Vulnerability of Major Wastewater Facilities to Flooding from Sea-Level Rise

July 2008

King County

Department of
Natural Resources and Parks
Wastewater Treatment Division

King County's Wastewater Treatment Division maintains 77 major facilities, 40 of which are situated adjacent to tidally influenced water bodies. As effects of climate change continue to grow, the potential for flooding at these facilities as the result of sea-level rise must be assessed and mitigated. The first step in planning for the effects of sea-level rise is to identify which facilities are at risk. This report identifies these facilities and their potential for flooding, considering the effects of both sea-level rise and storm surges, and then recommends the next steps in planning for this change.[1]

Tidally Influenced Facilities in King County's System

King County is located on Puget Sound and covers more than 2,200 square miles. With over 1.9 million people, King County is the 14th most populous county in the nation. The county's Wastewater Treatment Division (WTD) protects water quality and public health in the Central Puget Sound region by collecting and treating wastewater from 17 cities, 16 local sewer utilities, and 1 Indian tribe.

The regional wastewater system serves about 1.4 million people, including most urban areas of King County and parts of south Snohomish County and northeast Pierce County. The system includes two large regional treatment plants (West Point in the City of Seattle and South plant in the City of Renton), one small treatment plant and one community septic system on Vashon Island, four combined sewer overflow (CSO) treatment facilities in Seattle, over 335 miles of pipes, 19 regulator stations, 42 pump stations, and 38 CSO outfalls. Construction on two new treatment plants began in 2006: the Brightwater Treatment Plant, the system's third regional plant, scheduled for completion in 2010, and a smaller local treatment plant in the city of Carnation, scheduled for completion in mid 2008.

The impact of sea-level rise to WTD facilities will depend on both the degree and rate of the rise. It is expected that only facilities that lie near tidally influenced water bodies will be affected in the near future. For this analysis, pump stations, regulator stations, and treatment plants were selected that lie in a basin of naturally occurring drainage directly to Puget Sound or the Duwamish River. The Brightwater Sampling Facility and Flow Meter Vault at the junction of the effluent tunnel and marine outfall were also included because of their proximity to Puget Sound. Figure 1 shows the area considered and the location of facilities in this area.

Other facilities will be subject to impacts if sea-level rise exceeds 18.25 feet. Above this level, Puget Sound will match the height of Lake Washington. Facilities adjacent to Lake Washington, the lower portions of the Sammamish River, and the lower portions of the Cedar River would require consideration because of potential tidal influence, although impacts may be mitigated by the Hiram M. Chittenden locks. These impacts and the potential impacts to the Duwamish River upstream of the Turning Basin were not considered in this analysis.

[1] A storm surge is the local change in the elevation of the ocean along a shore caused by a storm.

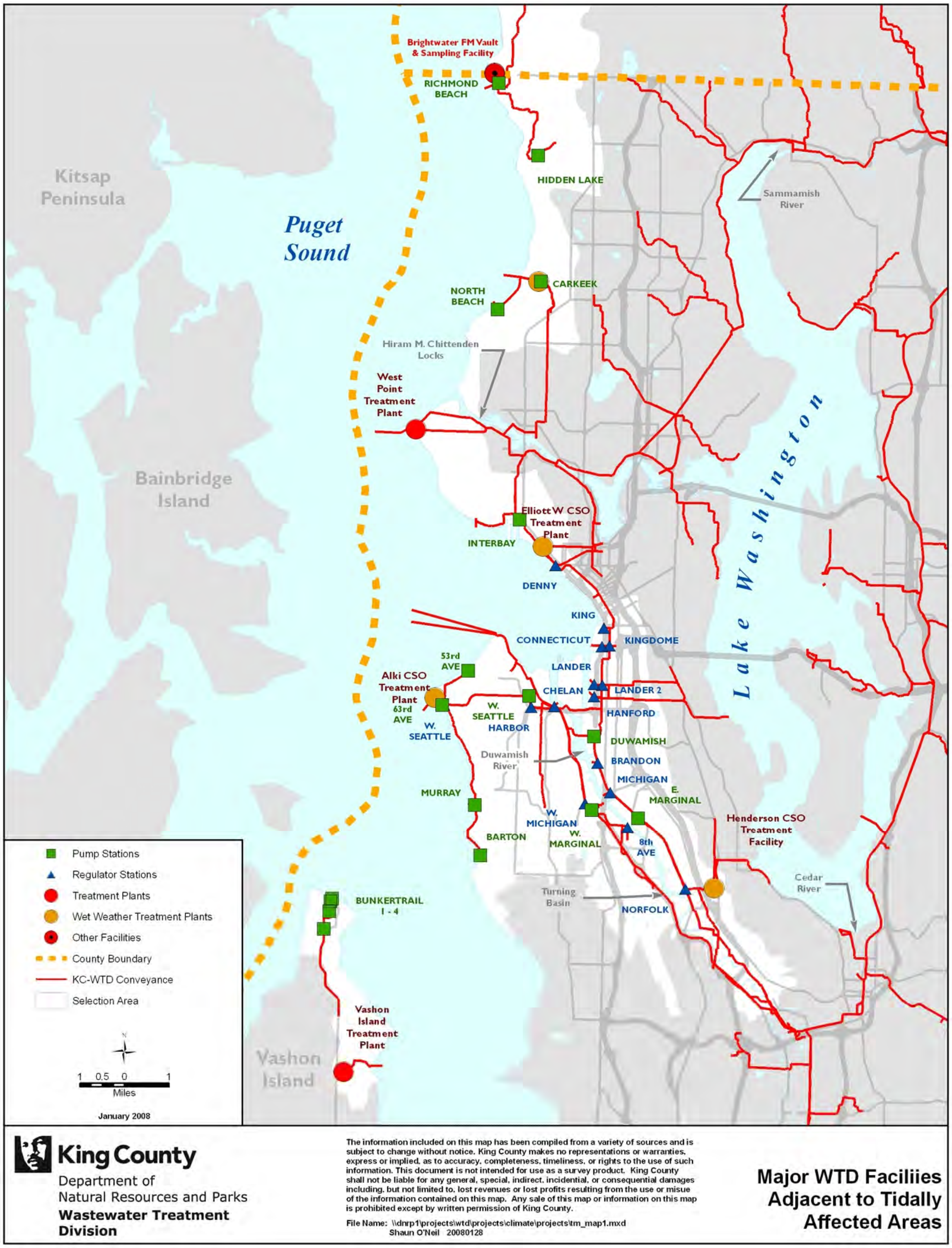

Figure 1. Major WTD Facilities Adjacent to Tidally Affected Areas

Sea-Level Rise Projections for Puget Sound

According to projections developed by the United Nations International Panel on Climate Change (IPCC), the planet could experience a mean sea-level rise in a range of 7 to 23 inches during the twenty-first century excluding future rapid dynamical changes in ice flow (IPCC, 2007). The IPCC based its projections on thermal expansion of the ocean and melting of land-based ice including glaciers, ice caps, and the Greenland and Antarctic ice sheets.

The University of Washington's Climate Impacts Group (UW CIG) completed a regional analysis of sea-level rise for Washington State's major tidally influenced water bodies (Mote et al., 2008). The study used the IPCC global projections combined with analysis of local changes in wind, which push coastal waters toward or away from shore, and local movement of land, primarily from tectonic forces. The results of the UW CIG analysis indicate that the medium scenario expected in Puget Sound is a sea-level rise of 6 inches by 2050 and of 13 inches by 2100 (Table 1).

Low-probability scenarios were estimated for sea-level rise at the low- and high-impact extremes. For the "very low" scenario, sea-level rise is predicted to be less than 3 inches by 2050 and less than 6 inches by 2100. For the "very high" scenario, sea-level rise is predicted to be more than 22 inches by 2050 and more than 50 inches by 2100.

The range of sea-level rise for all UW CIG scenarios runs from 3 to 50 inches (0.25 to 4.17 feet).[2] Probabilities were not quantified for the scenarios.

Table 1. Puget Sound Sea-Level Rise Scenarios (Mote et al., 2008)

Scenario	Predicted Sea-Level Rise	
	2050	2100
Very low sea-level rise—low probability–low impact	3 inches (0.25 feet)	6 inches (0.50 feet)
Medium sea-level rise	6 inches (0.50 feet)	13 inches (1.08 feet)
Very high sea-level rise—low probability–high impact	22 inches (1.83 feet)	50 inches (4.17 feet)

The assumptions regarding the rates and impacts of the melting ice sheets were modest in both the IPCC and UW CIG projections. Other studies predict more rapid melting of glaciers and ice sheets and their effects on sea-level rise for the planet (Csatho et al., 2008, and Hansen, 2007). Csatho et al. (2008), for example, indicate that ice sheet models usually do not include all the complexity of ice dynamics that can occur in nature. If current climate models from the IPCC had included data from ice dynamics in Greenland, the sea-level rise estimated during this century could be twice as high (University at Buffalo, 2008). Hansen (2007) indicates a possible "multi-meter" rise in sea level in the future.

Although these studies did not incorporate local analysis of sea-level rise, a 20-foot rise in sea level is included as a scenario ("rapid ice sheet melt" scenario) in this analysis to capture the wide range of possibilities. This level of rise is in the range of predictions made by the studies

[2] In the remainder of this paper, sea-level rise projections are given in feet rather than inches.

and allows for a very low-probability upper extreme for assessing potential impacts to facilities. Inclusion of these types of extreme scenarios, whether or not they are scientifically accepted, in the analysis is necessary to answer questions that arise from postulation of such scenarios.

Scope and Assumptions for this Analysis

This analysis was conducted to broadly evaluate current sea-level rise and storm event data and to roughly identify facilities that might be at risk at estimated levels of sea-level rise. The scope and assumptions for the analysis are as follows:

- Absolute sea-level rise was considered; no consideration was given to individual wave effects, coastal erosion, or tsunamis.
- The possibility of onsite flooding resulting from sea-level rise was considered: no consideration was given to the effects on system hydraulics.
- It was assumed that storm-triggered rise in sea level would continue to occur at historical levels for various storm return frequencies.
- All sites were assumed to be flat with no areas of higher elevation between the site and the tidally influenced water body that would protect the site from the potential impacts of sea-level rise.
- The GIS location in the center of each facility was assumed to be representative of the entire facility site.
- Facilities in a basin that naturally drains to Puget Sound or the tidally influenced lower section of the Duwamish River were considered regardless of elevation. No consideration was given to facilities located in basins that drain to non-tidally influenced water bodies.
- It was assumed that the U.S. Army Corps of Engineers will maintain the level of Lake Washington and some low-lying river reaches through its operation of the Hiram M. Chittenden locks.
- The rate at which the sea-level rise will occur is still the widest ranging variable in understanding sea-level rise. The emphasis in this analysis, therefore, is on which facilities will be impacted at various increases in sea level, regardless of when the increases would occur. This approach ensures that conclusions of the analysis will remain valid even as the model results change to incorporate additional data in the future.
- The analysis did not include policy level evaluations of acceptable risk and potential adaptive strategies to mitigate future onsite flooding.

Methodology

The following methodology was used to evaluate the impact of sea-level rise on WTD facilities:

- Determine the elevation of the identified facilities in the vicinity of tidally influenced water bodies
- Identify current tide levels
- Identify historical increases in tide heights from storm events with various return frequencies

- Calculate the tide height above mean higher high water for each combination of sea-level rise scenario and storm event
- Compare resulting tide heights to elevation of each facility
- Identify which facilities are at risk of onsite flooding from each combination of sea-level rise and storm event

Results

Facility Elevations

GIS technology and data were used to determine a representative elevation for each facility, typically at the center point of the facility (Table 2). The Facility Information Retrieval System (FIRS) database contains a point location for each facility. This point was used in conjunction with a LIDAR-derived triangulated irregular network (TIN).[3,4] The LIDAR data were created as a result of Puget Sound LIDAR Consortium flights in 2001 and 2002. The elevation data from the TIN were associated with each facility location using the SurfaceSpot tool from the Environmental Systems Research Institute (ESRI) ArcGIS software. The LIDAR elevations were recorded in North American Vertical Datum of 1988 (NAVD88) using feet as units.[5] This was the standard elevation used throughout this analysis. The root mean square error of the LIDAR elevation is 30 cm (1 foot). Because of this error level, each elevation is recorded to the nearest foot.

Table 2. Major WTD Facilities and their Elevations

Facility	Elevation (feet above NAVD88 zero)
53rd Street Pump Station	17
63rd Street Pump Station	21
8th Ave Regulator Station	13
Alki CSO Treatment Plant	28
Barton Pump Station	13
Brandon Regulator Station	17
Brightwater Sampling Facility	13
Brightwater Flow Meter Vault	14
Bunker Trail Pump Station 1	27
Bunker Trail Pump Station 2	76
Bunker Trail Pump Station 3	219
Bunker Trail Pump Station 4	363
Carkeek Pump Station	55
Carkeek CSO Treatment Plant	46

[3] LIDAR (Light Detection and Ranging) is an active sensor, similar to radar, that transmits laser pulses to a target and records the time it takes for the pulse to return to the sensor receiver. LIDAR is used for high-resolution topographic mapping by mounting a LIDAR sensor, integrated with Global Positioning System (GPS) and inertial measurement unit (IMU) technology, to the bottom of aircraft and measuring the pulse return rate to determine surface elevations.

[4] A triangulated irregular network (TIN) is a digital data structure used in a GIS to represent a surface. A TIN is a vector based representation of the physical land surface or sea bottom, made up of irregularly distributed nodes and lines with three dimensional coordinates (x,y, and z) that are arranged in a network of non-overlapping triangles.

[5] NAVD 1988 is a fixed reference for terrestrial elevations.

Chelan Regulator Station	15
Connecticut Regulator Station	16
Denny Regulator Station	16
Duwamish Pump Station	17
East Marginal Pump Station	18
Elliott West CSO Treatment Facility	14
Hanford 2 Regulator Station	15
Harbor Regulator Station	21
Henderson/MLK WWTF	58
Hidden Lake Pump Station	239
Interbay Pump Station	16
King Street Regulator Station	16
Kingdome Regulator Station	17
Lander 2 Regulator Station	16
Lander Regulator Station	15
Michigan Regulator Station	16
Murray Pump Station	19
Norfolk Regulator Station	18
North Beach Pump Station	39
Richmond Beach Pump Station	26
Vashon Wastewater Treatment Plant	284
West Marginal Pump Station	20
West Michigan Regulator Station	30
West Point Wastewater Treatment Plant	21
West Seattle Pump Station	23
West Seattle Regulator Station	22

Measured Tide Levels

Current tidal data were taken from the National Oceanic and Atmospheric Administration (NOAA) Tides and Currents Web site for the Seattle tide gauge located at Coleman Dock, which is centrally located to all facilities considered.[6] The data are based on the last tidal epoch, defined as the 19-year period from 1983 through 2001. For this analysis, the mean higher high water (MHHW) datum was used as the base elevation. MHHW is the average of the higher high water height of each tidal day over the course of the tidal epoch. It is the mean level at which the facilities will experience site flooding with the least amount of sea-level rise. For the Seattle tide gauge, the MHHW is 9.01 feet above NAVD88 zero feet (Table 3).

The highest observed level recorded at this gauge since recordkeeping began in 1899 is 12.14 feet above NAVD88 zero feet (3.13 feet above MHHW). This level reflects the impact of an extreme storm event.

[6] http://tidesandcurrents.noaa.gov/station_info.shtml?stn=9447130+SEATTLE,+PUGET+SOUND,+WA

Table 3. Seattle Tide Gauge Data (January 1983–December 2001)

	Elevation (above NAVD88 zero feet)
Highest observed water level (January 27,1983)	12.14
Mean higher high water (MHHW)	9.01
Mean high water (MHW)	8.15
Mean tide level (MTL)	4.32
Mean sea level (MSL)	4.29
Mean lower low water (MLLW)	-2.35
Lowest observed water level (January 4, 1916)	-7.38

Historical Effects of Storms on Tide Levels

Because they affect local tides, the frequency and intensity of storm events must be considered in the analysis of sea-level rise and its impact on WTD facilities. Generally, intense storm events occur less frequently than smaller storms. Zervas (2005) analyzed the response of extreme tide levels (from storms with a return frequency of 100 years) to long-term sea-level rise at various coastal stations, including Seattle. According to Zervas (2007), tidal heights above MHHW in Puget Sound range from 1.48 feet for a storm with a return frequency of once a year to 3.19 feet for a storm with a return frequency of once in 100 years. The extreme increase in tidal height from the 100-year storm conforms with the highest observed tide at (3.13 feet above MHHW) at the Seattle gauge.

Impacts of Sea-Level Rise Projections and Storm Effects on WTD Facilities

Projected increases in sea level for each of the three UW CIG scenarios (each divided into two timeframes) and for the rapid ice sheet melt scenario were coupled with increases based on historical data on storm events with return frequencies of once every 1 year, 2 years, 10 years, and 100 years. The UW CIG projections were also considered alone to assess the influence of climate change in the absence of a storm event. The resulting 35 permutations are shown in Table 4.

The resulting estimated high tide levels (MHHW plus sea-level rise projections and the effects of storm surges on tides) range from 9.26 to 32.20 feet above NAVD88 zero.

As shown in Tables 4 and 5, no facilities are at risk of flooding with a sea-level rise of less than about 0.8 feet.

Facilities could flood as early as 2050 under the UW CIG low probability–high impact sea-level rise scenario coupled with effects of 2-year, 10-year, and 100-year storms. During the 2-year and 10-year storms under this scenario, the three lowest elevation facilities would flood by 2050. These facilities are the Barton Pump Station, the 8th Avenue Regulator Station on the Duwamish River, and the new Sampling Facility on the Brightwater marine outfall. During the 100-year storm under the same scenario, an additional two facilities would flood by 2050 (the Brightwater Flow Meter Vault and the Elliott West CSO Treatment Facility).

By 2100, the three lowest elevation facilities would flood during a 100-year storm under the UW CIG medium sea-level rise scenario and would flood in non-storm conditions from the effects of sea-level rise only under the UW CIG low probability–high impact scenario. Under the same low probability–high impact sea-level rise scenario for 2100, five facilities would flood during the 1-year storm, eight facilities during the 2-year and 10-year storms, and fourteen facilities during the 100-year storm.

Under the rapid ice sheet melt scenario, 30 or more facilities would flood under non-storm conditions and under all storm events analyzed.

Figure 2 gives an example of the impacts of various scenarios for the Barton Pump Station, one of three lowest elevation facilities (13 feet). The figure shows that the pump station would flood by 2100 with a sea-level rise above 0.8 feet and rise in tide from a 100-year storm.

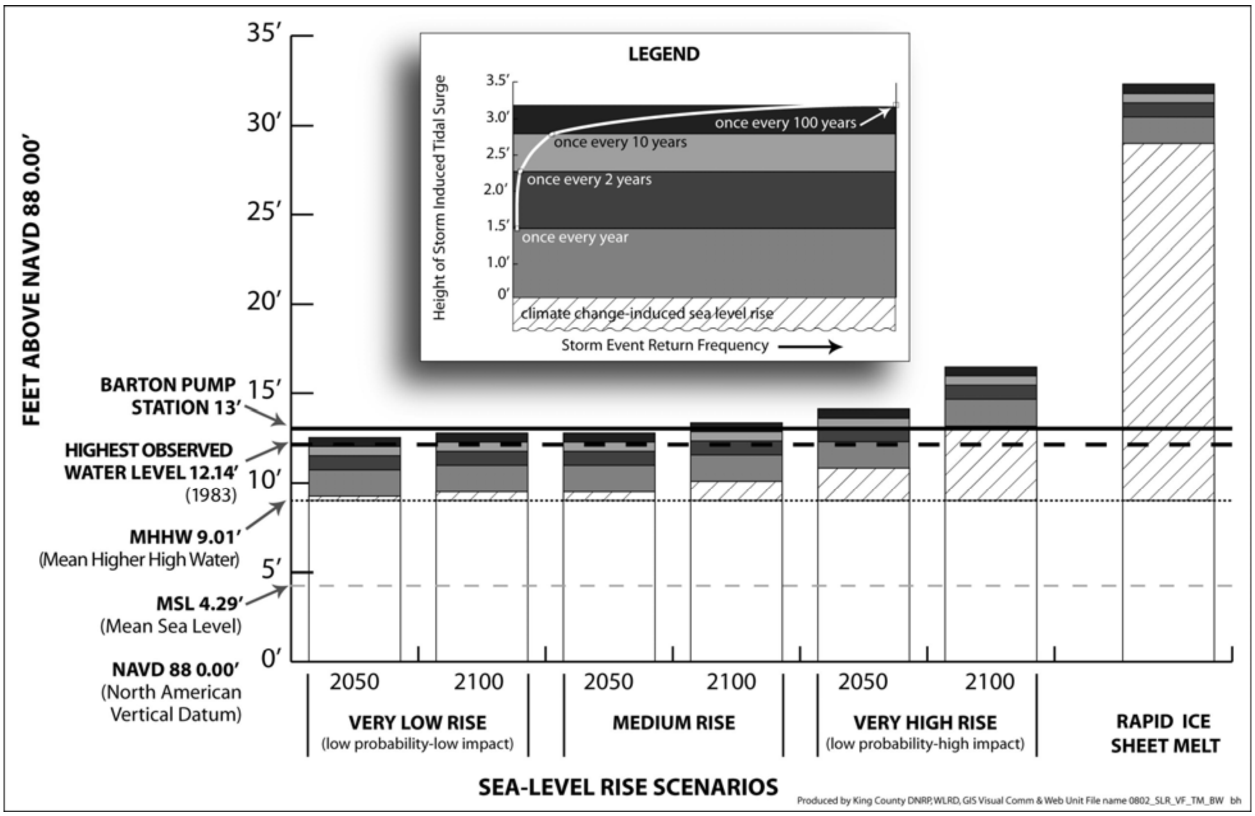

Figure 2. Potential for Flooding at the Barton Pump Station from Sea-Level Rise and Storm Surges

Table 4. Combination of Sea-Level Rise Projections and Historical Storm Effects on Tides (plus MHHW of 9.01 feet above NAVD88 zero)

	UW CIG Sea-Level Rise Scenarios (feet)[b]						Rapid Ice Sheet Melt Scenario[c]
	2050 Low Probability–Low Impact	2100 Low Probability–Low Impact	2050 Medium	2100 Medium	2050 Low Probability–High Impact	2100 Low Probability–High Impact	
Sea-level rise—no storm event	0.25 (9.26)	0.50 (9.51)	0.50 (9.51)	1.08 (10.09)	1.83 (10.84)	4.17 (13.18)	20 (19.01
Sea-level rise plus increase of 1.48 feet from once every 1 year storm (100%)	1.73 (10.07)	1.98 (10.99)	1.98 (10.99)	2.56 (11.57)	3.31 (12.32)	5.65 (14.66)	21.48 (30.49)
Sea-level rise plus increase of 2.27 feet from once every 2 years storm (50%)	2.52 (11.5)	2.77 (11.78)	2.77 (11.78)	3.35 (12.36)	4.10 (13.11)	6.44 (15.45)	22.27 (31.28)
Sea-level rise plus increase of 2.79 feet from once every 10 years storm (10%)	3.04 (12.00)	3.29 (12.30)	3.29 (12.30)	3.87 (12.88)	4.62 (13.63)	6.96 (15.97)	22.79 (31.80)
Sea-level rise plus increase of 3.19 feet from once every 100 years storm (1%)	3.44 (12.45)	3.69 (12.70)	3.69 (12.70)	4.27 (13.28)	5.02 (14.03)	7.36 (16.37)	23.19 (32.20)

Number of facilities at risk of onsite flooding: 0,3,5,8,14,>30

[a] Zervas, 2007.

[b] University of Washington Climate Impacts Group (Mote et al., 2008)

[c] Based on Csatho et al., 2008; Gornitz et al., 2007; Gregory et al., 2004; and Hansen, 2007.

Conclusions and Recommendations

The analysis indicates that more than 30 major WTD facilities are at risk of flooding from sea-level rise. This level of risk is based entirely on the rate at which the rise occurs and the probability of an extreme storm event. According to the 2008 UW CIG report, the probability of imminent impact is low. If the results in that report do not change over time, the risks of flooding remain low until after 2050. Given the current flux of climate change research, it is likely that these results will change. Not only could the estimates of rate of sea-level rise change but also the frequency of storm events.

Given the uncertainty of the rate and extent of change over the next century and the long life of WTD major facilities, recommendations are as follows:

- A more detailed analysis of the site terrain should be conducted of the five facilities that fall below expected sea-level rise for the UW CIG medium scenario by 2100 and low probability–high impact scenario by 2050 under the 100-year extreme storm event. Extensive site elevation data should be used to evaluate the entire site and its vulnerabilities, including direction of flood and site layout, and adaptive strategies short of relocation should be identified.
- A detailed analysis of the terrain should be conducted for the West Point Treatment Plant site because of its large size and wide range of elevations. The entire site should be evaluated to determine the lowest point, which would be at greatest risk of onsite flooding as a result of sea-level rise. The criticality of the facility to the operation of WTD's system lends even more urgency to this more detailed analysis.
- Because the Brightwater Sampling Facility and Flow Meter Vault sites are not complete, are potentially at high risk, and are many decades from any consideration of upgrades, a review should be conducted immediately of the design for the sites with regard to their vulnerability to sea-level rise. The impacts of flooding should be evaluated and the costs of redesign should be compared to the cost of a future upgrades that may be needed to adapt to potential flooding.
- An analysis of the impacts of sea-level rise to WTD system hydraulics should be conducted to determine if design or operational changes are needed to mitigate the potential effects of sea-level rise.
- Sea-level rise should be included as a factor in planning for major asset rehabilitation or conveyance planning that involves any of the facilities included in this analysis. Adaptive strategies to reduce the risk of flooding should be adopted and designed into rehabilitation or upgrades based on the outcome of a risk analysis for a site and an analysis comparing benefits and costs of adopting the adaptive strategy.
- Sea-level rise literature should be reviewed every five years in conjunction with updates to the Conveyance System Improvement program to determine if changes are needed to WTD's planning approach.

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Table 5. Risk of Onsite Flooding at Major Wastewater Treatment Division Facilities from Sea-Level Rise and Storm Events

		University of Washington, Climate Impacts Group, Sea-Level Rise Scenarios[a]																																		
		2050 Low Probability–Low Impact Sea-Level Rise Scenario (0.25 foot)					2100 Low Probability–Low Impact Sea-Level Rise Scenario (0.50 foot)					2050 Medium Sea-Level Rise Scenario (0.50 foot)					2100 Medium Sea Rise Scenario (1.08 feet)					2050 Low Probability–High Impact Sea-Level Rise Scenario (1.83 feet)					2100 Low Probability–High Impact Sea-Level Rise Scenario (4.17 feet)					Rapid Ice Sheet Melt Sea-Level Rise Scenario (20.00 feet)				
		No Event	Once a Year Event	Once Every Two Year Event	Once Every Ten Year Event	Once Every 100 Year Event	No Event	Once a Year Event	Once Every Two Year Event	Once Every Ten Year Event	Once Every 100 Year Event	No Event	Once a Year Event	Once Every Two Year Event	Once Every Ten Year Event	Once Every 100 Year Event	No Event	Once a Year Event	Once Every Two Year Event	Once Every Ten Year Event	Once Every 100 Year Event	No Event	Once a Year Event	Once Every Two Year Event	Once Every Ten Year Event	Once Every 100 Year Event	No Event	Once a Year Event	Once Every Two Year Event	Once Every Ten Year Event	Once Every 100 Year Event	No Event	Once a Year Event	Once Every Two Year Event	Once Every Ten Year Event	Once Every 100 Year Event
Sea-level rise plus storm surge (feet)		0.25	1.73	2.52	3.04	3.44	0.50	1.98	2.77	3.29	3.69	0.50	1.98	2.77	3.29	3.69	1.08	2.56	3.35	3.87	4.27	1.83	3.31	4.10	4.62	5.02	4.17	5.65	6.44	6.96	7.36	20.00	21.48	22.27	22.79	23.19
Elevation above NAVD88 0.00 feet: Tide elevation →		9.26	10.74	11.53	12.05	12.45	9.51	10.99	11.78	12.30	12.70	9.51	10.99	11.78	12.30	12.70	10.09	11.57	12.36	12.88	13.28	10.84	12.32	13.11	13.63	14.03	13.18	14.66	15.45	15.97	16.37	29.01	30.49	31.28	31.80	32.20
Facility elevation ↓																																				
Barton Pump Station	13																				●			●	●	●	●	●	●	●	●	●	●	●	●	●
8th Ave Regulator Station	13																				●			●	●	●	●	●	●	●	●	●	●	●	●	●
Brightwater Sampling Facility	13																				●			●	●	●	●	●	●	●	●	●	●	●	●	●
Brightwater Flow Meter Vault	14																									●		●	●	●	●	●	●	●	●	●
Elliott West CSO Facility	14																									●		●	●	●	●	●	●	●	●	●
Lander Regulator Station	15																												●	●	●	●	●	●	●	●
Hanford 2 Regulator Station	15																												●	●	●	●	●	●	●	●
Chelan Regulator Station	15																												●	●	●	●	●	●	●	●
King Street Regulator Station	16																														●	●	●	●	●	●
Connecticut Regulator Station	16																														●	●	●	●	●	●
Interbay Pump Station	16																														●	●	●	●	●	●
Denny Regulator Station	16																														●	●	●	●	●	●
Michigan Regulator Station	16																														●	●	●	●	●	●
Lander 2 Regulator Station	16																														●	●	●	●	●	●
53rd Street Pump Station	17																															●	●	●	●	●
Kingdome Regulator Station	17																															●	●	●	●	●
Brandon Regulator Station	17																															●	●	●	●	●
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West Marginal Pump Station	20																															●	●	●	●	●
Harbor Regulator Station	21																															●	●	●	●	●
63rd Street Pump Station	21																															●	●	●	●	●
West Point Treatment Plant	21																															●	●	●	●	●
West Seattle Regulator Station	22																															●	●	●	●	●
West Seattle Pump Station	23																															●	●	●	●	●
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Bunker Trail Pump Station 1	27																															●	●	●	●	●
Alki CSO Treatment Plant	28																															●	●	●	●	●
West Michigan Regulator Station	30																																●	●	●	●

[a] Mote, P., Petersen A., Reeder, S., Shipman, H., and Whitely Binder, L. 2008. *Sea Level Rise in the Coastal Waters of Washington State.* Report prepared by the Climate Impacts Group, University of Washington, Seattle, Washington, and the Washington Department of Ecology, Lacey, Washington.