Appendix C.

Building Code Regulations and Seismic Studies Used in the Structural Design of Brightwater Facilities

DRAFT SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT

Brightwater Regional Wastewater Treatment System

Technical Appendices

Brightwater
TREATMENT SYSTEM

Appendix C

Building Code Regulations and Seismic Studies Used in the Structural Design of the Brightwater Facilities

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1.0 INTRODUCTION

The Brightwater facility seismic design is in accordance with the provisions of the 2003 Edition of the International Building Code (IBC 2003), which is published by the International Code Committee (ICC). This code is a relatively new document that represents the current state of seismic-resistant design within the United States. IBC 2003 was adopted by the State of Washington in July 2004 to replace the previously applicable code, the 1997 Uniform Building Code (UBC 97).

The seismic provisions in IBC 2003 are based on the National Earthquake Hazards Reduction Program (NEHRP) Recommended Provisions for Seismic Regulations for New Buildings and Other Structures (FEMA 368 & 369, 2001). The fundamental purpose of the seismic provisions in IBC 2003 is to provide minimum building design standards that will maintain public safety of building occupants during a very strong earthquake. Structures designed in conformance with the IBC 2003 will, in general, be able to:

- Resist minor levels of earthquake ground motion without damage.
- Resist a moderate level of earthquake ground motion without structural damage, but possibly experience some non-structural damage.
- Resist a major level of earthquake ground motion – of intensity equal to the strongest earthquake, either experienced or forecast for the building site, without collapse.

It should be noted that the IBC 2003 is intended primarily for building design, and other industry-accepted regulations (AWWA D-100 Welded Steel Tanks for Water Storage, AWWA D-110 Wire Wound Circular Prestressed Concrete Water Tanks, ACI 318 Building Code Requirements for Structural Concrete and Commentary, and ACI 350 Code requirements for Environmental Engineering Concrete) are typically used in conjunction with the IBC 2003 provisions to provide earthquake resistance for water and waste water facilities.

An important concept associated with seismic design codes is that of “life safety.” The codes provide minimum design criteria for structures considering the need to protect the health, safety, and welfare of the general public by minimizing the earthquake-related risk to life. This provides a definition of “life safety.” Life safety does not, however, mean that the building will be undamaged during an earthquake. Rather, it indicates that damage that occurs is not expected to result in risk to life.

IBC 2003 seismic forces used for design are derived from three sources: (1) the estimation of Seismic-Induced Ground Motions, including adjustments for the type of soil expected at the site, (2) the Seismic Use Group, which is based on expected performance of the structure or building, and (3) the Seismic Design Category, which is based on expected ground motion. Code requirements within each of these areas are summarized in the following sections of this technical memorandum. The final sections of this technical memorandum provide a summary of these requirements relative to the design and performance of the Brightwater facility.

2.0 SEISMIC-INDUCED GROUND MOTIONS

The intent of the seismic provisions in IBC 2003 is to provide for uniform levels of performance for structures located anywhere in the United States. These performance goals consider the occupancy, use, and potential risks to society. To meet the uniform performance requirement, ground motion hazards are defined in terms of a Maximum Considered Earthquake (MCE). For most of the United States, the MCE is defined with a uniform probability of exceedence of 2 percent in 50 years or a return period of approximately 2,500 years. Stronger shaking than this can occur at a particular site, but it has been judged by the industry to be economically impractical to design for such a rare event.

A typical IBC 2003 seismic analysis estimates design ground motions from mapped spectral points based on a National Hazard Study conducted by the United States Geological Society (USGS). For most building sites, these mapped spectral points provide a suitably accurate estimate of the MCE. However, in some situations a site-specific probabilistic seismic hazard analysis (PSHA) is conducted to estimate ground motions required for design.

2.1 Site-Specific Ground Motions for Rock

Site-specific PSHAs are usually conducted when there has been either a significant change in the understanding of causes, locations, or frequencies of earthquakes in an area, or a significant change in how the earthquake wave propagation process is modeled. In this situation, the USGS national hazard maps may no longer represent the most up-to-date seismic source model for the area. IBC 2003 allows a site-specific PSHA to be conducted (see Section 1615.2) but imposes restrictions on the amount of reduction in ground motions that is permitted by the site-specific analyses relative to the USGS map values.

A site-specific PSHA was undertaken as a part of the Brightwater siting study to account for the location and activity of faults forming the Southern Whidbey Island Fault (SWIF) zone as reported by USGS in their Open File Report in March, 2004 (USGS, 2004). That information about the SWIF has been described in previous addenda to the Final Environmental Impact Statement (FEIS). The updated site-specific PSHA considered new information related to potential fault locations, seismic history, and chronicled past earthquakes that may have affected the Brightwater site resulting from the trench excavation along Lineament 4 in October, 2004. Appendix “A” to this SEIS document summarizes the results of the trench excavation work. From the results of the updated site-specific PSHA, site-specific ground shaking parameters were developed and are being used in the Brightwater design.

The site-specific seismic data used for the Brightwater design is from Shannon and Wilson’s PSHA, dated March 2005. The updated PSHA includes the effects of Lineament 4 and the postulated Lineament X of the Southern Whidbey Island Fault. Lineament 4 passes through the northeast corner of the Route 9 site, while the Lineament X occurs on the southern endof the plant site. Details of the site-specific PSHA are provided in Appendix “B” to this SEIS document

2.2 Adjustment for Soil Types

Site-specific ground motion is affected by the type of soil underlying the site. Results from the site-specific PSHA represent ground motions on rock, referred to as Site Class B in IBC 2003. For sites where the upper 100 feet of geology consist of soils, adjustments must be made to the results from the PSHA to account for the amplification or attenuation of seismic ground motions through the upper 100 feet of soil profile. To capture this amplification or attenuation, the IBC 2003 provides a Site Classification that is assigned to a site based on the types of soils present in the upper 100 feet and their engineering properties. The site-specific data used for design must be linked to the Site Classification. The IBC 2003 defined Site Classifications are as follows; a more detailed description of these classifications can be found in Table 1615.1.1 of the IBC 2003.

TABLE C-1
2003 IBC SITE CLASSIFICATION

Site Class	Soil Profile Name	Average Properties in Top 100 feet		
		Soil Shear Wave Velocity, v_s, (ft/sec)	**Standard Penetration Resistance, N**	**Soil Undrained Shear Strength (psf)**
A	Hard Rock	$v_s > 5,000$	N/A	N/A
B	Rock	$2,500 < v_s \leq 5,000$	N/A	N/A
C	Very Dense Soil and Soft Rock	$1,200 < v_s \leq 2,500$	$N > 50$	$S_u \geq 2,000$
D	Stiff Soil Profile	$600 \leq v_s \leq 1,200$	$15 \leq N \leq 50$	$1,000 < S_u \leq 2,000$
E	Soft Soil Profile	$v_s < 600$	$N < 15$	$S_u < 1,000$
E		Any profile with more than 10 feet of soil having the following characteristics: 1. Plasticity index PI > 20, 2. Moisture content, w, 40%, and 3. Undrained shear strength, S_u, < 500 psf		
F		Any profile containing soils having one or more of the following characteristics: 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. 2. Peats and/or highly organic clays (H > 10 feet of peat and/or highly organic clay where H = thickness of soil). 3. Very high plasticity clays (H > 25 feet with plasticity index PI > 75) 4. Very thick soft/medium stiff clays (H > 120 feet)		

2.3 Site-Specific Design Motions

For design, ground motions are represented as a response spectrum. A response spectrum consists of a graph with spectral acceleration on the ordinate (y-axis) and structure period on the absyssa (x-axis). The response spectrum is constructed using three values, the peak ground acceleration (PGA), the spectral acceleration at a period of 0.2 second (S_s - short period accelerations) and the spectral acceleration at a period of 1.0 second (S_1). It is generally accepted that 0.2 second is reasonably representative of the shortest effective period of buildings and structures that will be designed using the IBC 2003. Spectral response values for periods other than 1.0 second can generally be determined from the 1.0 second spectral acceleration. Therefore, PGA, S_s and S_1 are sufficient for constructing a response spectrum for the period range of importance for most buildings and structures designed using the IBC 2003.

For a simplified seismic analysis, a single value is read off the response spectrum and used to determine forces required for seismic design. For a more complex analysis (as may be warranted by the structure configuration or other factors), a modal analysis is typically performed in which the various response modes of the structure are determined. The structure response is obtained from superposition of individual natural modes of vibration, each mode responding with its own particular pattern of deformation (mode shape) and its own frequency (the modal frequency) and its own modal damping. IBC 2003 requires "special consideration of dynamic characteristics" (i.e., modal analysis) when the structure is assigned to Seismic Design Category D, E, or F and the building has a plan irregularity as defined in Table1616.5.1.1 of IBC 2003 and/or a vertical irregularity as defined in Table 1616.5.1.2 of IBC 2003. Although the structures within the Brightwater Facility are assigned to Seismic Design Category E and F, they do not possess plan or vertical irregularities, and therefore a modal analysis is not warranted.

The actual ground motions at a given site are a function of both soil conditions and directivity of the ground motion. Directivity refers to the spatial variation of ground motion amplitude around a fault; the change or amplification of the ground motion due to directivity depends on fault type, orientation of the site relative to the fault, and the direction of propagation. The IBC is silent regarding inclusion of the effects of directivity in development of site-specific seismic data for design. In the case of the Brightwater Facility, inclusion of directivity effects increases the spectral acceleration at 1 second approximately 1.3%.

The completely unadjusted (for a Class B site and no directivity effects) spectral accelerations determined from the site-specific PSHA for the Brightwater Facility are as follows:

- Peak ground acceleration (PGA) at period of 0.01 sec 0.65 g
- Spectral acceleration at a period of 0.2 sec (S_s) 1.50 g
- Spectral acceleration at a period of 1.0 sec (S_1) 0.74 g

The spectral accelerations for a Class B site but adjusted for directivity effects determined from the site-specific PSHA for the Brightwater Facility are as follows:

- Peak ground acceleration (PGA) at period of 0.01 sec 0.65 g
- Spectral acceleration at a period of 0.2 sec (S_s) 1.50 g
- Spectral acceleration at a period of 1.0 sec (S_1) 0.78 g

The actual ground motions at a given site are a function of the firm-ground seismic acceleration (Class B) and the soil response based on the type of soil at the site as well as directivity effects. The soils at the proposed Route 9 site consist of very dense soil and soft rock, which is categorized in the IBC 2003 as Site Class C. The spectral accelerations provided in the Shannon and Wilson report are adjusted to take account of the difference between Site Class B and Site Class C as well as dircetivity. The spectral accelerations for the Brightwater Route 9 site after these adjustments are made are as follows:

- PGA at a period of 0.01 sec 0.65 g
- Spectral acceleration at a period of 0.2 sec (S_s) 1.50 g
- Spectral acceleration at a period of 1.0 sec (S_1) 1.01 g

The actual ground motions used for design are based on a lower- bound estimate of the margin of collapse prescribed by the IBC 2003. This lower- bound, called design-level earthquake (DE), was selected by the committee developing the code based on experience and rigorous design studies, and is defined in IBC 2003 as two-thirds of the MCE. Therefore, the design-level spectral accelerations for the Brightwater project are as follows:

- PGA at a period of 0.01 sec 0.43 g
- Spectral acceleration at a period of 0.2 sec (S_s) 1.00 g

- Spectral acceleration at a period of 1.0 sec (S_1) 0.67 g

3.0 SEISMIC USE GROUP

As a part of seismic design evolution, the seismic force level that a particular structure is designed to resist is directly related to its use or seismic "performance objectives." The earthquake engineering community generally recognizes four performance objectives as follows:

- **Operational:** Negligible structural and non-structural damage when subjected to the design-level earthquake (2/3rds of the MCE). Facility is fully operational. Generally considered an impractical objective for ground motions associated with the 2,500-year earthquake in a moderately to highly seismic area.
- **Immediate Occupancy:** Similar to operational although more non-structural damage is anticipated. Safe to occupy, most equipment remains operational.
- **Life Safety:** Significant structural and non-structural damage, but retains a margin against collapse. Structure is not necessarily considered safe for occupancy.
- **Collapse Prevention:** Nearly complete damage. Non-structural elements may present falling hazards. Lowest cost but does not meet the intent of the code for new structures.

The IBC 2003 provides for these different performance levels through an Importance Factor (I), which is used to establish design-level seismic forces. Coupled with the importance factor is a structure's Seismic Use Group, which is based on the intended occupancy and use. The IBC 2003 provides for three Seismic Use Groups as follows:

- **Group I ─** Structures, not assigned to Group II or Group III. Importance Factor, I = 1.0
- **Group II ─** Structures, the failure of which would result in a public hazard (all of the new Brightwater facilities except those listed below). Importance Factor, I = 1.25
- **Group III ─** Essential facilities required for post-earthquake recovery and those containing substantial quantities of hazardous materials (Brightwater chemical and odor control buildings). Importance Factor, I = 1.50.

A structure designed as **Seismic Use Group I** is expected to provide "collapse prevention" behavior when subjected to the MCE, and to provide "life safety" under the Design Earthquake (DE). A structure designed as **Seismic Use Group III** is expected to provide "life safety" behavior when subjected to the MCE, and to provide "immediate occupancy" under the DE. **Seismic Use Group II** is expected to perform somewhere between Groups I and III.

4.0 SEISMIC DESIGN CATEGORY

The third part of determining the seismic design forces is the Seismic Design Category. IBC 2003 defines this as a classification assigned to a structure based on its seismic use group and the severity of the DE ground motion at the site. IBC 2003 provides for six Seismic Design Categories ranging from Category A (anticipated ground motions are minor) to Category F (regions located close to active major faults). A structure's Seismic Design Category helps establish allowable, lateral force-resisting systems, allowable heights, and detailing requirements.

The Brightwater facility structures are categorized Seismic Design Category E and F, depending upon Seismic Use Group. There is question as to the interpretation of including directivity effects in determination of Seismic Design Category. The Brightwater design takes the more conservative approach and uses directivity to determine seismic design category for design.

5.0 SEISMIC DESIGN AND DESIGN FORCES

IBC 2003 requires that each structure be designed to include complete lateral (horizontal) and vertical force-resisting systems for seismic loading. In addition, the structure must be designed to provide adequate strength, stiffness, and energy dissipation capacity to undergo prescribed seismic ground motions within code-set limits of deformation and strength demand. The force levels used for design of structural members are developed by taking into consideration materials of construction, configuration of the structure, and occupancy.

Materials of construction and configuration are used to determine “ductility.” Within the context of structural engineering, a structure is said to remain elastic if, when subjected to particular loads, it can deflect with no permanent deformations when the load is removed. For example, when a structure is subjected to frequently applied transitory loads such as live loads, it deflects or moves. When the load is removed, the structure returns to its original position and this is termed “elastic behavior.” On the other hand, when rare large transitory loads, such as those associated with a design-level earthquake, are applied to a structure, it will likely exhibit permanent deformations. That is, when the earthquake loads are removed, the structure will likely not return to its original position. This behavior is termed “inelastic.” It is well recognized that structures poses an inherent ability to absorb energy and behave inelastically without failure and that it is economically unjustified and impractical to require that a structure remain elastic under the rare design-level earthquake. Thus, the code limits allowable inelastic deformations to prevent collapse by applying a Response Modification Factor, R, to establish seismic design forces. The design response spectrum is divided by “R” as part of the process to establish structure design forces.

The value of R is determined based upon material type and the type of lateral force-resisting system. Some materials, such as steel, absorb a relatively large amount of energy and undergo large deformations without failure. Steel is considered a “ductile” material. Other materials, such as reinforced concrete, cannot absorb as much energy, do not have large deformation capacity, and are termed “brittle” – although the reinforcing from rebar allows the reinforced-concrete structure to exhibit some ductility. The structural configuration also plays a part in determining a system's ductility. For example, a concrete wall is very stiff and rigid, whereas a steel frame is comparatively flexible. The combination of material and structural configuration is used to determine “R” which ranges from 8 for ductile materials and configurations (e.g., steel frames) to 1.5 for brittle materials and configurations (unreinforced concrete shear walls). Brightwater facilities are typically constructed of steel or reinforced concrete.

In addition to the Response Modification Factor, R, each structure is assigned an importance factor, I, based on its Seismic Use Group as described in the previous section. The value of I ranges from 1.0 for ordinary structures to 1.5 for essential structures or those housing hazardous materials. The design response spectrum is multiplied by I to establish structure design forces. Brightwater facilities are designed using an I of either 1.25 or 1.5.

By way of example, Brightwater Structure design forces for ordinary braced frame structures (R=5) are as follows:

TABLE C-2
SPECTRAL ACCELERATIONS USED FOR DESIGN

	Spectral Acceleration – g		
		Seismic Use Group II	Seismic Use Group III
	Elastic	I = 1.25	I = 1.5
PGA, at period T = 0.01 sec	0.43	0.11	0.13
Spectral acceleration at a period of 0.2 sec (S_s)	1.00	0.25	0.30
Spectral acceleration at a period of 1.0 sec (S_1)	0.67	0.17	0.20

It is important to note that the seismic forces used to design structures are typically 4 to 5 times less than the forces the structures may expect to see during their design life. The difference between design force and actual force is resisted through a structure's ductility. During a design-level earthquake, a structure may experience both structural and non-structural damage. As described above, the forces the structure is subjected to exceed the forces used for design. In addition, it is expected that the structure will undergo inelastic deformations during the rare design-level seismic event; however, the code prescribes design deformation limits to prevent collapse and protect life safety. As the Seismic Use Group increases, the design forces also increase due to the increased I. The expected behavior increases to "operational" for I = 1.5. A structure that is "operational" may undergo both structural and non-structural damage from the DE, but it is anticipated that the damage will be localized and repairable while the remainder of the structure is in operation.

6.0 NON-BUILDING STRUCTURES

The majority of the structures that make up the Brightwater facility are below ground concrete water holding basins that are considered environmental structures. Environmental structures are designed using two fundamentally different parameters from those used to design typical buildings:

- The walls of the structures are subjected to sustained lateral loads from the soil on the outside and the liquid on the inside
- The structures need to be watertight, which is accomplished through strict attention to crack control.

Environmental structures are designed using the provisions of ACI 350 – Environmental Engineering Concrete Structures, in addition to the provisions of the IBC 2003. Historically, buried concrete liquid-holding structures that are designed according to the provisions of ACI 350, which take into account the crack control requirements to minimize leakage, behave quite well during earthquakes. Except in the case of ground rupture or liquefaction directly beneath the tanks, the basins themselves historically have not suffered significant damage. The damage to these structures most often occurs at piping connections into and out of the tanks and to non-structural elements such as equipment.

7.0 EQUIPMENT

Equipment located within a wastewater facility includes pumps, yard and process piping, electrical power and instrumentation, baffles, and clarifier mechanisms. Historically, these portions of the wastewater facilities suffer the most damage in an earthquake. The Brightwater design uses this knowledge and special attention is paid to provide adequate seismic resistance for these elements. It should be noted that the structure may be operational in terms of structural support or integrity, but the facility may not be operational if the equipment is damaged.

8.0 SUMMARY

The seismic design of the Brightwater facility is in accordance with the provisions of the 2003 Edition of the International Building Code (IBC 2003). This code is a relatively new document that represents the current state of seismic-resistant design within the United States. Structures designed in conformance with this code will in general, be able to:

- Resist minor levels of earthquake ground motion without damage.
- Resist a moderate level of earthquake ground motion without structural damage, but possibly experience some non-structural damage.
- Resist a major level of earthquake ground motion – of intensity equal to the strongest earthquake, either experienced or forecast for the building site, without collapse.

The site-specific probabilistic seismic hazard analysis (PSHA) conducted for the Brightwater site provides spectral accelerations for the maximum considered earthquake (MCE). The ground motions associated with the MCE account for recent studies regarding the activity at Lineament 4 in the northern portion of the Route 9 site and the potential activity of Lineament X located in the southern portion of the site. MCE ground motions are adjusted for fault directivity and soil amplification factors. In accordance with IBC 2003, the MCE is reduced by two-thirds to obtain the elastic design response spectra, referred to as the design earthquake (DE) for design of structures at the Route 9 site. Spectral values for the DE are further reduced to take into account the inherent ductility in the structures or the ability of the structure to absorb energy and deform without failure.

The majority of building structures at Brightwater are categorized as Seismic Use Group II. The seismic performance expectations for these structures are as follows:

- Between “collapse prevention” and “life safety” for “MCE”
- Between “life safety” and “immediate occupancy” for “elastic DE”

The odor control and chemical buildings are categorized as Seismic Use Group III, and the seismic performance expectations are as follows:

- “Life Safety” for the MCE
- “Immediate occupancy” for the DE. As previously discussed, immediate occupancy does not equate to a facility being fully operational. The structure may be able be occupied; however, equipment necessary to operate the facility may not be fully functional.

Water-holding basins and tanks are designed to either American Concrete Institute (ACI) 350 or the American Water Works Association (AWWA) standards for tank design depending on the configuration and material. These standards are used in conjunction with the IBC 2003. Typically, for concrete, liquid-holding basins, the reinforcing steel requirement based on crack control exceeds that required for seismic design. Theoretically, little or no structural damage is expected to these components under either the DE or the MCE. Damage is expected at pipe connections and possibly to equipment and non-structural elements.

The design of the Brightwater facility meets current state-of-the-profession seismic design provisions. A site-specific PHSA has been used to determine the ground acceleration for structural design and the most current seismic detailing practices are being utilized to confirm that the design of the structure and the non-structural components meets the seismic demand requirements. While the facility may suffer damage in its lifetime as a result of a strong seismic event, the structures will remain safe and provide protection for employees, the public, and the surrounding community.

9.0 REFERENCES

FEMA (2001). ***NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures – 2000 Edition***, Federal Emergency Management Agency, FEMA 368 – Part 1: Provisions and FEMA 369 – Part 2 Commentary, March.

IBC 2003, ***2003 International Building Code,*** International Code Council Inc., Chapter 16 – Structural Design.

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