in Scenario C. The Alderwood water supply line could be damaged if a surface rupture were to occur on Lineament X, as described in Scenario B, or if a surface rupture were to occur under treatment facilities, as described in Scenario C.

If strong ground shaking were to damage Cross Valley wells on the plateau northeast of the Brightwater Treatment Plant site, the wells could be repaired within a few days. If shaking or a surface rupture were to damage either the Cross Valley or Alderwood water supply lines coming into the plant, the lines could be repaired within a few days or weeks.

### 4.3.8 Wastewater Treatment and Conveyance

It is assumed for this analysis that the other two regional wastewater treatment plants operated by King County, the West Point Treatment Plant and the South Treatment Plant (see Chapter 3 and Figure 3-1), would be operational following a large earthquake along the SWIF. The West Point and South Treatment Plants are located about 15 and 22 miles from the southern edge of the SWIF, respectively. Wastewater flows could be redirected from the Brightwater Treatment Plant to one or both of these other treatment plants. (See the discussion of King County's Emergency Flow Management System in Chapter 3.)

Some of the local and regional sewer pipelines in the Brightwater Service Area could be damaged by shaking during a strong earthquake if they are located in soil that is subject to settlement or liquefaction, or they could be damaged by a surface rupture. The damaged pipelines could leak causing a reduction in the amount of wastewater being delivered to the treatment facilities. Large-diameter pipelines could float as the result of liquefaction of the soils. In this case, buoyant pressure could cause the pipelines to rise to the ground surface. It is estimated that repair of these pipelines could take many weeks.

### 4.3.9 Natural Gas

A major trunk line for delivery of natural gas throughout Western Washington is located on the ridge west of Little Bear Creek. A service line enters the Route 9 site at 228th Street SE. Both the trunk lines and the service line into the site are made of welded steel. While these pipelines are reportedly founded in competent soils and could withstand seismic shaking, a ground surface rupture on the SWIF could damage or rupture the pipelines.

Natural gas and digester gas would be used as a source of fuel in boilers for building and digester heating and in engine generators for the production of electrical energy at the Brightwater Treatment Plant. Should both fuel sources be unavailable, building temperatures and the temperature of the digested sludge may be less than the design minimum. Reduction in temperature would not affect the operation of the wastewater facilities as long as the reduction is short term, on the order of a few days, which is the expected time frame for repair of the natural gas pipelines.

## 4.4 What Has Happened to Other Water and Wastewater Treatment Plants During Large Earthquakes?

Many water and wastewater treatment plants are located in seismically active areas such as the western United States and Japan. These plants are complicated systems involving a number of belowground and aboveground basins and tanks connected by pipes with pumps and weirs used to control flow. Because many of these plants have experienced strong ground shaking during earthquakes, they provide real-world examples of the performance of water and wastewater treatment plants during an earthquake. This experience has been used to identify likely areas of damage to Brightwater facilities during an earthquake and to identify methods that can be used to minimize or prevent similar types of damage.

### 4.4.1 Reports From Four Earthquakes

Information on the performance of a number of treatment plants during the Loma Prieta, Northridge, Kobe, and Chi Chi Earthquakes has been documented by several professional engineering societies including the American Society of Civil Engineers (ASCE, 1995), the Earthquake Engineering Research Institute (EERI, 1990, 1995, 2001a), the National Center for Earthquake Engineering Research (now the Multi-Disciplinary Center for Earthquake Engineering Research) (NCEER, 1996), and the National Institute of Standards and Technology (NIST, 1996) Relying primarily on volunteer efforts, these organizations gather information and report on damage following major earthquakes throughout the world. These damage reports provide the best available documentation of impacts on treatment plants resulting from the Loma Prieta, Northridge, Kobe, and Chi Chi Earthquakes:

- In 1989, the M 7.1 Loma Prieta Earthquake in northern California affected the Palo Alto, San Mateo, Hayward, and Santa Cruz wastewater treatment plants and the Rinconada water treatment plant.
- In 1994, the M 6.7 Northridge Earthquake in southern California affected the Valencia and Saugus Water Reclamation Plants and the Jensen and Los Angeles Water Treatment Plants.
- In 1995, the M 6.9 Kobe Earthquake in Japan affected the Higashinada Wastewater Treatment Plant and the Hanshin/Uegahara Water Treatment Plants (two plants on a single site).
- In 1999, the M 7.6 Chi Chi Earthquake in central Taiwan affected a number of dams, pipelines, and treatment plants.

### 4.4.2 Observed Damage to Treatment Facilities

Each of these earthquakes produced ground shaking at treatment plant sites similar to or exceeding the ground shaking estimated for the proposed Brightwater Route 9 site (Appendix B). Fault rupture beneath treatment plant facilities did not occur in any of these four earthquakes, although fault ruptures in the Kobe and Chi Chi earthquakes caused pipeline damage. Most of the damage to treatment plant facilities resulted from liquefaction-induced lateral spreading or from differential settlement. Observed damage included basin failure, pipe rupture, and equipment damage.

Basin failures following the Kobe Earthquake were caused by settlement at the Hanshin/Uegahara Water Treatment Plants and by liquefaction at the Higashinada

Wastewater Treatment Plant. At the Higashinada plant, liquefaction and lateral spreading caused 7 feet of lateral differential movement and 3 feet of settlement across the plant site. As a result, the end of the aeration basins settled when the pile foundation system failed. In addition, the influent channel was offset by about 3 feet. Both the settlement and offset resulted in the release of wastewater. During the Northridge Earthquake, basin wall joints separated at the Valencia and Saugus Water Reclamation Plants in the San Fernando Valley. No basins failed at any treatment plants during the Loma Prieta Earthquake.

Damage during the Chi Chi Earthquake included breaking of water pipes due to fault rupture at the ground surface. Only one water treatment plant in Feg-Yaun suffered significant damage. Plant basins, reservoirs, and underground piping were damaged from ground shaking. Sloshing apparently damaged a number of submerged baffles in one of the settling basins. Submerged piping at bottom cells was severed, and reinforced concrete reservoir roofs collapsed. Wastewater facilities located close to the center of the earthquake suffered minor damage. Four wastewater treatment plants in Nan-Tou County continued to operate and perform very well, except that some pipelines suffered damage.

Minimal damage to treatment plant pipelines was observed during the Loma Prieta, Northridge, Kobe, and Chi Chi Earthquakes. Pipeline leaks that did occur happened at connections between process units and typically resulted from differential settlement and liquefaction. For example, during the Loma Prieta Earthquake, differential settlement at the Palo Alto Wastewater Treatment Plant caused a pipeline to pull away from its connection to a basin.

Several occurrences of non-structural damage to mechanical, electrical, and piping systems were observed during the four referenced earthquakes. For example, during the Loma Prieta Earthquake, a small-diameter pipe broke, due to inadequate pipe bracing, and resulted in flooding at the San Mateo Wastewater Treatment Plant. During the Kobe Earthquake, an unanchored or unbraced electrical cabinet toppled over at the Uegahara Water Treatment Plant. The instances of non-structural damage at treatment plants were few considering the thousands of pieces of equipment and piping installations at the treatment plants.

Chemical storage tanks designed to modern standards, as the Brightwater tanks will be designed, performed without failures in the Loma Prieta, Northridge, and Kobe Earthquakes. Reconnaissance reports for the Chi Chi Earthquake did not mention failures of chemical storage tanks, which suggests that if damage did occur, it was relatively minor. In addition, chemical piping connections generally performed well, and where failures occurred, the secondary containment system kept chemicals from discharging to the environment.

### 4.4.3 Lessons Learned from Other Earthquakes

Damage reports from these four large earthquakes clearly indicate that water and wastewater treatment plants have not been significantly damaged during previous earthquakes. This experience suggests that current design methods, particularly normal requirements for detailing of the structures and the mechanical and electrical support systems, are very effective in helping these structures and systems to withstand the levels of ground shaking from large earthquakes. These “lessons learned” provide a valuable basis for designing future wastewater treatment plants in highly seismic areas, and are being integrated into the design of the proposed Brightwater facilities.

The limited damage during these past large earthquakes is consistent with King County’s experience during the Nisqually Earthquake in 2001. Ground shaking was experienced at the West Point and South Treatment Plants. Inspections following the earthquake found that both treatment plants were undamaged by the ground shaking. The Central Treatment Plant in Tacoma also was unaffected by the ground shaking, and the Tacoma treatment plant is located much closer to the epicenter of the Nisqually Earthquake than either of King County’s plants.

## 4.5 What Would Happen if the Ground Were to Rupture on Lineament 4 Resulting in Very Strong Ground Shaking on the Site (Scenario A)?

All of the hypothetical scenarios are very unlikely to occur during the design life of the Brightwater Treatment Plant. Of all three hypothetical worst-case scenarios, Scenario A is the least unlikely to occur. Under Scenario A, the surface would rupture on Lineament 4 and very strong ground shaking would occur under treatment facilities and the combined conveyance tunnel on the proposed Route 9 site. The strong ground shaking could exceed 30 seconds. This event is estimated to have about a 1 percent probability of occurring during  the assumed 50-year life span of the Brightwater Treatment Plant. The assumptions of damage to facilities provide the basis for evaluating the environmental impacts of Scenario A in Chapter 5 of this Supplemental EIS. (See the Scenario Tables at the end of this document.)

### 4.5.1 Treatment Plant Damage Assumptions

Under Scenario A, strong shaking could cause damage to treatment plant facilities. Only minor, repairable structural damage would occur to newly constructed treatment facilities; however, buried pipes could crack and leak where they connect to process units. The existing StockPot Building could suffer severe damage.

#### Minimal Damage to Treatment Process Facilities

The damage to newly constructed buildings under Scenario A would be minimal because the new buildings would be designed consistent with the 2003 International Building Code (IBC 2003; see Chapter 3). Compliance with the IBC does not ensure that no damage will occur during an earthquake. Rather, IBC 2003 requires that buildings be designed to protect the health, safety, and welfare of the general public, including the building occupants, by minimizing the potential risk to life in the event of an earthquake. The IBC assigns buildings to a Seismic Use Group that takes into account the nature and use of the building and the intended level of operation of the building following an earthquake. Brightwater buildings are assigned to Seismic Use Group II or III (see Table 3-1). Buildings assigned to Seismic Use Group II could suffer damage that would require restrictions to use or operations until repairs could be made. Buildings assigned to Seismic Use Group III would be designed to prevent collapse, provide life safety, and remain operational following the earthquake.

It is anticipated that only minor, repairable structural damage would occur to liquid-holding tanks, digesters, or solids handling facilities under Scenario A. Minimal structural damage to these facilities is expected because tanks are designed for crack control, which provides a higher level of seismic resistance than simply designing to meet building code requirements. No damage or only minor damage would occur to the odor control systems, ductwork, and chemical storage facilities. If there were any leaks of the chemicals used in odor control, the leaks would be minor and would be contained within the odor control buildings and storage containment areas.

### Damage to StockPot Building

While damage to new facilities would be minimal, severe damage could occur to the existing StockPot Building on the Route 9 site. The existing StockPot Building was constructed prior to the seismic standards that took effect with the adoption of the IBC 2003 and before the presence of Lineament 4 had been established. King County has undertaken a study to determine what needs to be done to retrofit the StockPot Building to IBC 2003 life safety standards (King County, 2005). Possible plans for seismically retrofitting the StockPot Building are described in Chapter 1 of this Supplemental EIS.

### Leakage at Pipe Connections

While tanks would not sustain any significant structural damage under Scenario A, the buried pipes connecting to belowground process units could crack and leak. Damage during past earthquakes (see discussion earlier in this chapter) suggests that the amount of leakage would be relatively small (on the order of 10 to 20 percent of the total connecting piping). Pipe breaks and leakage within the belowground pipe gallery and basement structures could result in some short-term loss of treatment byproduct flow streams such as sludge and scum removal or ancillary systems such as the instrument air system within the plant. Because of the number of redundant units and shutoff valves and gates provided in the piping systems, no significant leakage or downtime would occur. Provided that leakage could be contained within the belowground gallery, the wastewater would not be released to the underdrain system or to groundwater. If the leakage were released to the underdrain system and the underdrain system were to become clogged or damaged, small quantities of wastewater could leak into surrounding soils and slowly migrate to shallow groundwater. If the underdrain system were functional (not clogged or plugged), small amounts of wastewater could reach surface waters through the stormwater drainage system (see Chapter 5).

For the worst-case analysis under Scenario A, it was assumed that up to 20 percent of the belowground wastewater pipes would break and their contents (up to 300,000 gallons) would infiltrate into the groundwater in the vicinity of the break. Because the contamination would move downgrade relatively slowly, it would be possible to contain and remove it from the ground before it reached Little Bear Creek.

No leakage of chemicals is expected from the chemical storage facilities on the Brightwater site under Scenario A. This is because the piping connections for chemical storage would be within concrete secondary containment areas that would be expected to remain intact with no significant cracking. In addition, there would be only one pipe connection subject to failure, and it would have an external automatic shutoff valve.

### 4.5.2 Combined Tunnel Damage Assumptions

Typically, tunnels are designed to withstand the loads associated with local ground conditions (earth and groundwater pressures). When ground shaking occurs, a tunnel may respond by compressing or extending, curving horizontally or vertically, and/or by changing from a circular shape to an oval shape. The Brightwater combined conveyance tunnel is being designed to withstand the levels of ground shaking that would be expected if a rupture were to occur on Lineament 4 at the north end of the site. This level of ground shaking would cause the combined tunnel to strain and deform, but the piping systems within the tunnel would remain operational and serviceable.

Deformation of the tunnel could cause the pipelines inside the tunnel to crack or cause the joints to open or become slightly offset. However, the tunnel itself would not break, and any leakage from internal pipes would be contained within the tunnel. It is anticipated that the cracked pipes or offset joints would not prevent the operation of the Brightwater System; they could be repaired, and the tunnel would be expected to remain in service until repairs were done.

### 4.5.3 Where Would the Wastewater Go?

Under Scenario A, if a ground rupture were to occur on Lineament 4 and cause some of the connecting pipes to crack, small quantities of wastewater could leak into surrounding soil and migrate toward the shallow groundwater, as described above. If left unremediated, the wastewater ultimately would discharge to Little Bear Creek. Wells in the Cross Valley Aquifer would not be affected, as discussed in the Brightwater EIS, because they are located upgradient of the Route 9 site.

As noted earlier, no structural damage to tanks would occur under Scenario A and the effluent pipeline would remain operational. However, if damage were to occur to connecting pipelines or other parts of treatment facilities that precluded full secondary treatment of wastewater flows, the split-flow treatment process could allow partial operation of the treatment plant and discharge of untreated or partially treated water to Puget Sound (see the discussion of the split-flow process later in this chapter). However, if the earthquake were to cause the Brightwater Treatment Plant to shut down for a period of time during wet weather, wastewater overflows could occur until the treatment plant was restarted (see Chapter 5).

If the treatment plant were to shut down, King County would immediately begin diverting wastewater into storage facilities in the north Lake Washington area; the wastewater would be stored until it could be conveyed to the West Point and South Treatment Plants for processing or until the Brightwater Treatment Plant was operational again.

The volume of storage that would be available in the conveyance system in the north Lake Washington area in the year 2050 and the amount of time that it would take to fill the storage would vary depending on flow conditions during an earthquake and the amount of flow that could be diverted under each of the flow conditions. Storage times and volumes are summarized in Table 4-2; the rerouting of flows is shown in Figures 4-3 and 4-4.

For the dry-season, low-flow condition in 2050, the existing conveyance system would have adequate capacity to divert all flows from the Brightwater Service Area to other treatment plants to prevent overflows to freshwaters. The available storage in the north Lake Washington area would begin filling during the first hours after the Brightwater Treatment Plant shut down. Before overflows into freshwaters could begin, the North Creek and York Pump Stations would begin transferring stored flows to other treatment plants, and, once the diversions began, the conveyance system would have adequate capacity to convey the flows, thus overflows would not occur.

For sustained flows above the maximum monthly flow, the conveyance system would not have enough capacity to convey all the flows. Once the storage time in Table 4-2 was exceeded, wastewater overflows to freshwaters could potentially occur. Overflows could occur into local streams—North Creek, Swamp Creek, and the Sammamish River—as well as along the eastern shore of Lake Washington (see Chapter 5).

If there were overflows, the length of time it would take for them to begin after the earthquake occurred would depend on weather conditions at the time and the amount of storage available in the wastewater system. The duration of overflows would depend both on weather conditions, the extent of damage to facilities, and the length of time needed to make repairs. The expected duration of wet weather overflows would be from a few hours up to 2 days depending on the intensity and duration of storms.

No untreated wastewater would be discharged through the Brightwater effluent pipeline to Puget Sound because if the treatment plant were to shut down, flows would not be conveyed through the Brightwater effluent system. They would be stored, and, if and when storage capacity was exceeded, they would be rerouted to the West Point and South Treatment Plants. Routing flows from the Brightwater Service Area to the other treatment plants would minimize untreated overflows to freshwater. The other treatment plants would have secondary treatment capacity of 133 mgd (West Point) and 144 mgd (South Plant). Because storm-influenced flows from their respective service areas would consume virtually all of the secondary treatment capacity at the plants, most, if not all, of the flow from the Brightwater Service Area would receive only primary treatment, or it could overflow to freshwater from the conveyance system before reaching the plants (see Chapter 5).

## Table 4-2. Storage, Flow Transfer, and Potential Overflow Rates During a Brightwater Treatment Plant Shutdown – Scenarios A, B, and C

| 2050 Flow Condition[a] | Hours to fill Available Storage (18.3 million gallons)[b,c] | Flow Transfer to West Point Treatment Plant | Flow Transfer to South Treatment Plant | Untreated Discharge to Puget Sound | Potential Maximum Overflow to Freshwater[d] |
|---|---|---|---|---|---|
| **Average dry-weather** (40 mgd) | 13.1 | 15 mgd | 30 mgd | None | None |
| **Maximum monthly** (76 mgd) | 6.9 | 14 mgd | 62 mgd (limited by North Creek Pump Station capacity) | None | None |
| **Peak hourly** (170 mgd) | 2.6 | 0 mgd | 66 mgd (limited by York Pump Station capacity) | **Scenario A:** 170 mgd Flows would be diverted to and receive partial treatment at the West Point and South Plants<br>**Scenario B:** up to 130 mgd after 4-6 weeks<br>**Scenario C:** 170 mgd after 7 days | **All scenarios:** 170 mgd (until North Creek and York Pump Stations are configured to reroute Brightwater flows to the South Plant<br>**Scenario B:** After bypass constructed, approximately 40 mgd |

[a] Conditions assume constant flow at the rate indicated.

[b] Times to fill storage facilities assume 12 million gallons (MG) of existing storage available (6 MG in the North Creek Storage facility, 4 MG in the Logboom Storage facility, and 2 MG in the Bothell-Woodinville Interceptor) in conjunction with 6.3 MG in the combined tunnel.

[c] Times to fill storage facilities assume that flow transfer to West Point Treatment Plant begins after 1 hour.

[d] Potential maximum overflow assumes that flow transfer to West Point Treatment Plant begins after 1 hour and flow transfer to South Treatment Plant begins after 6 hours. Actual volume of overflow would depend on the intensity and duration of the storm.

## 4.6 What Would Happen if the Ground Were to Rupture on Lineament X Resulting in a Break in the Combined Tunnel and Very Strong Ground Shaking on the Site (Scenario B)?

Under Scenario B, a surface rupture would occur on Lineament X at the south end of the Route 9 site. It is assumed that the ground movement around the combined conveyance tunnel on the site would cause the tunnel to break. Very strong ground shaking would occur under treatment facilities throughout the rest of the site. The strong ground shaking could exceed 30 seconds. In view of the lack of any direct evidence of surface rupture on Lineament X, the likelihood of Scenario B occurring is less than Scenario A, which is estimated to have about a 1 percent probability of occurring during the assumed 50-year life span of the Brightwater Treatment Plant.

### 4.6.1 Treatment Plant Damage Assumptions

Under hypothetical worst-case Scenario B, the type and extent of damage to treatment facilities, the quantity of releases, and the time for repair are expected to be similar to that discussed under Scenario A. However, no rupture would occur under the StockPot Building. While the building could sustain some damage from ground shaking, the damage would be less than would result from a rupture directly under the building.

As in Scenario A, a limited number of buried pipes that connect process units could crack or separate at the joints resulting in some leakage of wastewater to groundwater and surface water. The potential volume of leakage within the treatment plant site from connecting pipes under Scenario B would be similar to Scenario A (up to 300,000 gallons), and the impacts would be similar. In addition, leakage from the combined tunnel could occur, as discussed below.

The electrical power lines would enter the site from SR-9 south of 228th Street SE and connect to an electrical substation that would be located at the southern end of the site. The electrical power system could be damaged during an earthquake on Lineament X. If this were to occur, there could be some short-term loss of power until emergency generators could be started. Permanent repairs to the electrical power system could take from a few days to a few months (see the discussion later in this chapter).

### 4.6.2 Combined Tunnel Damage Assumptions

Damage to the combined tunnel would be much more severe under Scenario B than it would be under Scenario A. If a rupture were to occur on Lineament X under the combined tunnel, the worst-case scenario assumes that the outer tunnel (made of bolted and gasketed concrete segments) might fail as the individual concrete segmental panels were pulled apart at one or several joints. In addition, the pipelines inside the tunnel (Figure 3-3) potentially could break. The potential for breakage would depend on the location of the fault rupture in relation to a segmental pipe joint and the type of material used for the pipes.

The combined tunnel would be located 25 to 30 feet below the ground surface on the treatment plant site. With pipe breakage, the ground surrounding the tunnel would move into the open pipes and produce ground movement around the tunnel. Depending upon the location of the rupture, this ground movement could lead to surface settlements. However, ground subsidence would be expected to be localized and minor. A catastrophic failure of this nature would result in shutdown of the entire Brightwater System—both the treatment plant and the conveyance system.

If either the tunnel or the internal piping were to break, the system would be inspected and the extent and type of damage would be evaluated. Temporary repairs to the system could involve pressure grouting the soil surrounding the damaged area, to restrict further leakage. The suitability of this emergency repair would depend on the size and the location of the break. Final repair of the failed tunnel section would include constructing a shaft to access the tunnel and removing and replacing the broken pipelines. The length of time for final repairs if construction of an access shaft were required would be several months, depending on the extent of the damage and the tunnel depth at the failure location. Temporary repairs involving pressure grouting might be accomplished within a few weeks.

### 4.6.3 Where Would the Wastewater Go?

If a ground rupture were to occur on Lineament X and the combined tunnel were to fail, the influent pump station would shut down, no additional flows would be pumped to the treatment plant, and the emergency flow management strategies described in Chapter 3 and later in this chapter would be implemented. However, flows already in the pipeline would continue to move due to momentum and pressure. The worst condition for Scenario B would be if the surface rupture underneath the combined tunnel were to break every pipe in the tunnel. If this were to occur, the maximum volume of liquid that could potentially leak from the tunnel pipelines underground before the influent pump station stopped flow to the treatment plant would be about 440,000 gallons. Table 4-3 summarizes the potential discharge volumes that would occur under the peak hourly flow condition (170 mgd).

**Table 4-3.** **Maximum Potential Discharge from a Ruptured Combined Tunnel**

| Liquid | Maximum Potential Discharge Volume (gallons) |
|---|---|
| Untreated influent | 200,000 |
| Treated effluent | 200,000 |
| Class A reclaimed water | 40,000 |
| Total | 440,000 |

NOTE: Discharge volume assumes peak hourly flow conditions (170 mgd) for the influent and effluent pipeline and that the reclaimed water system is in operation. The maximum potential discharge volumes would be less under low-flow conditions or if the reclaimed water system were shut down.

The tunnel would be closest to the groundwater table at the treatment plant property line. Scenario B assumes that the ground rupture would occur at this point. The potential discharge from the conveyance tunnel at this location would occur 25 to 30 feet below the ground surface, and the wastewater could slowly migrate into the groundwater. If left unremediated, the contaminated groundwater ultimately would discharge into Little Bear Creek. Wells in the Cross Valley Aquifer would be not contaminated, as discussed in the Final EIS, because they lie upgradient of the Route 9 site.

Following the initial spill of treated effluent, the influent forcemains and reuse pipeline would remain full of wastewater and reclaimed water, respectively, but groundwater could inflow into the effluent pipeline at the point of rupture. The effluent pipeline would be free-flowing out to Point Wells. The effluent pipeline would have an isolation valve near Point Wells, and in the event of a tunnel rupture, the effluent pipeline would be isolated to prevent any discharge of groundwater at the outfall.

As noted, the influent pump station would be turned off and flows to the treatment plant would be diverted to other facilities. When this takes place, overflows could occur intermittently into North Creek, Swamp Creek, the Sammamish River, and along the eastern shore of Lake Washington, as described under Scenario A. Depending on where the combined tunnel were to break and the extent of damage, King County would construct a temporary pipeline at the location of the tunnel break to divert influent flows into the effluent pipeline. This temporary modification would take up to 6 weeks to construct. When completed, the diversion to the effluent pipeline could accommodate a flow rate up to 130 mgd.

Once the bypass to Puget Sound was constructed, the volume and frequency of overflows to freshwaters would be significantly reduced, but such overflows could still occur for short periods of time during wet weather. Because permanent repairs would take longer under Scenario B than they would under Scenario A, these types of overflows would occur over a longer period of time under Scenario B than under Scenario A, up to 6 months compared to a few days.

## 4.7 What Would Happen if the Ground Were to Rupture Between Lineaments 4 and X Resulting in Damage to Treatment Facilities and Very Strong Ground Shaking on the Site (Scenario C)?

Of the three hypothetical worst-case scenarios, Scenario C is the most unlikely to occur on the Brightwater Treatment Plant site during an earthquake. There is no evidence to date to suggest that this scenario would, in fact, ever occur. Under Scenario C, a surface rupture would occur on an unknown and hypothetical fault between Lineaments 4 and X on the proposed Route 9 site. Very strong ground shaking would occur throughout the rest of the site at a level similar to that in Scenario A. The displacement of the ground beneath one of the new Brightwater structures between Lineaments 4 and X would result in major damage to affected treatment facilities. The strong ground shaking could exceed 30 seconds. In view of the lack of any evidence of a fault between Lineaments 4 and X, the likelihood of Scenario C occurring during the assumed 50-year life span of the Brightwater Treatment Plant is less than for either Scenario A or B.

Which treatment facilities, if any, would be damaged and the environmental impacts that would result would vary depending on where on the site the surface rupture occurred. Therefore, multiple locations are considered in Scenario C in an attempt to account for the worst-case impact to the environment.

### 4.7.1 General Treatment Plant Damage Assumptions

#### Damage to Facilities Directly Above Rupture Zone

Under Scenario C, portions of any aboveground buildings located directly over the surface rupture may collapse or suffer significant damage, regardless of their Seismic Use Group designations, given the amount of hypothesized ground displacement. Significant structural damage also would be expected to occur to liquid-holding tanks, digesters, or other structures and pipelines located directly above the surface rupture zone. Cracks would be expected in tanks that are above and near the rupture; their liquid contents would likely leak to surface water and/or groundwater. If a fault were to rupture beneath the chemical storage or odor control facilities and if this rupture were to cause cracks in the concrete secondary containment structure, there could be some discharge of chemicals onto the ground or methane into the atmosphere.

It is assumed that pipe breaks and leakage would occur within the pipe gallery and basement structures located above or near the surface rupture, resulting in mid-to-long-term loss of some treatment byproduct flow streams such as sludge and scum removal or ancillary systems such as the instrument air system within the plant. It also is assumed that the pipe gallery structure would crack and contents would leak to the shallow groundwater and underdrain system. Nonstructural damage to mechanical and electrical equipment would be expected to occur to facilities above and in proximity to the surface rupture, resulting in substantial downtime for repair.

Damage to structures from ground surface rupture during an earthquake is not addressed by the IBC seismic design requirements. It is generally accepted that strong ground shaking is more likely than surface rupture to occur over the design life of a structure. Further, while small fault movements can be accommodated by design, the amount of movement assumed in Scenario C (3 to 6 feet both horizontally and vertically) cannot be accommodated by practical design methods.

### Non-Process Facilities

Several non-process facilities (Table 3-2) on the Brightwater site could suffer major damage under this scenario. The proposed Brightwater Treatment Plant would have one diesel storage tank onsite to provide fuel to the essential services generator; this diesel storage tank is the one non-process facility that has the most potential for direct impact on the environment. The diesel tank is located near the Solids Odor Control Building and is buried below finished grade. Similar to a service station installation, the diesel tank is constructed of double-walled fiberglass with a 4,000-gallon capacity. All pipes and fittings are located at the top of the tank. If the tank were to move or tip during an earthquake, diesel fuel would not be expected to leak since all the fittings are located on top and the tank is double walled. In the highly unlikely event of a rupture occurring directly beneath the tank, diesel fuel could leak into the surrounding ground. This would occur only if both tank walls were damaged. Diesel fuel would not reach the surface, but it could migrate toward the shallow groundwater. The impacts to groundwater and cleanup methods are described in Chapter 5.

The electrical power system could be damaged as discussed in Scenario B.

### Damage to Facilities Outside of Rupture Zone

Buildings and liquid-holding tanks located away from the surface rupture zone would be expected to experience strong ground shaking, with a magnitude similar to the level described for Scenario A, and the buildings and tanks would suffer similar damage. As in Scenario A, ground shaking would be expected to cause some leakage at pipe-to-basin connections based on experience from past earthquakes.

### Multiple Locations Considered for Scenario C Earthquake

Most of the treatment plant facilities on the Route 9 site are located between Lineaments 4 and X. Under hypothetical worst-case Scenario C, a surface rupture could occur under any of the facilities in this area. As there is no evidence to suggest a fault in this area, this scenario is extremely unlikely to occur. Which treatment facilities would be damaged and the environmental impacts that would result would vary depending on where in this area a rupture were to occur. To account for this uncertainty and to provide a basis for assessing worst-case impacts in Chapter 5, Scenario C considers the following:

- Damage to facilities that would have the greatest impact on shallow groundwater (such as aeration basins and primary sedimentation tanks)
- Damage to facilities that would have the greatest impact on surface water (such as digester tanks)
- Damage to facilities that could result in chemical leaks (such as the odor control system or the chemical storage buildings)

Each of these scenarios is described in detail below.

### 4.7.2 Damage to Facilities That Would Have the Greatest Impact on Groundwater

#### Damage to Aeration Basins

The aeration basins are the largest unit process with the most volume of wastewater below the ground surface. If the ground were to rupture beneath portions of the basins, the basins would likely fail. However, the closely-spaced reinforcing steel in the walls of the concrete tanks would hold the basin walls together and prevent gaping holes from developing. Nevertheless, the worst-case analysis assumes that very large quantities of untreated wastewater would be released to the shallow groundwater or the underdrain system. The total volume assumed to leak from the tanks and the connecting piping between primary sedimentation and aeration could be as great as 9.4 million gallons if all six aeration basins were to fail. While it is highly improbable that all six basins would suffer similar levels of damage, the worst-case analysis assumes all basins would be damaged to such an extent that all contents would be lost.

#### Where Would the Wastewater Go?

If the aeration basins were damaged, partially treated wastewater could infiltrate into the shallow groundwater or to surface waters. If the underdrain system remained operational, wastewater could enter the underdrain, and, if the underdrain were not manually plugged, wastewater could reach surface waters through the storm drainage system in the wetscapes along the western portion of the site. If the underdrain were damaged or plugged, wastewater would infiltrate into the shallow groundwater. If unremediated, the contaminated groundwater ultimately would discharge into Little Bear Creek. Wells in the Cross Valley Aquifer would not be contaminated, as discussed in the Brightwater Final EIS, because they are located upgradient of the Route 9 site.

If the aeration basins were damaged, portable pumps would be used to bypass the damaged tanks. This could take up to 1 week, and during that time, untreated or partially treated wastewater would be diverted to other treatment plants for discharge to Puget Sound or to freshwaters at overflow locations in the conveyance system (see Figures 4-3 and 4-4 and Chapter 5). Repair of the damaged tanks could take from 2 months to 1 year.

Partial treatment of the wastewater would resume in about 2 months; full treatment would resume in 6 months to 1 year.

### 4.7.3 Damage to Facilities That Would Have the Greatest Impact on Surface Water

#### Damage to Digesters

The digesters would contain the greatest volume above ground of all the tanks on the treatment plant site. If the ground were to rupture beneath these circular tanks, the tanks would fail. However, similar to aeration basins, the reinforcing steel and cables wrapped around each tank would hold the walls together like a “wrapped silo” until such time that repairs could be made. Nevertheless, the worst-case analysis assumes that up to 4 million gallons of partially treated solids would be released from the digesters, primarily to surface waters. This volume is based on up to four of the six digesters losing their contents. While it is improbable that four tanks would suffer similar levels of damage, the worst-case analysis assumes that four digesters would be damaged to such an extent that all contents would be lost.

#### Where Would the Wastewater Go?

If the ground were to rupture under the digesters and four digesters were to crack, about 4 million gallons of wastewater solids could rapidly discharge from the cracked tanks. The escaping wastewater solids would spread across much of the southern portion of the Route 9 site and flow downhill toward the west boundary of the site to SR-9 and beyond (Figure 3-2). As the escaping wastewater solids spread, the peak flow at any single point would diminish, a process known as flow attenuation. Some of the wastewater solids would flow to the southernmost of the three stormwater canals where it would be detained for a period of time before flowing to the treatment wetlands at the southern end of the site (known as the South Wetscape). From there it would pass through a culvert under SR-9 to Little Bear Creek. A portion of the flow also would escape via the South Mitigation Area and through the Howell Creek culvert under SR-9.

The majority of the escaping wastewater solids would flow down the southern access road to the treatment plant site. This road is in line with 233rd Place SE. At the intersection of 233rd Place SE with SR-9, the escaping wastewater solids would flow across the surface of SR-9. From there, they would continue flowing west into nearby Little Bear Creek. There would be no discharge of solids to Puget Sound because the solids would not enter the effluent pipeline.

Once the digesters had been emptied of their contents, no further releases would occur; the wastewater would be pumped around the treatment facilities to the effluent tunnel, and solids would be trucked to other treatment plants until repairs had been completed. Repair of the solids handling facilities could take up to 1 year.

King County considered building a dike or a concrete containment wall around the digesters to contain overflows in the event of digester failure. However, these options would be cost prohibitive in light of the extremely remote likelihood of such a catastrophic event occurring directly under the digesters at the Route 9 site within the life span of the treatment plant.

### 4.7.4 Damage to Facilities That Could Result in Chemical Leaks

#### Damage to Chemical Storage Areas

Several chemicals are used in the wastewater treatment and odor control processes. These chemicals would be kept on the Brightwater Treatment Plant site in large bulk-chemical storage, handling, and distribution facilities located on the proposed treatment plant site (see Chapter 3 and Figure 3-2). If the ground surface were to rupture under a chemical storage area, if all storage tanks were to fail, and if the containment areas were to crack, then chemicals could spill onto the ground surface or leak into the surrounding soil and groundwater. The chemicals that would be stored on the Brightwater site are sodium hypochlorite, sodium hydroxide, sulfuric acid, ferric chloride, polyaluminum chloride, and citric acid.

The storage facilities for alkaline and acidic chemicals on the Brightwater Treatment Plant site will be approximately 1,200 feet apart, a much greater separation than required by code. The 1,200 feet of separation between the alkaline and acidic chemical storage areas would prevent mixing of the two types of chemicals and the resulting formation of chlorine gas. These chemicals are not volatile, provided mixing does not occur; therefore, they would not enter the atmosphere.

The volumes of chemicals that would be stored on the Brightwater Treatment Plant site are listed in Table 3-2. The time required to repair chemical storage areas or odor control facilities could range from days to months depending on the extent of the damage.

#### Where Would the Chemicals Go?

If the ground were to rupture under one of the chemical storage areas or under one of the odor control systems, chemicals could leak to surface water or groundwater. However, the 1,200 feet of separation between the alkaline and acidic chemical storage areas would prevent the mixing of these two types of chemicals.

The chemicals could enter the stormwater drainage systems; however, the stormwater drainage systems for the alkaline and acidic storage areas are separated so that the two types of chemicals would not mix in the stormwater system. Some of the chemicals could flow offsite via either the Main Entry Road or the treatment plant stormwater system and enter Little Bear Creek.

### 4.7.5 Combined Tunnel Damage Assumptions

The impacts on the combined tunnel would be the same as described for Scenario A. The pipelines inside the combined tunnel could crack, but the tunnel itself would not break. Any leakage would be contained within the tunnel, and the tunnel would remain operational. Overflows, time for repairs, and the emergency flow management procedures for the combined tunnel in Scenario C are the same as those described for Scenario A (see the discussion earlier in this chapter).

## 4.8 How Would King County Respond to an Earthquake at the Brightwater Treatment Plant?

The Brightwater Treatment Plant, like most wastewater systems, is designed with redundant units to ensure operational reliability. Multiple tanks, pumps, pipes, and other equipment are provided in order to allow treatment to continue during maintenance of any single system component. In addition, gates and valves between treatment process units and between individual tanks within a process can be used to isolate the contents. These features make it possible to isolate earthquake damaged facilities so that complete release of contents from the entire plant will not occur and so that a temporary power source can be provided to continue operations until permanent repairs can be made. Examples of this redundancy and isolation are described below.

### 4.8.1 Independent Power Sources

Two independent power feeds from the Snohomish County Public Utility District would serve the Brightwater Treatment Plant (see Final EIS, Chapter 8). The two independent power lines would be mounted on separate poles from the Parkridge and Turners Corner substations to the intersection of SR-9 and 228th Street SE. From there to the Brightwater Treatment Plant substation, the lines would be mounted on the same poles. These poles carrying both lines would be made of steel. If one power feed were to fail along the distance where the lines were mounted separately, the other could be used. However, if one of the steel poles supporting the two power lines near or on the Route 9 site were to be damaged and both power feeds were to fail, short-term loss of power would occur.

An essential services generator with a 48-hour fuel supply would be installed in the treatment plant; this generator could provide power for essential life safety services and limited treatment (primary treatment and disinfection) under all flow conditions until additional portable generation equipment could be brought to the site. Additional power generation capacity would be required to provide secondary treatment. If needed, flows could be diverted to other treatment plants, as described in Chapter 3. It could take a few weeks to months to make permanent repairs to the electrical lines that extend from the regional power grid onto the Route 9 site itself.

Power at the influent pump station would not be affected by a power failure on the treatment plant site because primary power to the pump station is provided by another utility, Puget Sound Energy, which is separate from the power feed to the treatment plant. In addition, backup emergency power generation equipment would be provided on the pump station site for operating the pump station at full capacity. In addition, portable emergency generators are available to keep pump stations operational in the event of power outages.

### 4.8.2 Four Control Centers

Equipment located both on and off the plant site, including equipment in the influent pump station, is designed to be controlled remotely from one of four control centers distributed throughout the proposed Brightwater Treatment Plant site. The main control center would be located in the Operations and Maintenance Building (either in the existing StockPot Building at the north end of the site or in a new building at the south end of the site; see Chapter 1 and Figure 1-4). Satellite control centers would be located in the Membrane Bioreactor (MBR) Basin Building, the Solids Building, and the Energy and Cogeneration Building (see Figure 1-4). Treatment processes and the influent pump station could be shut down from any of these control centers. Following an earthquake, flow to Brightwater could be shut off immediately and would not be restarted until inspections had occurred and the system was deemed safe to operate in accordance with King County emergency response procedures.

If an earthquake were to occur as assumed in Scenario A, B, or C and if main control in the Operations and Maintenance Building were to be damaged, it is assumed that at least one of the three other control centers would suffer only minimal damage and would be fully operational within a short period of time (from a few hours to a few days). The operating control center (or centers) would be used for monitoring and control of the influent pump station and the treatment plant in lieu of main control.

### 4.8.3 Stopping Flow to the Plant and Between Process Units

In a wastewater treatment plant, fixed weirs or pumps control the liquid levels within each of the liquids and solids unit processes. Following an earthquake, the pumps at the offsite influent pump station and the transfer pumps at the Brightwater Treatment Plant would be shut down immediately from one of the four control centers. All flow to the plant would be shut off, flow between process units at the plant would stop, and contents would be contained within the tanks and transfer pipes by the fixed weirs or by shutdown of the transfer pumps.

When flow to the plant stops, the volume of wastewater within the basins, tanks, and pipes would be fixed; the tanks would be full, and no additional flow would come into the plant. Shutoff gates and valves between each tank and basin in the plant are used to isolate the tanks and equipment for normal maintenance and repair. Following an earthquake, these shutoff devices would allow isolation between process units and between individual tanks within a process until repairs could be made.

### 4.8.4 Partial Treatment of Wastewater Using the Split-Flow Process

As discussed in the Final EIS and Chapter 1 of this Supplemental EIS, the proposed Brightwater Treatment Plant would use the split-flow MBR process for treatment of the wastewater. Split-flow means that sustained flows up to a threshold of 39 mgd for Phase 1 and 58 mgd for Phase 2 would receive full secondary biological treatment in the aeration and MBR basins and disinfection at the reclaimed water facility. Flows in excess of the threshold would receive preliminary treatment, advanced primary treatment, and disinfection. The two flows would then be blended prior discharge to Puget Sound.

For this seismic damage assessment, it is assumed that the split-flow treatment capability would allow partial operation of the treatment plant even if individual facilities are damaged. The secondary treatment process would be downstream of the primary treatment process. If an earthquake were to render only the secondary treatment facilities inoperable, Brightwater would have the capability to provide preliminary and advanced primary treatment. If the primary treatment process were not operational, staff would need to bring in portable pumps, pipes, and other equipment to temporarily pump the wastewater around the damaged facilities and into the effluent pipeline. If the effluent pipeline were to remain operational after an earthquake, the system could still discharge the untreated or partially treated effluent to marine waters in Puget Sound rather than allowing uncontrolled overflows onto surface streets or into nearby freshwater streams and lakes.

### 4.8.5 Inspection, Evaluation, Repair

An emergency response plan will be prepared for the Brightwater Regional Wastewater System similar to those used at the West Point and South Treatment Plants (King County, 2003 and 2004). The emergency response plan would require flow to Brightwater to be shut off immediately following an earthquake; flow between process units at the plant would be stopped, and contents would be contained within the tanks and transfer pipes. Flow to the plant would not resume until inspections had occurred and the system was deemed safe to operate.

#### Response in the First 12 Hours After an Earthquake

In the first 12 hours after an earthquake, the main control center at the treatment plant, if undamaged, would become the command center for the plant and its offsite facilities and collection system. If the main control center were damaged, one of the satellite control centers would be designated as the command center. The designated incident commanders would have full authority to mobilize resources and take the actions necessary to respond to the emergency.

The first step would be to perform immediate life-saving functions, including roll call, search-and-rescue, and first aid. Plant personnel would then verify the operation of the communications systems (telephone, radio system, fire alarm system, Internet). They then would perform an initial damage assessment of critical systems and restore plant operations, if possible. (Critical systems are considered to be the electrical distribution system; essential services generator; chemical systems; utilities; and digester gas.) The initial response to hazardous materials releases will be outlined in the Brightwater emergency response plan.

The next steps would be as follows:

- Establish contact with the Wastewater Treatment Division (WTD) representative at the King County Emergency Coordination Centers (ECCs) and report known damage and operational status. Contact with Snohomish County's emergency center would be made through the King County ECC network.
- Establish contact with West Point and South Treatment Plants.
- Help on-duty employees contact their families, if possible.
- Recall available critical personnel.
- Initiate inspection of pipelines, basins, tanks, and buildings.
- Provide physical site security.
- Compile damage reports.
- Determine and inventory basic needs supplies (water, food, and so forth).
- Determine status of equipment and personnel resources.
- Working with the WTD ECC representative, determine viable transportation routes between WTD facilities.
- Report assistance requirements to the WTD ECC representative.
- Prioritize facility and equipment restoration efforts.
- Document known damage and repairs (if possible, take photographs).

### Procedures for Facility Inspection and Repair

Two groups of pre-registered volunteer building inspectors (the Structural Engineers Association of Washington and the American Institute of Architects Disaster Preparedness and Response Committee) would assist in conducting inspections following an earthquake; they would continue providing services until additional resources could be brought into the area.

Before approaching tanks or entering galleries, equipment buildings, tunnels, containment areas, and so forth, inspectors would check the exteriors for major cracks, damaged or offset support pillars, separation or offset between walls and roof, bulging or leaning walls, twisted or buckled columns or beams, and any other damage that could pose a safety risk. All unsafe areas would be secured and cordoned off.

After assessing the operational status of facilities, King County would make temporary emergency repairs, bypasses, and alterations until permanent repair and restoration could be done.

Table 4-4 shows the specific areas of the Brightwater Treatment Plant that would be inspected.

### Table 4-4. Inspection of Brightwater Treatment Plant Facilities Following an Earthquake

| Facility | Inspection Task |
|---|---|
| Operations and Maintenance Building | Inspect main control, laboratory, offices, and warehousing facilities. |
| Chemical storage | Inspect containment areas, tank integrity, chemical dispensing/metering pumps. |
| Plant substation | Check condition of plant substation and Energy and Cogeneration Building. |
| Influent headworks | Inspect raw sewage pump discharges, screen room, distribution channel, and grit chambers. Inspect grit area galleries. Inspect grit dewatering equipment and off-loading facilities. Inspect headworks odor control facility. |
| Primary tanks | Inspect chemical dosing facilities, topside of primary tanks, and primary galleries. |
| Primary effluent structure | Inspect topside as well as effluent pipes. |
| Aeration basins | Inspect topside tank covers and sidewall structures. Inspect aeration equipment galleries. |
| MBR facilities | Inspect topside and gallery equipment. |
| Effluent and reclaimed water facilities | Inspect contact tanks, pump station, and chemical dosing equipment. |
| Primary odor control | Inspect odor control facilities. |
| Secondary odor control | Inspect odor control facilities. |
| Effluent discharge structure | Inspect condition of effluent discharge structure. |
| Solids Building | Inspect gravity belt thickener room and equipment. Inspect dewatering level for centrifuge status, conveyer conditions, storage hopper status. Inspect chemical tanks and associated pumps. Inspect hauler’s loading facilities. |
| Solids Odor Control Building | Inspect odor control facilities. |
| Digesters | Inspect all levels (including roof) of digestion facilities, using extreme caution in case of digester gas odors and leaks. |
| Plant grounds | Look for leaks coming from underground services (water, air, chemicals, and so forth). |

Inspections of the Brightwater conveyance system, including the North Creek, York, Hollywood, and Woodinville Pump Stations, would be similar to those performed for the treatment plant. A multiple-person crew would be dispatched to the influent pump station to perform immediate inspection. They would look for obvious signs of damage, such as heavy cracking of concrete, pipe supports torn from walls, leaking pipes, and other signs of significant structural or mechanical failures. Crews from West Point and South Treatment Plant offsite operations and the facilities inspection group also would be dispatched to inspect the remainder of the facilities associated with the conveyance system. Crews would first inspect the pump stations for signs of major damage. After all of the pump stations had been inspected, crews would drive the route of the force mains looking for obvious signs of force main failure such as surface disruptions or flowing wastewater. Force main discharges would be inspected for signs of mud in the wastewater flow possibly indicating a major force main break. After the force mains and pump stations were inspected the rest of the structures and gravity lines in the conveyance system would be inspected. To protect public health and safety, King County would immediately initiate emergency cleanup actions for spills, overflows, and backups from its conveyance system that have an impact on public and/or private property.

Repair of minor cracks in the pipelines within the combined tunnel that could occur under Scenarios A and C would be added to King County's list of scheduled maintenance activities. This activity would be planned to occur during the summer, when all wastewater flows would be the lowest and could be transferred from the Brightwater Service Area to King County's other two treatment plants with the least risk of emergency overflows. Once all flows had been transferred, the conveyance tunnel would be shut down and repairs would be made.

If the combined tunnel and the internal piping were ruptured under Scenario B, the treatment plant and conveyance system would be shut down. Repair to the failed tunnel section would include the excavation of a shaft to access the tunnel break and the removal and replacement of the broken concrete segments and internal piping. Several months would be needed to make the repairs.

### Time Frame for Repair of Facilities

For Scenario A the time frame for repair is expected to be relatively short, on the order of hours to a few days depending on the location and extent of damage.

Under Scenario B, the combined tunnel would break, and up to 6 months would be required to repair the break. Under Scenarios A and C, the pipelines and pipeline joints within the tunnel could crack or become offset, but the tunnel itself would not break. The tunnel would remain operational, and pipelines and joints would be repaired as part of scheduled system maintenance.

For Scenario C, where more significant damage would be expected, more time would be needed for treatment plant repairs so that the system is operational and damaged structures are safe to occupy:

- From a few hours to 6 months for electrical feed and essential liquid treatment systems and up to a year for complete liquids treatment
- From 1 week to a year for solids building, digester building, and energy building
- From weeks to months for buildings not essential to the treatment process, such as the Operation And Maintenance Building and the Community-Oriented Building

## 4.9 References


ASCE (American Society of Civil Engineers) Technical Council on Lifeline Earthquake Engineering. 1995. Northridge Earthquake, Lifeline Performance and Post-Earthquake Response. Anshel Schiff, Editor. August 1995.

Blakely, R.J., Wells, R.E., Weaver, C.S., and Johnson, S.Y. 2002. Location, structure, and seismicity of the Seattle Fault Zone, Washington: Evidence from aeromagnetic anomalies, geologic mapping, and seismic-reflection data. *Geological Society of America Bulletin, 114*, 169-177.

Brocher, T.M., Blakely, R.J., and Wells, R.E. 2004. Interpretation of the Seattle uplift, Washington, as a passive-roof duplex. *Bulletin of the Seismological Society of America*, *94* (4), 1370-1401.

Earthquake Engineering Research Institute (EERI). 1990. Earthquake Spectra. Supplement to Volume 6. Soma Prieta Earthquake Reconnaissance Report. Lee Benuska, Editor. May 1990.

Earthquake Engineering Research Institute (EERI). 1995. Earthquake Spectra. Supplement C to Volume 11. Northridge Earthquake Reconnaissance Report, Volume 1. John F. Hall, Editor. April 1995.

Earthquake Engineering Research Institute (EERI). 2001a. Earthquake Spectra. Supplement A to Volume 17. 1999 Chi Chi, Taiwan Earthquake Reconnaissance Report, Roger Borcherdt, Editor. April 2001.

Earthquake Engineering Research Institute (EERI). 2001b. The Nisqually, Washington, Earthquake of February 28, 2001: EERI Learning from Earthquakes Preliminary Reconnaissance Report. University of Washington, Seattle, WA. March 2001.

Earthquake Engineering Research Institute (EERI), in press. *Scenario for a magnitude 6.7 earthquake on the Seattle Fault*. Oakland, CA.

Haugerud, R.A., Ballantyne, D.B., Weaver, C.S., Meagher, K.L., and Barnett, E.A. 1999. *Lifelines and earthquake hazards in the greater Seattle area.* U.S. Geological Survey Open-File Report 99-387.

Johnson, S.Y., Potter, C.J., and Armentrout, J.M. 1994. Origin and evolution of the Seattle fault and Seattle basin, Washington. *Geology, 22*, p. 71-74.

Johnson. S.Y., Potter, C.J., Armentrout, J.M., Miller, J.J., Finn, C., and Weaver, C.S. 1996. The Southern Whidbey Island Fault: An active structure in the Puget Lowland, Washington. *Geological Society of America Bulletin, 108*, 334-354.

Johnson, S.Y, and Sherrod, B.L. 2003. *Active tectonics, Island County, Washington.* Washington Section AEG field trip, May 17-18, 2003.

King County. 2003, revised 2004. Emergency response plan: South Treatment Plant. Publication 280. Seattle, WA: Department of Natural Resources and Parks, Wastewater Treatment Division.

King County. 2004. Emergency response plan: West Point Treatment Plant. Publication 280. Seattle, WA: Department of Natural Resources and Parks, Wastewater Treatment Division.

King County. 2005. *Assessment for utilization of StockPot Building*. Prepared for King County Wastewater Treatment Division by CH2M HILL, Brown and Caldwell, Mithun, and Associated Firms. Seattle, WA. March 16, 2005.

National Center for Earthquake Engineering Research (NCEER). 1996. The Hanshin-Awaji Earthquake of January 17, 1995, Performance of Lifelines.

National Institute of Standards and Technology (NIST). 1996. The January 177, 1995, Hyogoken-Nanbu (Kobe) Earthquake, Performance of Structures, Lifelines, and Fire Protection Systems. NIST Special Publication 901. Riley Chung, Editor. July 1996.

Sherrod, B.L., Brocher, T.M., Weaver, C.S., Buckham, R.C., Blakely, R.J., Kelsey, H.M., Nelson, A.R., and Haugerud, R. 2004. Holocene fault scarps near Tacoma, Washington, USA. *Geology, 32* (1), 9-12.

## LIST OF FIGURES


Figure 4-1 Regional Transportation System

Figure 4-2 Lifelines and Earthquake Hazards in the Puget Lowland

Figure 4-3 Rerouting of Average Dry-Weather and Maximum Monthly Flows During Brightwater Treatment Plant Shutdown

Figure 4-4 Rerouting of Flows Above Maximum Monthly Flow and Overflow Locations During Brightwater Treatment Plant Shutdown