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Guide Brief 4A – Example for Determining Anticipated Performance

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Community Resilience

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Guide Brief 4A – Example for Determining Anticipated Performance

Applicable Section(s) of Guide: Volume 1, End of Section 4.1.4, Determine Anticipated Performance, p. 46

Guide Briefs supplement the Community Resilience Planning Guide for Buildings and Infrastructure Systems (NIST SP1190)

Purpose and Scope

This Guide Brief provides an example of how to determine the anticipated performance of water and wastewater systems subjected to an earthquake and tsunami event. The methodology can be applied to all infrastructure systems. The example demonstrates the information required to complete the performance goal tables and determine the anticipated system performance for building clusters and supporting infrastructure systems. This Guide Brief is intended to be read with Guide Brief 4, *Determining Anticipated Performance*. It can also applied with Section 16 in Volume II of the Guide.

The example addresses the fictitious community of Shady Grove, Oregon. The hazard scenario is a magnitude (M_w) 9.0 subduction earthquake and tsunami. This event is considered a "design" earthquake with a 500-year return period.[1]

The intended user of this Guide Brief is an engineer familiar with the operation of the infrastructure being evaluated and the potential impacts of the hazards under consideration.

1. Hazard, Facility and Pipe Data

The first step is characterizing hazards and facilities. Figure 1 through Figure 4 show tsunami inundation, shaking, liquefaction and landslide hazards on community maps overlaid with the water and wastewater facilities and pipelines. Table 1 and Table 2 further define facilities and pipelines characteristics.

Figure 1 maps the hazards and facilities. The hazards include:

- Tsunami inundation (red line)
- Earthquake induced liquefaction (downward cross hatch)
- Earthquake induced landslide (upward cross hatch)

[1] This example was originally prepared by the Portland Water Bureau (PWB) to use as part of an Oregon Water/Wastewater Agency Response Network (ORWARN) exercise scenario. It is a work of fiction.

- Earthquake ground motion (not depicted)
    - Peak Ground Acceleration (PGA): 0.33 g_n (where g_n is acceleration due to gravity) throughout the community
    - Peak Ground Velocity (PGV): 54.9 cm/s (21.6 in./s) throughout the community
    - Peak Ground Displacement (PGD): varies by zone (see Table 3 and Table 4)

Water facilities include:

- Water Treatment Plant (W in blue square)
- Wells 1 – 6 (W in blue circle); Wells 2 and 4 have backup generators
- Storage Tanks 1 – 4 (T in blue circle)
- Maintenance Yard (Y in blue square)

Wastewater system facilities include:

- Sewage Treatment Plant (S in green square)
- Pump Stations 1 and 2 (P in green circle)
- Maintenance Yard (Y in green square)

The following figures and tables provide further details on the system components:

- Figure 2 provides information about the age and type of development in the service area. This information helps assess the age of facilities serving those areas. The original city development and the mid-century development took place prior to the 1980s, and the recent development occurred after 1995. This information is useful in identifying the design standards used in various parts of the community.
- Figure 3 shows the water system, including pipelines differentiated by pipe material and pipe diameter.
- In Figure 4 the sewer and storm drainage systems contain pipe differentiated by diameter. For this example, all pipe within each system is the same material. Use this information to assess the fragility of the pipe.
- Table 1 shows the water and wastewater systems facilities with material, date of construction, and other comments. This information helps evaluate the facility vulnerability associated with its date of construction and associated building code.
- Table 2 shows the water and wastewater systems pipe length and material by hazard area.

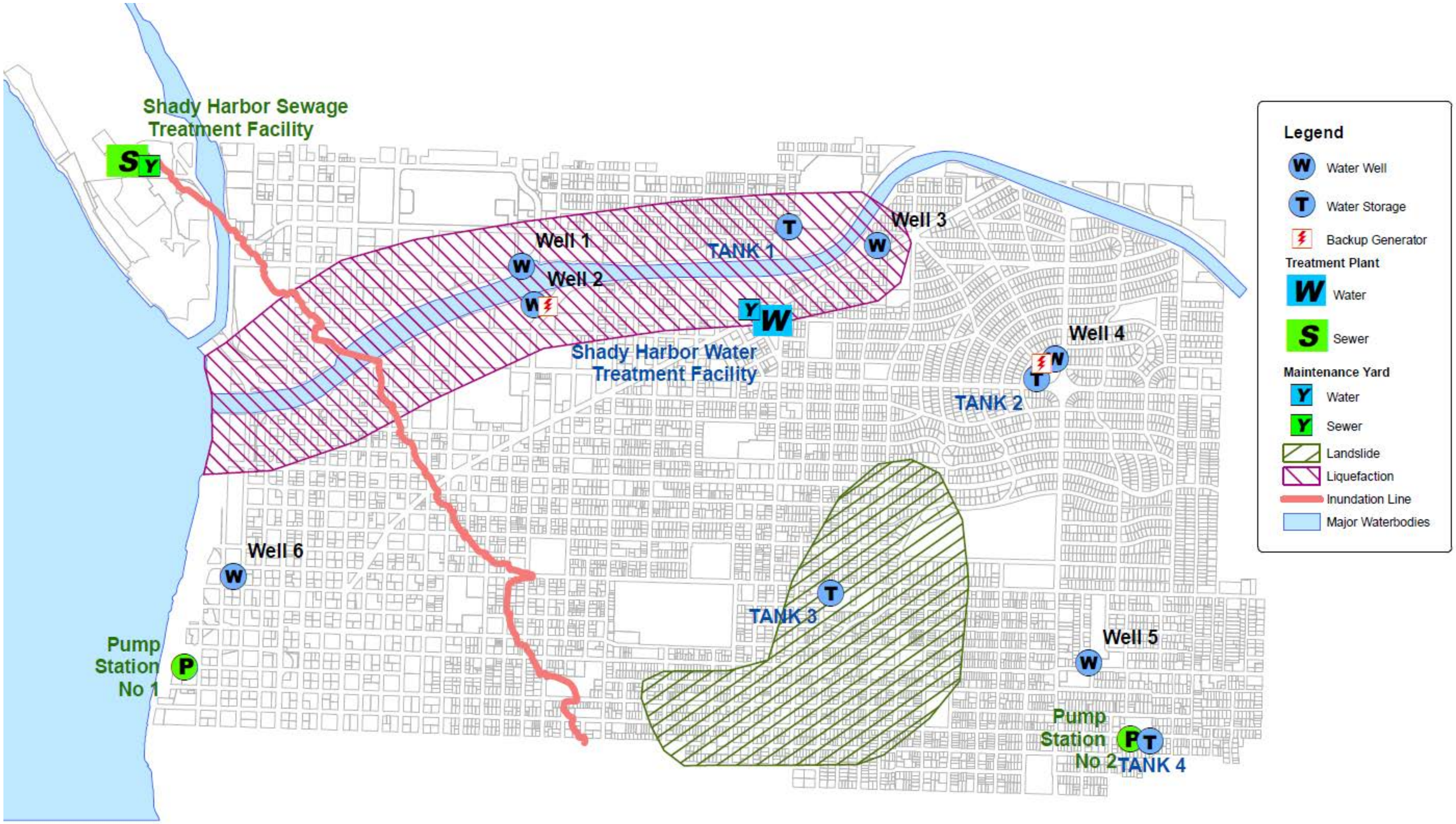


Figure 1. Shady Harbor Oregon, Water Supply and Wastewater Facilities and Hazards [ORWARN Conference Presentation, Seaside Oregon September 24, 2012]

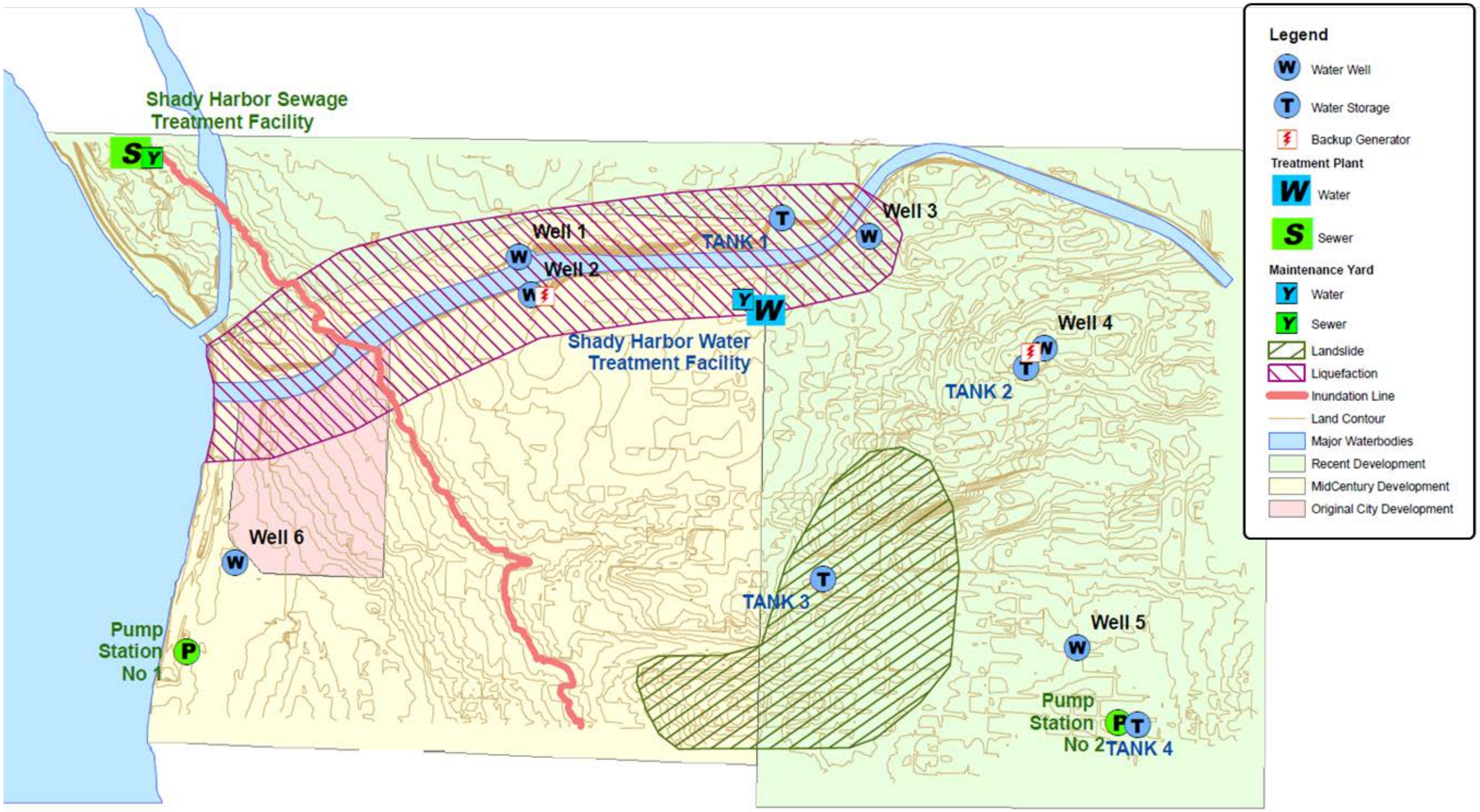
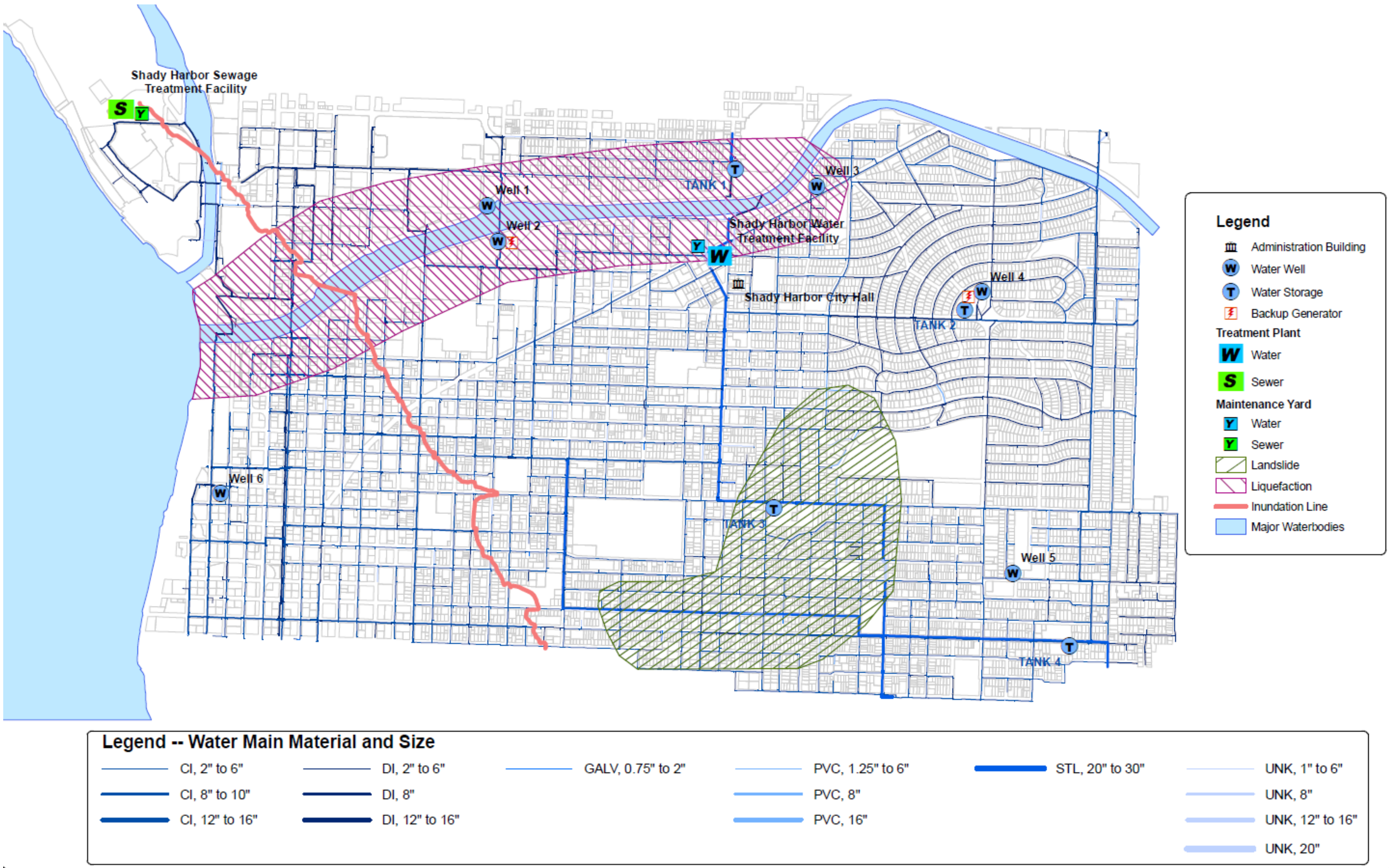
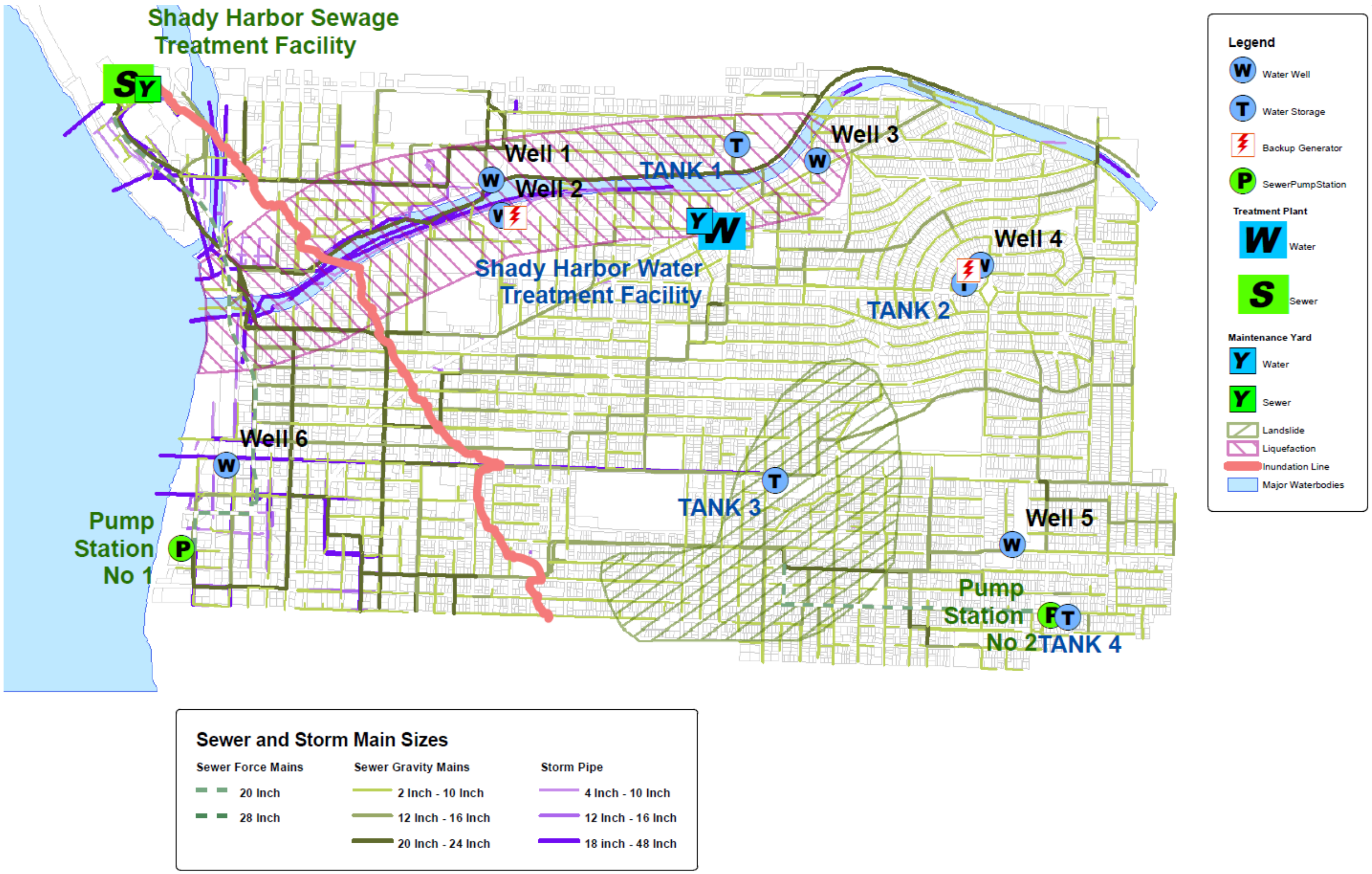


Figure 2. Development Eras [ORWARN Conference Presentation, Seaside Oregon September 24, 2012]



Conversions: 1 in. = 2.54 cm

Figure 3. Water Supply System [ORWARN Conference Presentation, Seaside Oregon September 24, 2012]



Conversions: 1 in. = 2.54 cm

Figure 4. Sewer and Storm Drainage System [ORWARN Conference Presentation, Seaside Oregon September 24, 2012]

Table 1. Water and Wastewater (Sewer) System Facilities with Material, Date of Construction and Other Comments

Conversions: 1 MGD = 3.79 ML/Day 1 MG = 3.79 ML

Facility	Material	Date of Construction	Comments
Shady Harbor Water System			
Water treatment plant			6 million gallons per day (MGD)
Control building	Concrete masonry unit	1982	
Intake Pipe	Ductile iron pipe	1982	
Flocculation	Cast in place concrete basin	1982	
Coagulation	Cast in place concrete basin	1982	
Sedimentation	Cast in place concrete basin	1982	
Filtration	Cast in place concrete basin	1982	
Sodium hypochlorite storage tank	Plastic tank	1982	
Flocculant tank (activated silica)	Ground level steel tank	1982	Badly corroded
Filter backwash tank	Plastic tank	1982	Replaced rusted steel tank
Maintenance yard	Metal building with metal siding	1985	
Wells			
Well #1		1976	Submersible
Well #2		1981	Turbine
Well #3		2005	Turbine
Well #4		1941	Turbine
Well #5		1930	Submersible
Well #6		1976	Submersible
Tanks			
Tank #1	Elevated steel	1980	0.5 million gallons (MG)
Tank #2	Prestressed concrete	2000	1 MG
Tank #3	Ground level steel	1960	1.5 MG
Tank #4	Cast in place concrete	2002	1.0 MG
River Crossings on Bridges			
River crossing #1 (Downstream)	On bridges	1976	Did not address liquefaction
River crossing #2 (Middle)	On bridge	1995	Addressed liquefaction in design
River crossing #3 (Upstream)	On bridge	2003	Addressed liquefaction in design
Shady Harbor Wastewater System			
Wastewater treatment plant			6.0 MGD
Control building	Concrete masonry unit	1979	
Influent pipeline	Ductile iron pipe	1970	
Grit chambers	Cast in place concrete	1950	
Primary clarifier	Circular steel	1970	
Secondary treatment/digesters	Cast in place concrete	1990	
Blower/pump building		1990	
Disinfection/elevation tank		1995	
Disinfection tanks	Cast in place concrete	1980	
Outfall		1970	
Onsite fuel storage	Horizontal steel above grade	1950	
Maintenance yard	Concrete masonry unit	1970	
Pump stations			
PS #1	Cast in place concrete, unreinforced masonry above grade	1950	Wet well
PS #2		1980	Submersible

Table 2. Water System and Sewer Pipe Material and Length (ft) by Hazard Area

Conversions: 1 ft = 0.3048 m

Water					
Pipe Materials	**Total**	**Inundation**	**Landslide**	**Liquefaction**	**PGV**
Cast Iron (CI)	267,012	101,629	34,075	35,795	95,513
Ductile Iron (DI)	91,374	25,271	8,944	14,614	42,545
Steel (STL)	10,889	0	5,150	1,072	4,667
Total	369,275	126,900	48,169	51,481	142,725
Wastewater					
Gravity Lines	**Total**	**Inundation**	**Landslide**	**Liquefaction**	**PGV**
Cast Iron (CI)	99,100	0	16,000 (1)	18,000 (1)	65,100 (1)
Concrete	149,618	50,518	16,000 (1)	18,000 (1)	65,100 (1)
PVC	138,356	39,256	16,000 (1)	18,000 (1)	65,100 (1)
Total	387,074	89,774	48,000	54,000	195,300
Force Main Lines	**Total**	**Inundation**	**Landslide**	**Liquefaction**	**PGV**
Ductile Iron (DI)	6,900	2,000	1,500	2,000	1,400

Note (1): Estimated from available data

2. Water and Wastewater System Summary and Evaluation

Given the hazard, facility, and pipeline data, the vulnerabilities of the water and wastewater systems are assessed. Table 3 and Table 4 summarize the available information for the water and wastewater systems. In some cases, assumptions are made about the type of construction and pipe failures. Assume the person evaluating the system is generally knowledgeable about the particular hazard and the types of impacts that hazard have on the particular system.

The table column headings for Table 3 and Table 4 are:

- ***Facility and Description –*** As shown.
- ***Consequence –*** Based on the capacity the specified component provides for the overall system. This descriptor is only used to give a general idea of the relative importance of the facility.
- ***Emergency Power –*** As described.
- ***PGA/PGV and PGD –*** Earthquake hazard intensities. The evaluation tables show the values for Peak Ground Acceleration (PGA) or Peak Ground Velocity (PGV) and Peak Ground Displacement (PGD). This information should be available from the USGS and state departments of geology. PGV was converted to units of in./s for use in pipe failure equations.
- ***Pipe K value –*** Based on pipe material from American Lifelines Alliance (ALA). K values can be modified upward to address the pipe condition degraded by corrosion.
- ***Inundation, Liquefaction, Landslide –*** Taken from the system maps.
- ***Date of Construction –*** From area of town/age of development and other assumed dates.
- ***Pipe –*** Failures calculated from ALA equations at bottom of table and percent of area that will liquefy or be subject to a landslide.
- ***Type of Construction –*** Previously provided or assumed.
- ***Pipe Failures –*** Calculated using ALA relationships at the bottom of the table.

- ***Damage State –*** Based on comments in the table.

RED SHADING – Cells shaded in red indicate the controlling hazard (PGA, PGV, PGD) or the data that allows the evaluator to reach the indicated conclusion.

2.1. Water System Summary and Evaluation

The water system evaluation is summarized using the rows in Table 3 with further explanations as follows:

- ***Water Treatment Plant –*** Overall facility out of service due to damaged intake.
- ***Control/Lab Building*** – It was constructed in 1980, prior to significant seismic design code requirements in Oregon that were not implemented until the mid-1990s. This would give it a "Low Code" designation in Hazus (see Hazus Technical Manual, Chapter 5).

  The building is constructed of lightly reinforced cement masonry units (CMU), giving it a URML Building Type. Using Table 5.16c Equivalent-PGA Structural Fragility – Low Code, Seismic Design Level, subjected to a level of shaking of 0.33 g_n, the building would undergo "Extensive" Damage. It's damage state would be not-usable but repairable.
- ***Intake –*** Damaged due to liquefaction/lateral spread.
- ***Plant Piping –*** As noted.
- ***Non-structural –*** As noted.
- ***Maintenance Yard –*** Steel moment frame/braced buildings. This would be Hazus building type S1L/S2L. The building was built in 1985, so is still considered Low Code in Oregon. Using Hazus Table 5.16c, with a 0.33 g_n ground motion the building would have "Extensive" damage.
- ***Wells 1 – 3 –*** It is assumed that well casings subjected to PGDs of 61.0 cm (24 in.) would be bent laterally, making them inoperable.
- ***Wells 4 and 5 –*** Well houses are unreinforced masonry (URM). They are considered Pre-code design. Using Hazus Table 5.16d, a URML structure subjected to 0.33 g_n would be expected to be near collapse.
- ***Well 6 –*** Contaminated by saltwater inundation (as experienced by many wells in the 2011 Japanese earthquake).
- ***Tank 1 –*** Liquefaction, loss of foundation bearing.
- ***Tank 2 –*** Built in 2000, this wire wrapped concrete tank has a Hazus label of PST1, On-ground Anchored. It would be expected to have only slight damage when subjected to 0.33 g_n shaking.
- ***Tank 3 –*** Constructed in 1960, this is categorized in Hazus as On-Ground Unanchored Steel, PST4. It is also subject to 30 cm (12 in.). PGD due to landslide. Looking at Hazus Technical Manual Table 8.9, Damage Algorithms for Water Storage Tanks, PST4 subjected to 0.33 g_n shaking would have moderate damage. However, the PGD is assumed to render the tank inoperable.
- ***Tank 4 –*** Similar to Tank 2, except cast in place concrete, this tank would have only slight damage.
- ***Bridge Crossing #1 (downstream)–*** Collocated on bridge. This bridge would collapse due to abutment failures due to liquefaction. The water line crossing failed.
- ***Bridge Crossing #2 (middle))–*** Collocated on bridge. The bridge remains intact and the water main remains intact.

- ***Bridge Crossing #3 (upstream)–*** Collocated on bridge. The bridge remains intact and the water main remains intact.
- ***Pipe –*** Damage calculated as per ALA equations shown at the bottom of the table.

2.2. Wastewater (Sewer) System Evaluation

The Wastewater Treatment Plant and Pump Station #1 are in the tsunami inundation zone. In the 2011 Japanese subduction earthquake, the Sendai WWTP was inundated and completely damaged. Above grade equipment and piping was ripped off the foundations. The effluent pump station was impacted with a 33 ft (10 m) high wall of water, bending the reinforced concrete outside wall inward.

The wastewater system evaluation is summarized on Table 4 with further explanations as follows:

- ***Wastewater Treatment Plant –*** Completely damaged due to tsunamis.
- ***Pump Station #1 –*** Completely damaged due to tsunamis.
- ***Pump Station #2 –*** The pump station is outside the inundation zone. This submersible type pump station is inherently rugged when subjected to earthquake ground motions.

Collection system and stormwater system piping damage is estimated using the ALA equations shown at the bottom of the table or as otherwise noted in the table.

Table 3. Water System Summary and Evaluation (cells shaded in red indicate the controlling hazard (PGA, PGV, PGD) or the data that allows the evaluator to reach the indicated conclusion on damage state)

Conversions: 1 MGD = 3.79 ML/Day 1 MG = 3.79 ML 1 in. = 2.54 cm 1 in./s = 2.54 cm/s

Facility	Description	Consequence	Emergency Power	PGA (% gravity), PGV (in./s)	PGD	Pipe K Value
Water Treatment Plant	**3 MGD**	**0.5**	**Yes**	**33%**		
Control building				**33%**		
Intake	River below			33%	36 in.	
Process tanks				33%		
Plant piping				33%		
Non-structural				33%		
Maintenance yard				33%	12 in.	
Wells				**33%**		
Well #1	Submersible	0.1	No	33%	24 in.	
Well #2	Submersible	0.1	Yes	33%	24 in.	
Well #3	Turbine	0.1	No	33%	24 in.	
Well #4	Turbine	0.1	Yes	33%		
Well #5	Turbine	0.1	No	33%		
Well #6	Submersible	0.1	No	33%		
Tanks				**33%**		
Tank #1	0.5 MG	0.125		33%	24 in.	
Tank #2	1 MG	0.25		33%		
Tank #3	1.5 MG	0.375		33%	12 in.	
Tank #4	1.0 MG	0.25		33%		
Bridge Crossings						
Bridge Crossing #1	12 in.	0.1		33%	24 in.	
Bridge Crossing #2	12 in.	0.1		33%	24 in.	
Bridge Crossing #3	12 in.	0.1		33%	24 in.	

Note 1

Repair Rate for Wave Propagation	RR = K × 0.00187 × PGV	where PGV in in inches/second
Repair Rate for PGD	RR = K × 1.06 $PGD^{0.319}$	where PGD is in inches
Repair Rate for PGD	Assumes 25% of mapped liquefaction/landslide areas undergo PGD	

Table 3. Water System Summary and Evaluation (cells shaded in red indicate the controlling hazard (PGA, PGV, PGD) or the data that allows the evaluator to reach the indicated conclusion on damage state) (continued)

Conversions: 1 MGD = 3.79 ML/Day 1 MG = 3.79 ML 1 in. = 2.54 cm 1 in./s = 2.54 cm/s

Facility	Description	Consequence	Emergency Power	PGA (% gravity), PGV (in./s)	PGD	Pipe K Value
Pipelines (Note 1)						
CI	95,513			21.6 in./s		1
CI	101,629			21.6 in./s		1
CI – 25% PGD	8,949				12in.	1
CI – 75% No PGD	26,846			21.6 in./s		1
CI – 25% PGD	8,519				12in.	1
CI – 75% No PGD	25,556			21.6 in./s		1
DI	42,545			21.6 in./s		0.5
DI	25,271			21.6 in./s		0.5
DI – 25% PGD	3,654				12 in.	0.5
DI – 75% No PGD	10,961			21.6 in./s		0.5
DI – 25% PGD	2,236				12 in.	0.5
DI – 75% No PGD	6,708			21.6 in./s		0.5
STL	4,667			21.6 in./s		0.3
STL	0			21.6 in./s		0.3
STL – 25% PGD	268				12 in.	0.3
STL – 75% No PGD	804			21.6 in./s		0.3
STL – 25% PGD	1,288				12 in.	0.3
STL – 75% No PGD	3,863			21.6 in./s		0.3
Total Pipe Failure						

Note 1

Repair Rate for Wave Propagation	$RR = K \times 0.00187 \times PGV$	where PGV in in inches/second
Repair Rate for PGD	$RR = K \times 1.06\ PGD^{0.319}$	where PGD is in inches
Repair Rate for PGD	Assumes 25% of mapped liquefaction/landslide areas undergo PGD	

Table 3. Water System Summary and Evaluation (cells shaded in red indicate the controlling hazard (PGA, PGV, PGD) or the data that allows the evaluator to reach the indicated conclusion on damage state) (continued)

Conversions: 1 MGD = 3.79 ML/Day 1 MG = 3.79 ML 1 in. = 2.54 cm 1 in./s = 2.54 cm/s

Facility	Inundation	Liquefaction	Landslide	Date of Construction / Pipe Repair Rate[1]	Type of Construction / Pipe Failures	Damage State
Water Treatment Plant	**No**	**No**	**No**	**1982**		**Plant inoperable because of damaged intake**
Control building	No	No	No	**1982**	Lightly reinforced concrete masonry unit (CMU)	Heavily damaged
Intake	No	**Yes**	No	1982	Ductile iron pipe (DIP)	Severed due to liquefaction/lateral spread
Process tanks	No	No	No	1982	Cast in place (CIP) concrete basins	OK
Plant piping	No	No	No	**1982**	DIP, inadequately braced	Several broken flanges on equipment connections
Non-structural	No	No	No	**1982**	Poorly anchored	Equipment movement damaging connections
Maintenance yard	No	**Yes**	No	1985	Steel moment/braced frame	Extensive Damage, Hazus Table 5.16c
Wells						
Well #1	No	**Yes**	No	1976	Inadequately reinforced CMU	Casing bent, no power, not functional, building CMU cracked, red-tagged
Well #2	No	**Yes**	No	1981	Inadequately reinforced CMU	Casing bent, submersible continues to operate with emergency power, building CMU cracking, red tagged
Well #3	No	**Yes**	No	2005	Reinforced CMU	Casing bent, no power, not functional, building OK
Well #4	No	No	No	1941	Unreinforced masonry (URM)	Casing collapses due to corrosion, building collapses
Well #5	No	No	No	1930	URM	Well OK, pump house collapsed
Well #6	**Yes**	No	No	1976	Inadequately reinforced CMU	Well contaminated, unusable
Tanks						
Tank #1	No	**Yes**	No	**1980**	Elevated Steel	Collapses due to foundation failure and failure of support structure
Tank #2	No	No	No	2000	Wire wrapped concrete tank	OK
Tank #3	No	No	**Yes**	**1960**	Ground level steel	Tank displaces on site, rocks on foundation, breaks connecting piping, buckles
Tank #4	No	No	No	2002	CIP concrete	OK
Bridge Crossings						
Bridge Crossing #1	Yes	Yes	No	1976	DIP supported on bridge	Bridge collapsed due to tsunamis and rotation of abutments as a result of liquefaction.
Bridge Crossing #2	No	Yes	No	1995	DIP supported on bridge	Bridge remans functional
Bridge Crossing #3	No	Yes	No	2003	DIP supported on bridge	Bridge remans functional

Note 1

Repair Rate for Wave Propagation	$RR = K \times 0.00187 \times PGV$	where PGV in in inches/second
Repair Rate for PGD	$RR = K \times 1.06\ PGD^{0.319}$	where PGD is in inches
Repair Rate for PGD	Assumes 25% of mapped liquefaction/landslide areas undergo PGD	

Table 3. Water System Summary and Evaluation (cells shaded in red indicate the controlling hazard (PGA, PGV, PGD) or the data that allows the evaluator to reach the indicated conclusion on damage state) (continued)

Conversions: 1 MGD = 3.79 ML/Day 1 MG = 3.79 ML 1 in. = 2.54 cm 1 in./s = 2.54 cm/s

Facility	Inundation	Liquefaction	Landslide	Date of Construction / Pipe Repair Rate[1]	Type of Construction / Pipe Failures	Damage State
Pipelines (Note 1)				**Pipe Repair Rate[1]**	**Pipe Failures**	
CI	No	No	No	0.4	3.9	
CI	Yes			0.4	4.1	Pipe in inundation zone OK, but all surrounding facilities heavily damaged
CI – 25% PGD		Yes		0.59	5.2	
CI – 75% No PGD		No		0.04	1.1	
CI – 25% PGD			Yes	0.59	5.0	
CI – 75% No PGD			No	0.04	1.0	
DI				0.02	0.9	
DI	Yes			0.02	0.5	Pipe in inundation zone OK, but all surrounding facilities heavily damaged
DI – 25% PGD		Yes		0.29	1.1	
DI – 75% No PGD		No		0.02	0.2	
DI – 25% PGD			Yes	0.29	0.7	
DI – 75% No PGD				0.02	0.1	
STL				0.01	0.1	
STL	Yes			0.01	0.0	Pipe in inundation zone OK, but all surrounding facilities heavily damaged
STL – 25% PGD		Yes		0.18	0.0	
STL – 75% No PGD		No		0.01	0.0	
STL – 25% PGD			Yes	0.18	0.2	
STL – 75% No PGD			No	0.01	0.0	
Total Pipe Failure					24.1	About 50% of the failures are leaks and the remainder are breaks

Note 1

Repair Rate for Wave Propagation	$RR = K \times 0.00187 \times PGV$	where PGV in in inches/second
Repair Rate for PGD	$RR = K \times 1.06\ PGD^{0.319}$	where PGD is in inches
Repair Rate for PGD	Assumes 25% of mapped liquefaction/landslide areas undergo PGD	

Table 4. Wastewater System Summary and Evaluation (cells shaded in red indicate the controlling hazard (PGA, PGV, PGD) or the data that allows the evaluator to reach the indicated conclusion on damage state)

Conversions: 1 MGD = 3.79 ML/Day 1 MG = 3.79 ML 1 in. = 2.54 cm 1 in./s = 2.54 cm/s 1 ft = 0.3048 m

Facility	Description	Consequence	Emergency Power	PGA (% gravity), PGV (in./s)	PGD	Pipe K Value
Wastewater TP	**3 MGD**	**1**		**33%**		
Control building				33%		
Influent pipeline	Ductile iron pipe (DIP)			33%	12 in.	
Grit chambers				33%		
Primary clarifier				33%		
Secondary treatment/digesters				33%		
Blower/pump building				33%		
Disinfection/elevation tank				33%		
Disinfection tanks				33%		
Outfall				33%		
Onsite fuel storage				33%		
Maintenance yard				33%		
Pump Stations				**33%**		
PS #1	Wet well/Dry well	0.25	Yes	33%		
PS #2	Submersible	0.25	Yes	33%		
Collection (Note 1)						
Force mains DIP	1,400 ft			21.6 in./s		0.5
Force mains DIP	2,000 ft			21.6 in./s		0.5
Force mains DIP 25% PGD	500 ft				12 in.	0.5
Force mains DIP 75% No PGD	1,500 ft			21.6 in./s		0.5
Force mains DIP 25% PGD	375 ft				12 in.	0.5
Force mains DIP 75% No PGD	1,125 ft			21.6 in./s		0.7
Concrete	65,100 ft			21.6 in./s		0.7
Concrete	50,518 ft			21.6 in./s		0.7
Concrete 25% PGD	4,500 ft				12 in.	0.7
Concrete 75% No PGD	13,500 ft			21.6 in./s		0.7

Note 1		
Repair Rate for Wave Propagation	$RR = K \times 0.00187 \times PGV$	where PGV in in inches/second
Repair Rate for PGD	$RR = K \times 1.06\ PGD^{0.319}$	where PGD is in inches
Repair Rate for PGD	Assumes 25% of the mapped liquefaction/landslide areas undergo PGD	

Table 4. Wastewater System Summary and Evaluation (cells shaded in red indicate the controlling hazard (PGA, PGV, PGD) or the data that allows the evaluator to reach the indicated conclusion on damage state) (continued)

Conversions: 1 MGD = 3.79 ML/Day 1 MG = 3.79 ML 1 in. = 2.54 cm 1 in./s = 2.54 cm/s 1 ft = 0.3048 m

Facility	Description	Consequence	Emergency Power	PGA (% gravity) PGV (in./s)	PGD	Pipe K Value
Concrete	4,000 ft				12 in.	0.7
Concrete 75% No PGD	12,000 ft			21.6 in./s		0.7
Cast iron	65,100 ft			21.6 in./s		1
Cast iron	0 ft			21.6 in./s		1
Cast iron 25% PGD	4,500 ft				12 in.	1
Cast iron 75% No PGD	13,500 ft			21.6 in./s		1
Cast iron 25% PGD	4,000 ft				12 in.	1
Cast iron 75% No PGD	12,000 ft			21.6 in./s		1
PVC	65,100 ft			21.6 in./s		0.8
PVC	39,256 ft			21.6 in./s		0.8
PVC 25% PGD	4,500 ft				12 in.	0.8
PVC 75% No PGD	13,500 ft			21.6 in./s		0.8
PVC 25% PGD	4,000 ft				12 in.	0.8
PVC 75% No PGD	120,00 ft			21.6 in./s		0.8
Total Pipeline Failures						
Storm water concrete pipe						

Note 1		
Repair Rate for Wave Propagation	RR = K × 0.00187 × PGV	where PGV in in inches/second
Repair Rate for PGD	RR = K × 1.06 $PGD^{0.319}$	where PGD is in inches
Repair Rate for PGD	Assumes 25% of the mapped liquefaction/landslide areas undergo PGD	

Table 4. Wastewater System Summary and Evaluation (cells shaded in red indicate the controlling hazard (PGA, PGV, PGD) or the data that allows the evaluator to reach the indicated conclusion on damage state) (continued)

Conversions: 1 MGD = 3.79 ML/Day 1 MG = 3.79 ML 1 in. = 2.54 cm 1 in./s = 2.54 cm/s 1 ft = 0.3048 m

Facility	Inundation	Liquefaction	Landslide	Date of Construction/ Pipe Repair Rate[1]	Type of Construction / Pipe Failures	Damage State
Wastewater TP	Yes					**All above grade structures heavily damaged**
Control building	Yes			1979	Concrete masonry unit (CMU)	Walls blown in by tsunami
Influent pipeline	Yes	Yes		1970		Influent pipeline severed in river crossing
Grit chambers	Yes			1950	Cast in place (CIP) concrete	All equipment heavily damaged
Primary clarifier	Yes			1970	Circular steel	Clarifier floats
Secondary treatment/digesters	Yes			1990	CIP concrete	All equipment heavily damaged
Blower/pump building	Yes			1990		Walls blown in by tsunami
Disinfection/elevation tank	Yes			1995		Tank washed away
Disinfection tanks	Yes			1980	CIP concrete	All equipment heavily damaged
Outfall	Yes			1970		Heavily damaged by tsunami
Onsite fuel storage	Yes			1950	Horizontal Storage above grade	Washed away
Maintenance yard	Yes			1970	CMU	Walls blown in by tsunami
Pump Stations						
PS #1	Yes	No	No	1950	CIP concrete/URM above ground	PS inundated, all equipment damaged, superstructure collapses
PS #2	No	No	No	1980	Steel can	OK
Collection (Note 1)				**Pipe Repair Rate[1]**	**Pipe Failures**	
Force mains DIP				0.02	0.0	
Force mains DIP				0.02	0.0	Pipe in inundation zone OK, but all surrounding facilities heavily damaged
Force mains DIP 25% PGD				0.29	0.1	
Force mains DIP 75% No PGD		Yes		0.02		
Force mains DIP 25% PGD		No		0.29	0.1	
Force mains DIP 75% No PGD			Yes	0.02		
Concrete			No	0.03	1.8	
Concrete	Yes			0.03		Pipe in inundation zone OK, but all surrounding facilities heavily damaged
Concrete 25% PGD		Yes		0.41	1.8	

Note 1		
Repair Rate for Wave Propagation	$RR = K \times 0.00187 \times PGV$	where PGV in in inches/second
Repair Rate for PGD	$RR = K \times 1.06\ PGD^{0.319}$	where PGD is in inches
Repair Rate for PGD	Assumes 25% of the mapped liquefaction/landslide areas undergo PGD	

Table 4. Wastewater System Summary and Evaluation (cells shaded in red indicate the controlling hazard (PGA, PGV, PGD) or the data that allows the evaluator to reach the indicated conclusion on damage state) (continued)

Conversions: 1 MGD = 3.79 ML/Day 1 MG = 3.79 ML 1 in. = 2.54 cm 1 in./s = 2.54 cm/s 1 ft = 0.3048 m

Facility	Inundation	Liquefaction	Landslide	Date of Construction/ Pipe Repair Rate[1]	Type of Construction / Pipe Failures	Damage State
Concrete 75% No PGD		No		0.03		
Concrete			Yes	0.41	1.6	
Concrete 75% No PGD			No	0.03		
Cast iron				0.04	2.6	
Cast iron	Yes			0.04		Pipe in inundation zone OK, but all surrounding facilities heavily damaged
Cast iron 25% PGD		Yes		0.59	2.6	
Cast iron 75% No PGD		No		0.04		
Cast iron 25% PGD			Yes	0.59	2.3	
Cast iron 75% No PGD			No	0.04		
PVC				0.03	2.1	
PVC	Yes			0.03		Pipe in inundation zone OK, but all surrounding facilities heavily damaged
PVC 25% PGD		Yes		0.47	2.1	
PVC 75% No PGD		No		0.03		
PVC 25% PGD			Yes	0.47	1.9	
PVC 75% No PGD			No	0.03		
Total Pipeline Failures					19.3	Just over 50% of failures are in areas subject to PGD.
Storm water concrete pipe	Yes	Yes				Pipelines in liquefiable area will float/move laterally due to lateral spread

Note 1		
Repair Rate for Wave Propagation	$RR = K \times 0.00187 \times PGV$	where PGV in in inches/second
Repair Rate for PGD	$RR = K \times 1.06\ PGD^{0.319}$	where PGD is in inches
Repair Rate for PGD	Assumes 25% of the mapped liquefaction/landslide areas undergo PGD	

2.3. Water System Performance and Restoration Time

Introduction

The team evaluating the restoration time for Shady Grove is comprised of seasoned engineers and operations personnel. The team members have participated in professional conferences and have learned about damage and recovery of other water utilities subjected to hazard events across the US and around the world. They have professional colleagues, contractors, equipment sales people, and consulting engineers who are generally knowledgeable about equipment availability and the time it takes to build various types of projects.

The evaluators are aware that the hazard scenario covers a large region and that mutual aid from near-by utilities may be difficult to obtain.

The evaluators categorized the system into supply, storage, and distribution. The way this system is configured, there are no transmission mains, and there are no pump stations other than the well pumps and high-lift pump at the water treatment plant (WTP).

The supply comes from the WTP and 6 wells. The evaluators knew they needed to produce average winter demands (AWD) in the months following the event, and that either the WTP or the 6 wells combined could produce the AWD. They talked with their well driller and generator supplier. Knowing the well damage scenario, with information from the well driller and generator supplier, the evaluators believed they could get three wells operable within two days (see details below). This would give them about 50 % of the required production.

The evaluators assessed the WTP damage scenario, the building was nearly collapsed and the intake broken. Knowing the WTP could not recover within months, they looked elsewhere. They contacted their county emergency manager, who evaluated sources of portable WTP. He got back to them with information that there were several possible suppliers. The Army Corps of Engineers had five portable plants in storage in the mid-west; a WTP manufacturer maintained several portable plants in Utah for emergency use. The 3 wells and the portable WTP would provide the supply they needed to deliver AWD.

The damage scenario indicated that two of the water system tanks would be completely damaged, but the two newer tanks would remain operable. In conferring with the water system operations staff, the evaluators determined they could operate pumps continuously, throttled back, and operate the system without the two reservoirs.

Shady Grove had one field maintenance crew with a small excavator. The evaluators were aware mutual aid for this type of event would be in short supply. The Water Superintendent contacted a local contractor who installed pipe for the City on a regular basis. The contractor agreed it could provide a pipe repair crew in an emergency. The City and contractor agreed on a multi-year contract to provide a repair crew in the event of an emergency. Based on pipe repair records, the Water Superintendent estimated the contractor's repair crew could make two repairs per 12-hour shift per crew.

The evaluators concluded they could get the AWD supply and pipe restored within two weeks following the event, with service to critical facilities coming earlier.

Evaluation

Using the vulnerability of the various system components, the overall system functionality and recovery is evaluated. This section describes where to place the "X"s in the performance matrix, which is then used to identify gaps in infrastructure system performance for a design level earthquake event.

- ***Assumption.*** Either the water treatment plant or wells can provide winter demand flows when they are fully operable. Winter demand flows can also be met when both supplies are operating at 50 % capacity.

- ***Water Treatment Plant Damage Summary.***
  - Control Building/Lab near collapse
  - Intake severed
  - Equipment moved damaging connections

  The Control Building requires replacement. Estimated restoration time with a temporary building is 6 months. Other damage can be repaired while the control building is being replaced.

  Assume a portable WTP producing 50 % of the original WTP flow, using a temporary intake can be installed within 2 weeks.

  Lab samples are transported to the next adjacent community for testing.

- ***Wells.*** Five wells are inoperable, due to bent casings, pump house collapse or contamination
  - ***Well No 1.*** Requires power, building bracing – 2 days restoration time
  - ***Well No. 2 .*** Continues to operate on emergency power. Building requires bracing – 2 days
  - ***Well No 3.*** May be operable with emergency power – 2 days required
  - ***Well No 4.*** Not recoverable
  - ***Well No 5.*** Temporary shelter and new control cabinets required – 2 weeks
  - ***Well No 6.*** Contaminated not recoverable

  Well capacity can be restored to 50 % (3 wells) in 2 days and 67 % (4 wells) in 2 weeks.

  The Shady Harbor has emergency supply (50 % of winter demand) in 2 days from the 3 wells, and 100 % winter demand within 2 weeks after a temporary portable WTP is put in place.

- ***Tanks.***
  - ***Tank #1.*** Collapsed. System remains operable with continuous pumping
  - ***Tank #2.*** OK
  - ***Tank #3.*** Broken piping – 2 weeks to repair. System remains operable with continuous pumping
  - ***Tank #4.*** OK

  Tank damage states allow the system to remain operable with two undamaged tanks and two tanks that can be bypassed with continuous pumping.

- ***Pipelines.*** A total of 24 pipeline failures occurred. Two repair crews with equipment and repair materials are available within 2 days following the event. It is estimated that each crew can repair 2 failures/day totaling 4/day. It will take an estimated 8 days (2 days to begin and 6 days to repair) to restore the pipe after the event. Repair crews will start pipe restoration at the functioning wells, first connecting critical facilities such as hospitals. It is estimated it will take 4 days to connect the well supply to hospitals after the event.

- ***System Restoration Time.*** System functional component restoration can be recovered, following the Guide Table 9-14 Riverbend water infrastructure performance goals for design earthquake as follows:
  - ***Source.*** 50 % of the well capacity (which includes raw water, conveyance and pumping) is operable within 2 days. Place the "X" at 2 days (noting 50 % available) for these categories. A temporary WTP is operable within 2 weeks allowing the system to meet 100 % winter demand flow. This meets the 90 % category. Place an "X" at 2 weeks (noting 100 %) for these three

categories. Fire flow at 90 % demand is only available after 2 weeks after the temporary WTP comes on line.

- ***Transmission.*** All 6 wells and the WTP are in town, and do not depend on transmission lines to move water to the distribution system. However it will take 4 days to get water through the backbone system in town to get water to the hospital. Place the "X" at 1-4 weeks noting 1 week for delivery to the hospital.
- ***Supervisory Control and Data Acquisition (SCADA).*** The SCADA system monitors the system operation logging such information as flows and pressures, and makes system control such as turning pumps on and off based on preprogramed rules. The SCADA system was in the Control Building, which collapsed. A temporary WTP will be in place within 2 weeks, but restoration of the SCADA system will take longer. The "X" location depends on the status of the SCADA system.
- ***Distribution.*** Water will be available for Community Distribution at the 3 operable wells within 2 days. Place the "X" at 1-3 days noting 50 % capacity. Water will be available at the hospital within 4 days. Place the "X" at 1-3 weeks. The system will be fully functional at winter demand flows within 2 weeks. Place the "X" for other distribution categories at 1-4 weeks.

2.4. Water System Strategies for Reducing the Anticipated Recovery Time

This section provides preliminary ideas that could reduce the water system restoration time.

The WTP was constructed before significant seismic building codes were in place in this region. The control building was constructed with lightly reinforced concrete masonry units which are highly vulnerable to earthquakes. The intake was located in liquefiable soils. Half of the wells were located in areas with liquefiable soils making them, and even new wells, vulnerable to earthquakes. The owner should consider strengthening the WTP structures and anchoring equipment and piping to resist the moderate ground motions expected in this scenario.

While two of the tanks were old, storage did not limit the recovery time of the system. Upgrade of the two old tanks could be beneficial at some point.

Pipeline damage had the greatest impact on recovery times. The most failures were in cast iron pipe in liquefiable soils. Replacement of that pipe with seismic resistant pipe over the long term (say 50 years) would reduce the expected recovery time.

2.5. Wastewater System Performance and Restoration Time

Recovery of the wastewater system was evaluated in a similar manner to the water system. Using the vulnerability of the various system components, the overall system functionality and recovery was evaluated. This section describes where to place the "X"s in the performance matrix, which is then used to identify gaps in infrastructure system performance for a design level earthquake event.

- ***Wastewater Treatment Plant.*** The treatment plant was heavily damaged due to tsunami inundation and a 1 to 2 year restoration anticipated. The WTP will discharge raw sewage into the river and/or ocean until the treatment plant is repaired.
- ***Pump Stations:***
    - ***PS #1.*** The pump was inundated, equipment damaged, and the superstructure collapsed. Approximately 6 months to 1 year restoration anticipated. The WTP will discharge raw sewage into the river and/or ocean until the treatment plant is repaired.

  - ***PS #2*** – Remained functional.

- ***Sewer Pipelines.*** 19 pipeline failures occurred, some in liquefaction areas, some in landslide areas. Significant effort to route raw sewage into receiving waters to avoid human contact. Use the same crews as for water supply. Estimated start is about 8 days following the event after the water system is restored. Time to route sewage to receiving water is using the same repair rate as for water, 2 crews at 2 repairs/day equals 5 days. The sewage collection system, moving sewage away from people, will be functional within 13 days following the earthquake. As the PS #1 and the WWTP are not functional, raw sewage will be discharged in the river and/or ocean. It will take months to restore the sewers in liquefiable soils crossing the river.

- ***System Restoration Time.*** System components can recover, following Guide Table 9-15:

  - ***Treatment Plant.*** Place the "X" at 4-24 months for both WWTP subcategories as the WWTP will require 1 to 2 years to rebuild.

  - ***Trunk Lines.*** Place the "X" at 4-24 months to rebuild PS #1 and the interceptor going to the WWTP.

  - ***Control Systems.*** Place the "X" at 4-24 months as the SCADA systems at the WWTP and PS # 1 will need to be rebuilt.

  - ***Collection.*** Place the "X" at 1-4 weeks as it will take 13 days to route raw sewage to the river or ocean.

    It is assumed that business as usual can continue once raw sewage is diverted to the river of ocean even though it will result in an environmental impact.

2.6. Wastewater System – Possible Strategies for Reducing the Anticipated Recovery Time

The only impact failure of the wastewater system had on recovery time was the time it took to redirect raw sewage into the river and ocean. This raw sewage discharge would however result in some environmental damage. It may be useful to have raw sewage overflows that could be activated in the event of the catastrophic failure of the WWTP and PS#1.

In the long term, possibly at the point the existing plant is approaching the end of its useful life, it may be worth considering relocating the WWTP outside the inundation zone.

Community Resilience

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