DRAINAGE SYSTEMS ANALYSIS

Flooding Topic Area

Drainage System Capacity Evaluation

October 2, 2020

Seattle Public Utilities

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Flooding Topic Area

Technical Memorandum

Project: Drainage Systems Analysis

Topic Area: Flooding

Deliverable: Drainage System Capacity Evaluation

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Abbreviations

cfs/acre	cubic feet per second per acre
City	City of Seattle (organization)
city	city of Seattle (place)
Consultant	Brown and Caldwell
DDF	depth-duration-frequency
DSA	Drainage System Analysis
DS&G	Design Standards & Guidelines
DWW	Drainage and Wastewater
EPA	U.S. Environmental Protection Agency
ft	feet
ft^2	square feet
ft^3	cubic feet
GIS	geographic information system
HGL	hydraulic grade line
hr	hour
IDF	intensity-duration-frequency
ISP	Integrated System Plan
LOB	line of business
LOS	levels of service
MH	maintenance hole
MHHW	mean high higher water
mi	mile
NAVD88	North American Vertical Datum of 1988
ROW	right-of-way
SPU	Seattle Public Utilities
SWMM	Storm Water Management Model
TM	technical memorandum
WA	Work Assignment
WWSA	Wastewater System Analysis
yr	year

1. Introduction

Seattle Public Utilities (SPU) is completing a Drainage System Analysis (DSA) to provide data collection and technical analyses that support the development of the *Vision Plan* and *Integrated System Plan (ISP)* for the Drainage and Wastewater (DWW) line of business (LOB). The DSA will compile and update existing information related to SPU's drainage system and receiving waters, as well as perform new analyses that focus on flooding, climate change impacts, and water quality issues. The DSA efforts are divided into multiple topic areas, including a flooding topic area.

SPU contracted with Brown and Caldwell (Consultant) to perform technical analyses for the DSA's flooding topic area. Key objectives for the flooding topic area include:

- Develop a prioritized inventory of drainage capacity risk areas.
- Define Performance Thresholds for the drainage system and complete modeling to evaluate the capacity under existing and future conditions.
- Estimate inundation extent and develop risk maps for extreme storm events, sea level rise, and creek flooding.
- Estimate runoff and flow in areas served by ditches and culverts.
- Calculate flow metrics in creek watersheds and prioritize areas for runoff reduction to reduce erosive flows to creeks.

The development of the Performance Thresholds for drainage system capacity and identification of areas at risk of not meeting drainage system performance goals are documented in two technical memorandums (TM):

This **Drainage System Capacity Evaluation TM** documents the selection of Performance Thresholds for capacity modeling. The Consultant team performed citywide capacity modeling simulations to evaluate performance parameters (i.e., flood volume and/or hydraulic grade line [HGL] that defines when simulated flooding represents a potential flooding impact) for different types of drainage assets (pipes, ditches, culverts, creek culverts, and storage ponds) using design storms. The models used to perform these simulations represent SPU's drainage system under existing conditions. SPU used the initial results to select Performance Thresholds specified as a performance parameter and an amount of rainfall falling over a given duration. The Consultant team then used the selected Performance Thresholds to identify drainage assets that exceeded the thresholds under both existing and future conditions. The methods and results from the system capacity modeling are presented herein.

Subsequently, SPU and the Consultant team used the identified assets to delineate potential risk areas that will be prioritized in subsequent tasks. These risk area delineations will be discussed separately in the **Risk Area Prioritization TM**. Project and programmatic solutions for the risk areas will be developed as part of the ISP.

The following sections in this TM provide background on Performance Thresholds, a detailed technical methodology, and a summary of results from citywide modeling analyses of existing and future conditions.

2. Background

SPU's DWW LOB provides drainage and wastewater collection and conveyance services to residents and businesses throughout the city of Seattle (city). Levels of service (LOS) define the SPU's DWW LOB's desired system performance needed to ensure customer's highest priorities and regulatory requirements are met (SPU 2016).

The LOS for the drainage system were established in the Comprehensive Drainage Plan (SPU, Comprehensive Drainage Plan, Volume I 2004) and refined in the SPU Strategic Business Plan (SPU 2015). In 2016, SPU's DWW LOB developed a draft LOS Framework (SPU 2016), shown in Appendix A. The LOS Framework provided recommendations for DWW Service Goals. The LOS Framework identified the need to complete technical studies to develop specific and measurable targets or thresholds for DWW system performance.

The LOS Framework was the basis for the DSA. Drainage system capacity performance goals were established from the DWW Service Goals. The performance goals are to:

- Provide adequate capacity in the public drainage system to minimize the risk of flooding into private property.
- Provide adequate capacity in the public drainage system to minimize the risk of flooding in the public right-of-way (ROW).

Performance Threshold defines adequate capacity; it was used for the citywide modeling analyses to identify drainage system capacity risk areas. Performance Thresholds are made up of two components—a design storm and a performance parameter.

A **design storm** is a specified amount of rainfall distributed over time and space.

A **performance parameter** is a set flood volume or hydraulic grade line (HGL) that defines when simulated flooding represents a potential flooding impact.

Since developing the LOS Framework, SPU decided to use the term "Performance Threshold," rather than "Performance Target." A ***Performance Threshold*** defines adequate capacity; it was used for the citywide modeling analyses (described herein) to identify drainage system capacity risk areas. Performance Thresholds are made up of two components: a design storm and performance parameter. A ***design storm*** is a specified amount of rainfall distributed over time and space. A ***performance parameter*** is a set flood volume or hydraulic grade line (HGL) that defines when simulated flooding represents a potential flooding impact[1].

Section 3.1. describes the design storms that were evaluated for this project. Section 3.2 describes the performance parameters that were used.

[1] The design storm and performance parameters were developed for this citywide modeling analysis; they are not design standards.

3. Evaluation and Selection of Performance Thresholds

The Consultant team performed hydrologic and hydraulic simulations using the Stormwater Management Model (SWMM)[2] developed by the U.S. Environmental Protection Agency (EPA) for managing urban drainage systems. SPU has developed a total of 66 drainage basin models in SWMM (listed in Appendix B), covering most of the separated and partially separated stormwater systems in the city. These models, and the drainage infrastructure represented within them, were used for this drainage system capacity analysis to evaluate Performance Thresholds. Detailed information regarding the previous development, calibration, and validation of the drainage basin models, and parameter adjustments made during this effort is described in Appendix C.

The following subsections describe the design storms and performance parameters that were selected and how the SWMM models were used to identify potential risk areas in the drainage system.

3.1 Design Storms

The SWMM models were used to simulate four synthetic design storms: 5-, 10-, 25- and 50-year, 24-hour storms. Most of the synthetic, 24-hour design storms were developed during the Wastewater System Analysis (WWSA) with the intention of citywide use for both the WWSA and the DSA. For the DSA, a larger-magnitude storm with a 50-year return period was used since the city's drainage system was designed to convey larger flows than the wastewater system.

These design storms consisted of hyetographs created by an alternating block method (Chow, Maidment and Mays 1988), which ensures that the peak precipitation occurs at the midpoint of the storm and the falling limbs of the hyetograph successively decrease in depth (Aqualyze, Inc. 2018a). Intensity-duration-frequency (IDF) curves from *Intensity Duration Frequency Curves and Trends for City of Seattle* (Tetra Tech 2018) were used to develop depth-duration-frequency (DDF) values to define the 24-hour duration hyetographs for 5-, 10-, 25-, and 50-year storms. A 24-hour duration was used, given rainfall response varies from short term to longer durations across the city. These design storms were used to provide storms of equal duration where intensity increased for each less frequent event. The DDF values developed using 17 rain-gage stations in SPU's network are summarized in Table 1.

2 SWMM is a stand-alone, dynamic hydrology-hydraulic simulation model used for single-event or long-term (continuous) simulation of runoff quantity and quality. SWMM is primarily intended for use in urban drainage areas. Note that SPU uses PCSWMM software as an interface for constructing, editing, and running SWMM models based on the SWMM 5.1.012 engine.

Table 1. DDF Values for 5-year, 10-year, 25-year, and 50-year Recurrence Intervals				
Duration	**Total rainfall depth (inches)**			
	5-year	**10-year**	**25-year**	**50-year**
5 minutes	0.149	0.176	0.212	0.240
10 minutes	0.225	0.265	0.317	0.358
15 minutes	0.273	0.320	0.385	0.435
30 minutes	0.366	0.430	0.520	0.590
1 hour	0.500	0.578	0.682	0.765
2 hours	0.714	0.816	0.950	1.052
6 hours	1.326	1.554	1.860	2.100
24 hours	2.688	3.240	4.032	4.704

The 5-minute value was set at the middle of the storm. Then, the difference in depth between two adjacent durations of rainfall were evenly distributed over each 5-minute increment on either side of the midpoint of the storm to generate the 24-hour hyetographs (Figure 1).

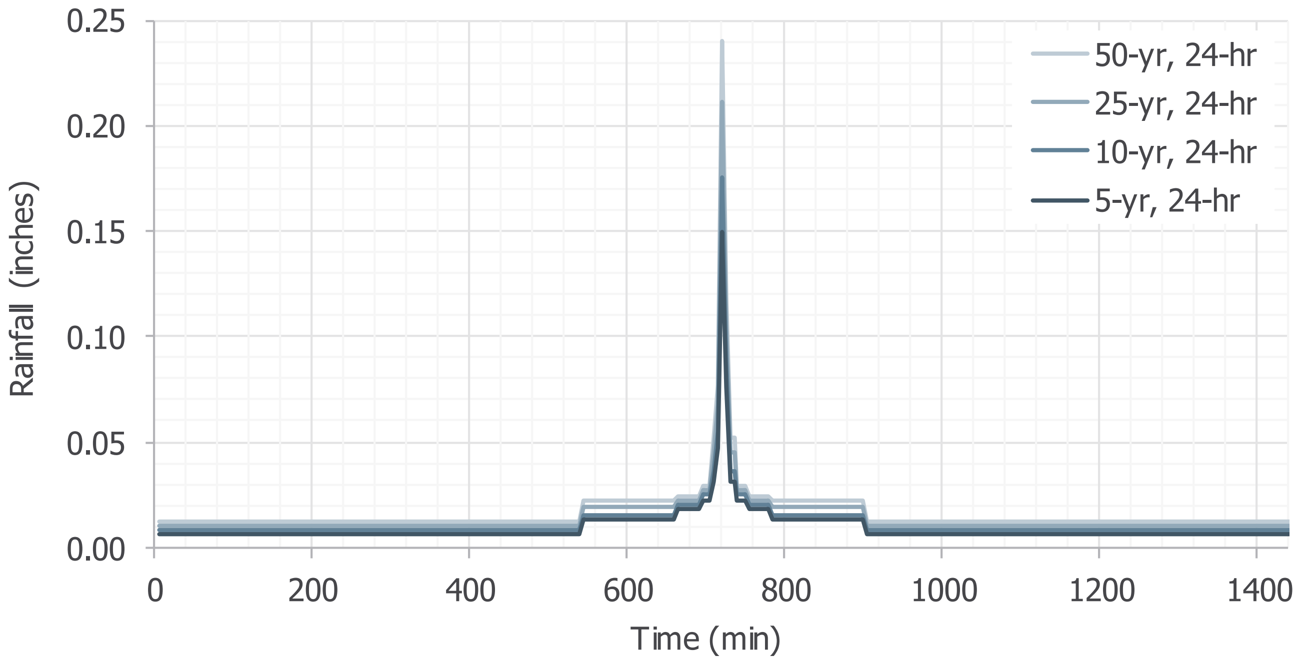

Figure 1. Synthetic rainfall hyetographs developed using alternating block method

While design storms are described by their frequency and duration throughout this memo, the selected design storm will be described by depth of rain over a duration in hours as presented in the LOS Framework.

3.2 Performance Parameters and Performance Threshold Results

The SWMM drainage models represent the physical conditions of drainage basins and infrastructure that represent the drainage system within the city. Model elements used to build SPU's SWMM drainage models include subcatchments, junctions (or nodes), conduits, outfalls, and storage facilities that may include other special structures such as orifices, weirs, and outlets. Figure 2 shows an example of a modeled drainage network.

Figure 2. Example area showing modeled assets

Subcatchments represent smaller areas that generate surface water runoff that contribute flow to catch basins and maintenance holes (MH). During a simulation, when a subcatchment receives rainfall, runoff is generated. This runoff, as well as groundwater inflows, is routed through the drainage system using one-dimensional computations, where the quantity of runoff generated from each subcatchment is tracked for each routing time step as the flows are routed through a system of nodes and conduits. During this process, flooding is simulated in the models when the water depth exceeds the maximum available depth at a given node.

Performance parameters are set flood volumes or HGLs that define when simulated flooding in the model represents a potential flooding impact. The performance parameters for different drainage system assets within the models—drainage pipes, creek culverts, ditches, culverts, and storage ponds—are unique. Table 2 summarizes the drainage system performance parameters that were selected for each asset for this capacity evaluation.

Table 2. Drainage System Performance Parameters

Asset	Performance parameter(s) for adequate capacity
Drainage pipes	Maintenance hole flooding • less than 400 cubic ft (ft^3), for ROW • less than 2,400 ft^3, for the private property
Creek culverts	When creek is modeled with: • an irregular cross section: HGL in creek cross section less than 1 foot above the crown of the culvert inlet • a regular ditch-like cross section: no surcharging (creek overtopping) at the inlet
Ditches	No overtopping
Culverts	No surcharging at the inlet
Storage ponds	Pond-specific criteria (see Table 4)

The subsections below describe how the performance parameter for each asset was defined, as well as the quantity of assets simulated as under capacity for the four design storms.

3.2.1 Piped Drainage Systems

Piped drainage systems are modeled as networks of conduits (representing pipes) and nodes on either end (representing MHs) as shown in Figure 3. When a conduit is simulated as under capacity, water will back up and surcharge in the upstream node. When the surcharged water increases above the rim elevation, the flooded water collects atop the node. The simulated flooded water collects over an area of 5,000 square feet (ft^2) and is re-introduced into the conduit as conditions in the network permits.

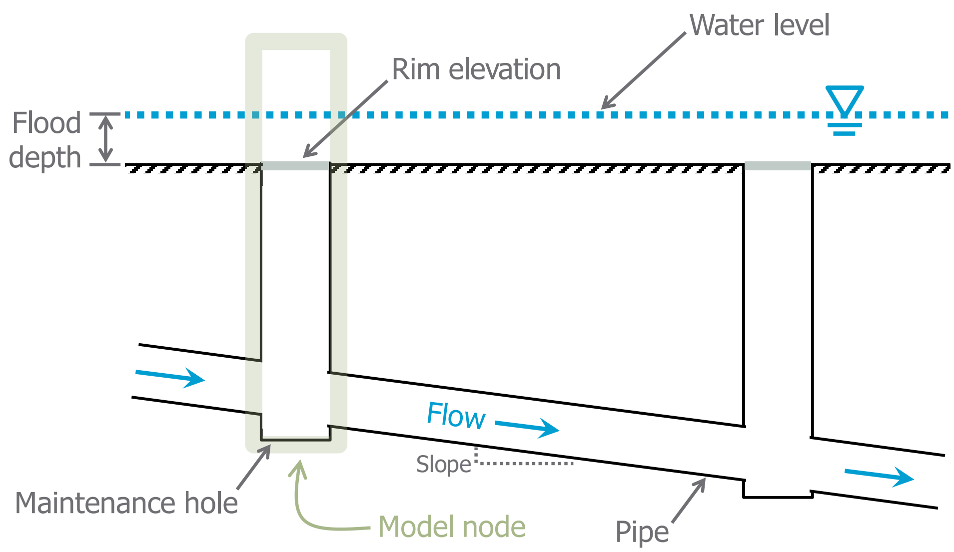

Figure 3. Schematic profile for a piped system

SPU estimated that a flooding water depth of at least 1 inch on a roadway could impact safe mobility on the roadway. This was used to set the performance parameter for impacts to the ROW as simulated flood volume of 400 cubic feet (ft^3), which corresponds to 1-inch water depth ponded on 5,000 ft^2 of area above the MH (Figure 4). The ponded depth of 5,000 ft^2 is built into SPU's models. It is the approximate area of a street intersection.

SPU identified that potential flooding impact to private property could occur when the roadway fills up and overtops the curb. For a 20-foot-wide roadway, with 2 percent crown slope and a 6-inch-high curb, the roadway cross section can contain about 8 ft^2 of water. Multiplying this cross-sectional area by a length of 300 feet for a street block (assuming inlets at each end of the block), results in a volume of 2,400 ft^3 (Figure 4); therefore, the performance parameter for impacts to private property was set as a simulated flooding volume over 2,400 ft^3 at a MH.

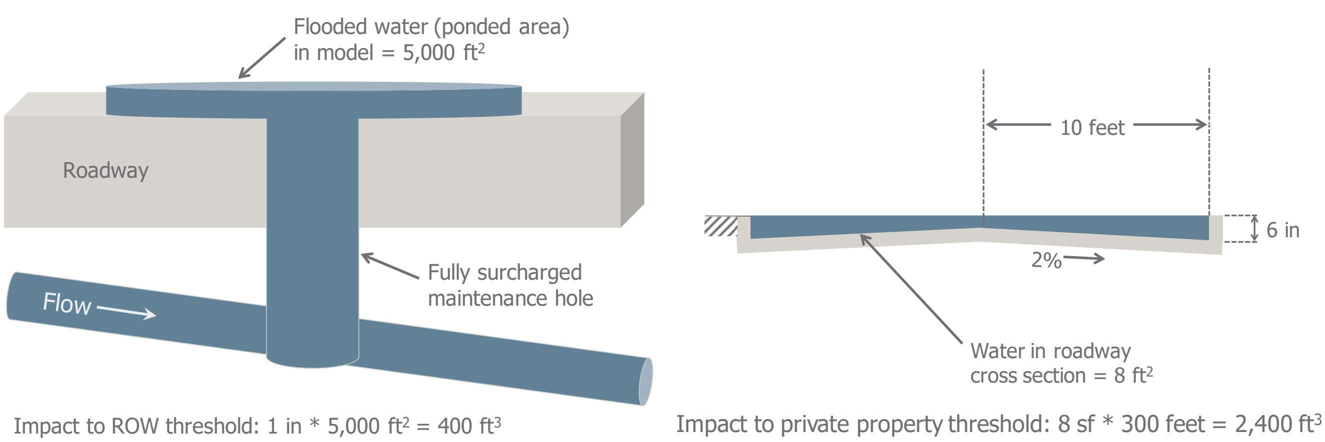

Figure 4. Performance parameters for impacts to ROW and private property

Figure 5 shows an example of the piped drainage system simulated as under capacity for the design storms.

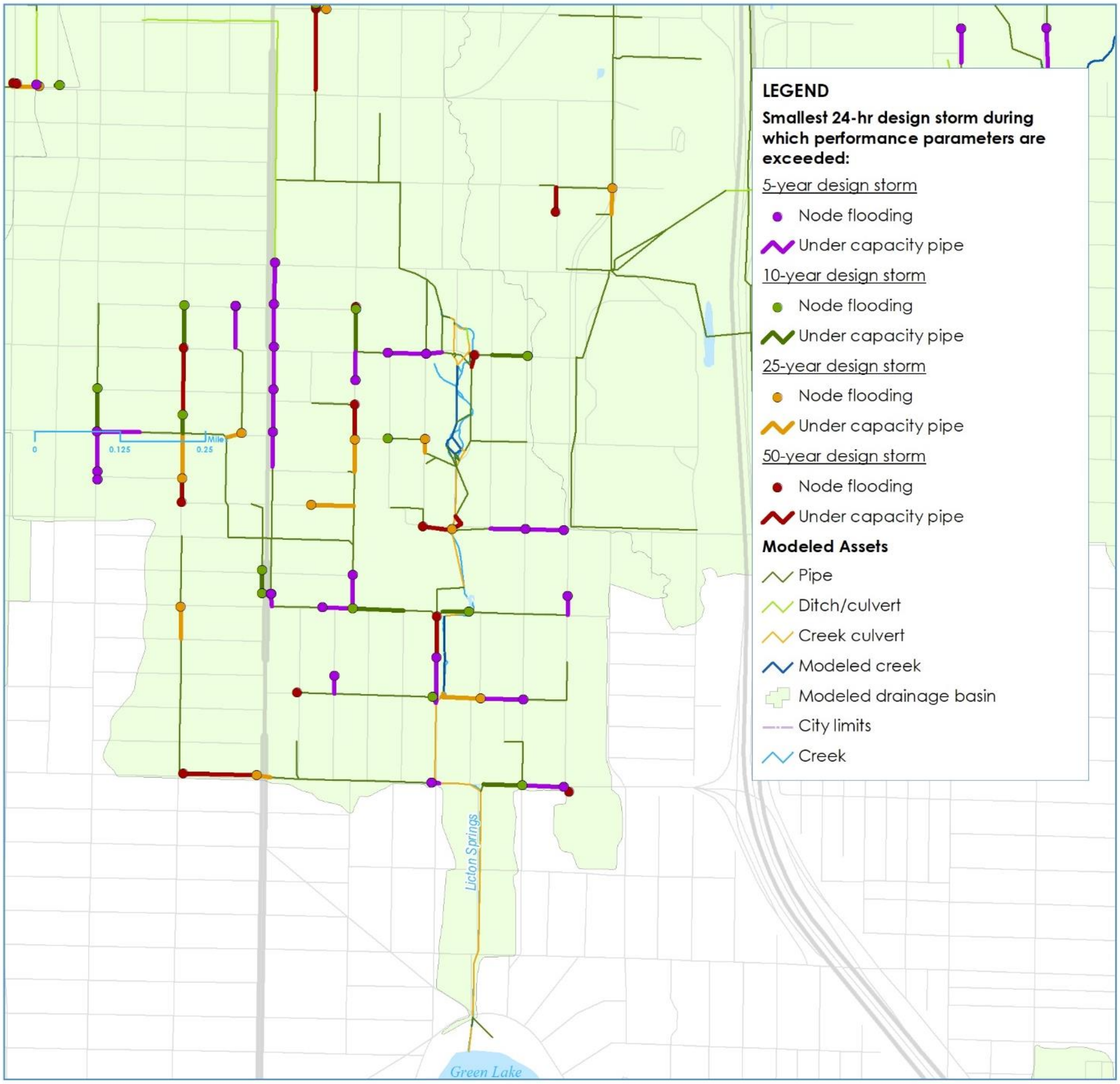

Figure 5. Example of the piped drainage system simulated for capacity evaluation

Figure 6 shows simulated under-capacity conduits by length and count for the modeled piped network. The drainage system models include 432 miles of drainage pipe, approximately 92 percent of SPU's piped drainage system. In Figure 6, conduits are further characterized as those that could have an impact on the ROW and private property, based on the upstream node flooding volume. The number and length of under-capacity conduits approximately doubles between design storms, with the exception of 25-yr to the 50-year event. Also, most under-capacity pipes have a potential flooding impact that is estimated to be limited to the ROW.

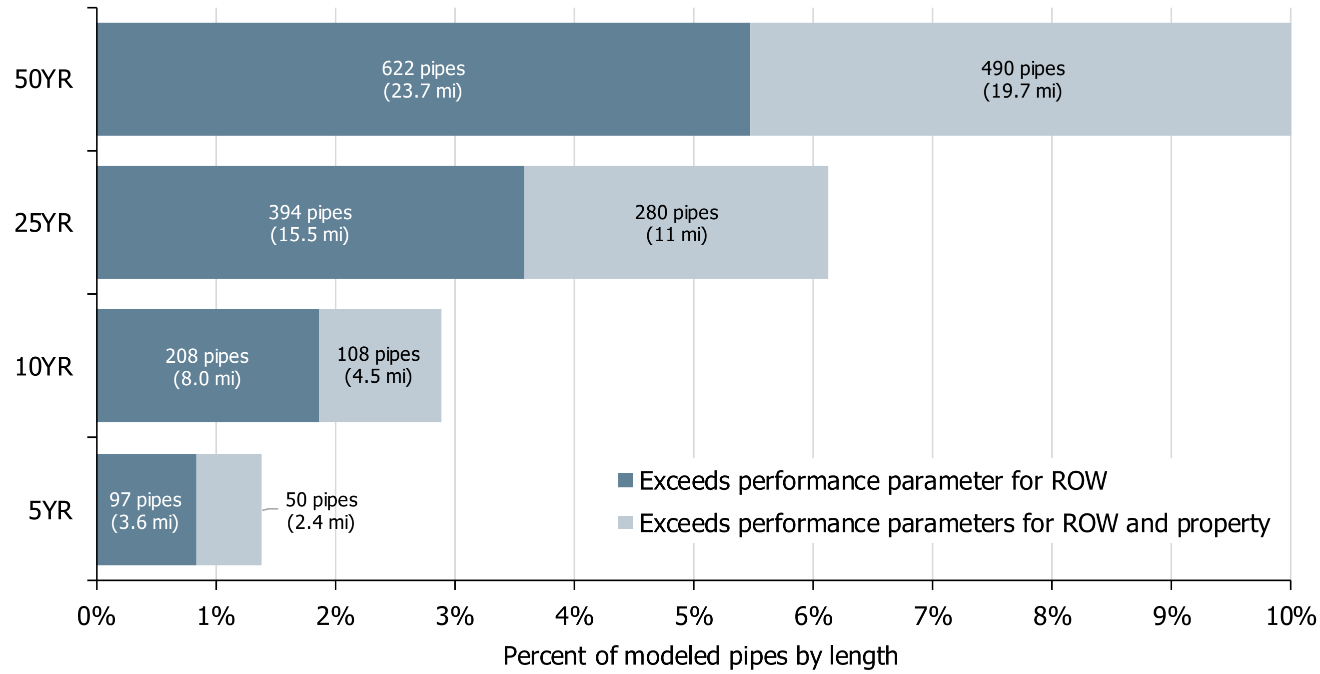

Figure 6. Pipes exceeding performance parameters for selected design storms

3.2.2 Ditches and Culverts

There are areas within the city where the drainage system is primarily comprised of an informal system of ditches and culverts. While culverts are modeled as closed conduits in the SWMM models, ditches are modeled as open channel conduits with different cross sections as shown in Figure 7.

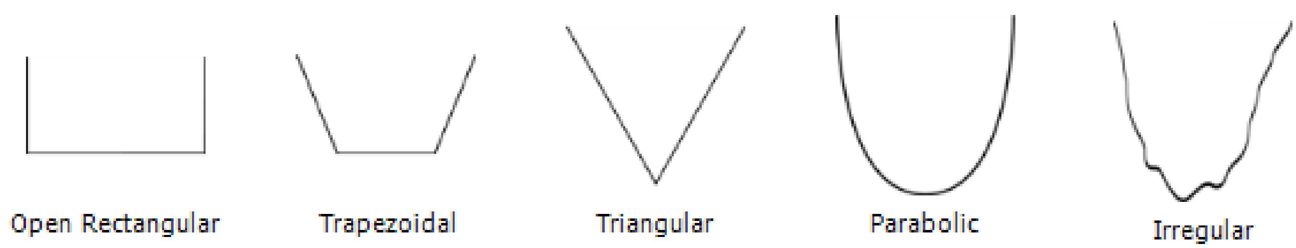

Figure 7. Open channel conduits with different cross-sectional shapes

Although the SWMM models include nodes that connect a ditch and a culvert, these nodes do not represent MHs. They represent the connection point (the junction) between the two types of drainage assets, and the top of the node represents the top of the ditch, as shown in Figure 8.

Similar to a pipe conduit, when a ditch or culvert conduit is simulated as under capacity, water will back up and surcharge in the upstream node. Unlike piped systems, ditches and culverts are typically found in areas with no curb and gutter; therefore, when the simulated water depth increases above the node rim elevation, it is simulating flooding that could impact both the ROW and private property. Figure 12 shows an example of ditches and culverts simulated as under capacity for the design storms.

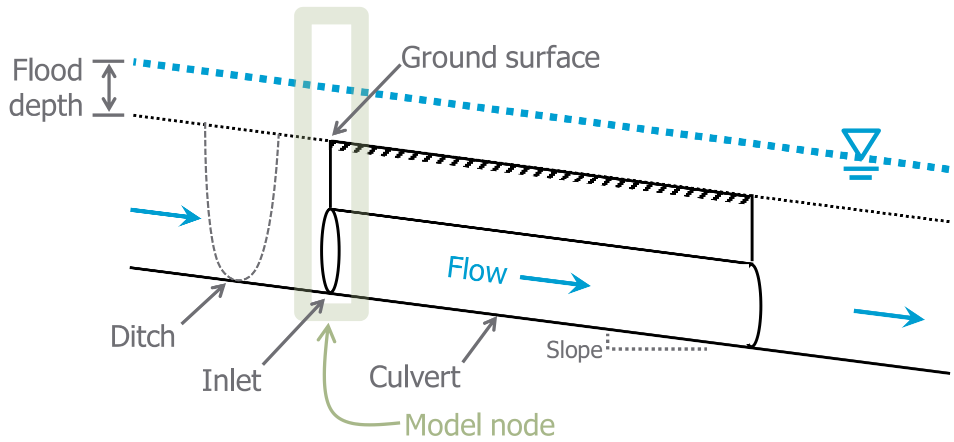

Figure 8. Schematic profile for a ditch and culvert

Figure 9. Example of the ditch and culvert drainage system simulated for capacity evaluation

Figure 10 shows simulated under-capacity conduits by length and count for the ditches and culverts. Only 31 miles (15 percent) of the city's ditches and culverts are represented in the models.

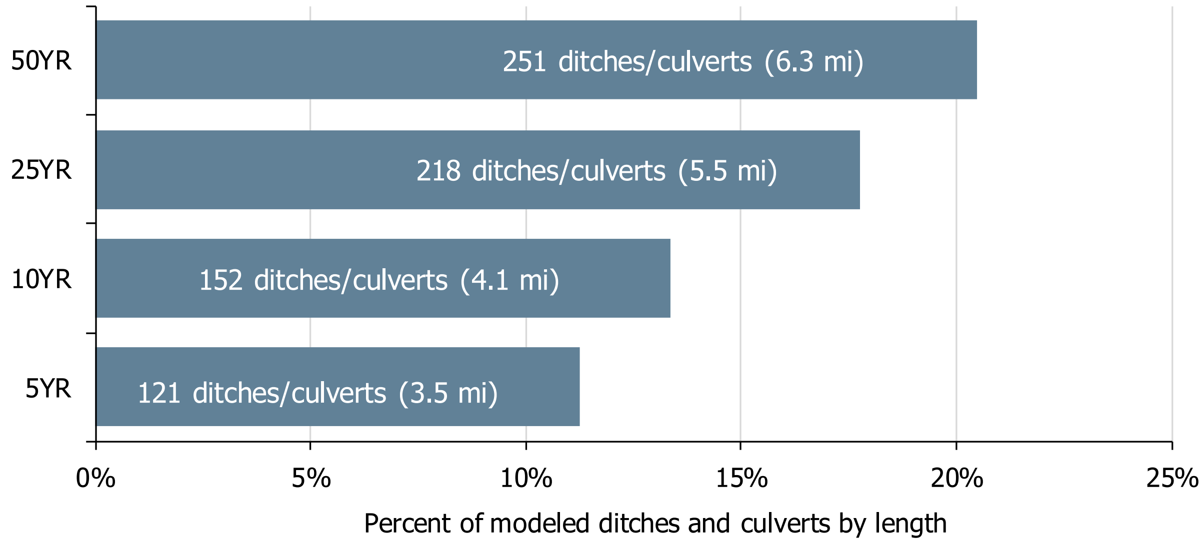

Figure 10. Ditches and culverts exceeding performance parameters for selected design storms

3.2.3 Creek Culverts

A creek culvert is any pipe with a creek flowing through it. Creek culverts are structures that allow creeks to flow under a road, trail, railway, or other type of crossings or may route creeks underground. Some creeks are modeled like ditches, i.e., open channel conduits with varying cross-sectional shapes (Figure 7). Some major creeks, however, are modeled as irregular-shaped open-system transects characterized by survey stations and elevations, as shown in Figure 11. When the models were developed, transect data were developed either from SPU's contour data or from surveyed cross sections that extend beyond the bank points.

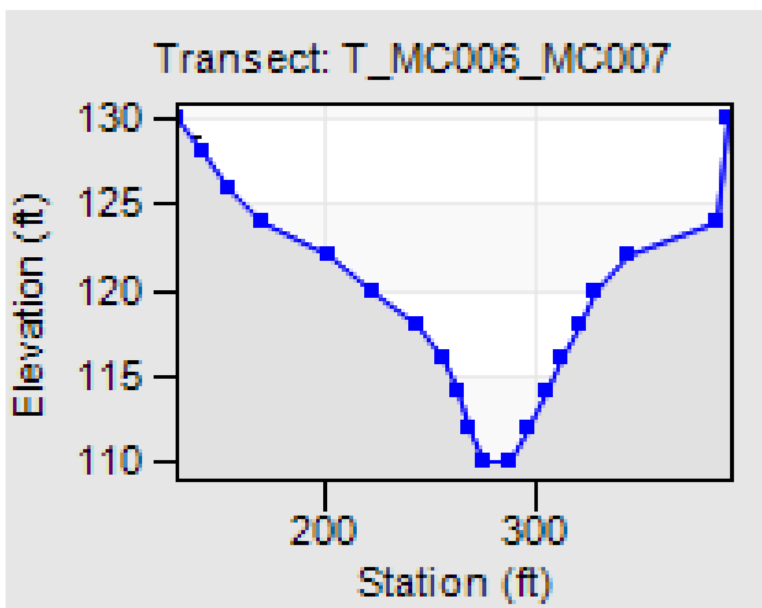

Figure 11. Irregular transect for open channel conduit

Flooding impacts from creek culverts occur when water levels reach the crossing or over top the banks laterally but can also occur before water levels reach the crossing. The potential impacts (the performance parameters) were based on how the creek, upstream of the creek culvert, was modeled. There were three possibilities:

1. **Closed conduit or flow control structure (e.g., a weir) upstream.** The creek culvert is evaluated as if it were part of a piped system. The creek culvert is evaluated based on the flooding volume calculated at the creek culvert inlet node (discharge above the rim of the maintenance hole). A calculated flooding volume between 400 and 2,400 cubic feet indicates impacts to ROW, and a calculated flooding volume greater than 2,400 cubic feet indicates impacts to ROW and property.
2. **Ditch upstream or no upstream conduit.** The creek culvert is evaluated based on if there is flooding at the creek culvert inlet node (discharge above the top of the ditch). If there is flooding, it is considered to have an impact on the ROW and property.
3. **Transect upstream.** The creek culvert is evaluated based on the water surface elevation (HGL) at the creek culvert inlet node. A calculated HGL that is 1 ft above the top of the creek culvert indicates an impact to ROW and property. Figure 12 shows an example profile of a creek culvert with the creek upstream modeled with a transect.

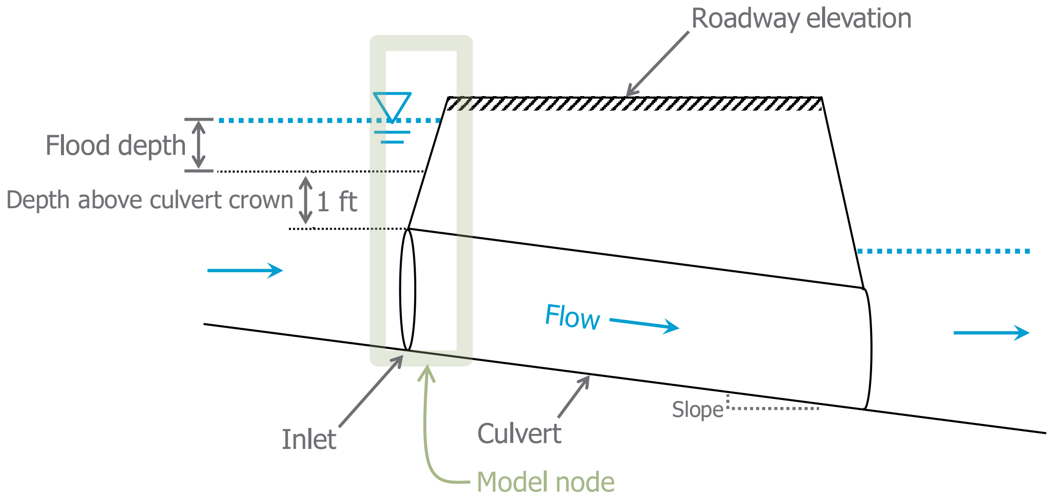

Figure 12. Schematic profile for a creek culvert

Figure 13 shows an example map with creek culverts simulated as under capacity for the design storms.

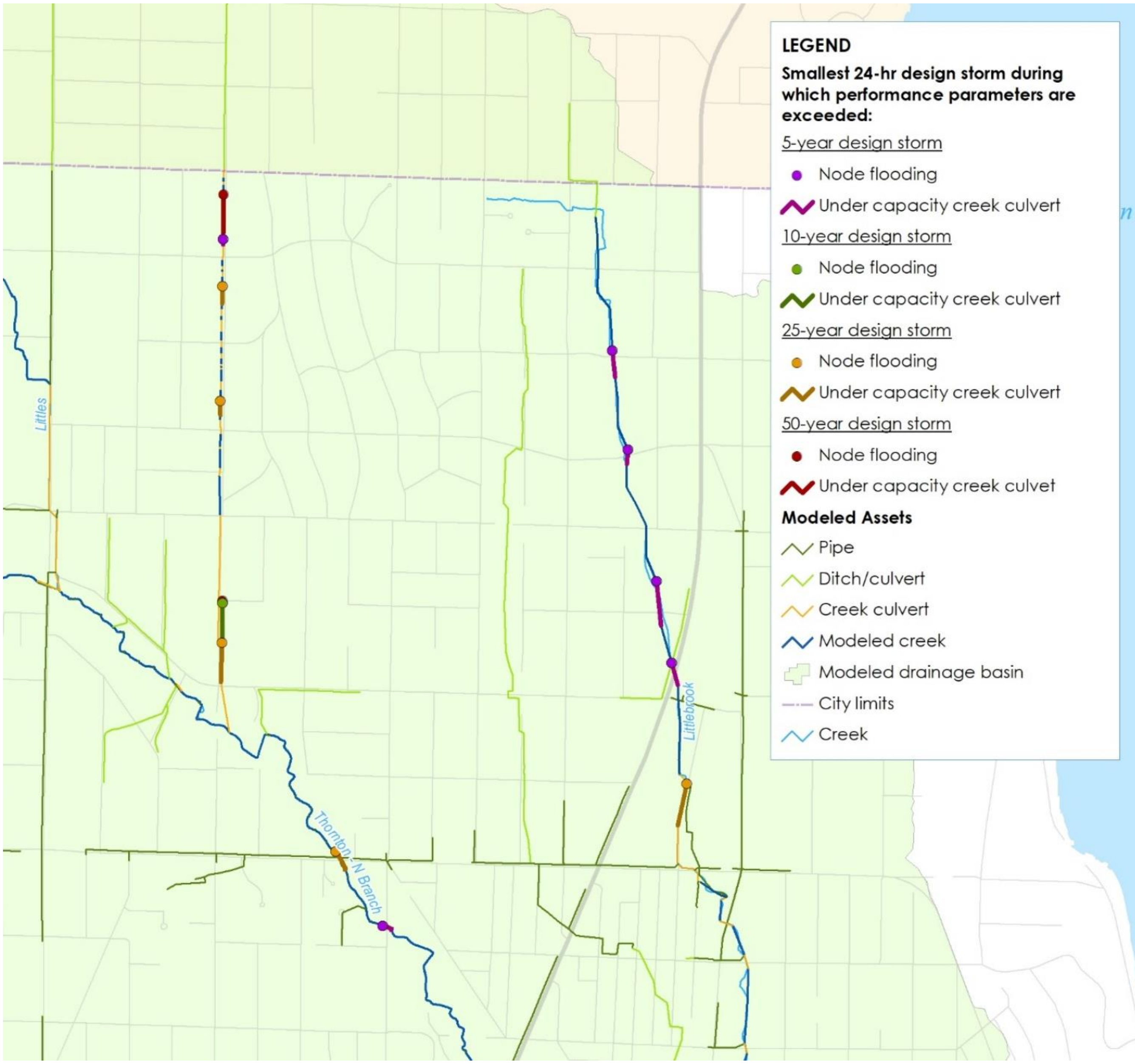

Figure 13. Example of the creek culvert drainage system simulated for capacity evaluation

The number and length of creek culverts simulated as under-capacity is shown in Figure 14 and Table 3. Approximately 9.7 miles (85 percent, by length) of SPU-owned creek culverts were evaluated using the drainage basin models.

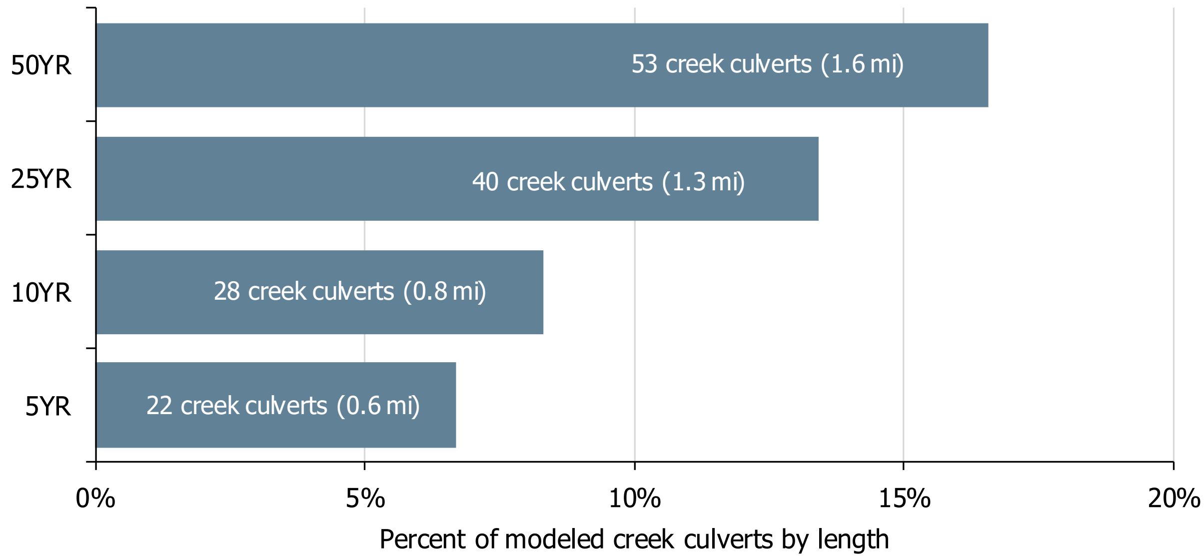

Figure 14. Creek culverts exceeding performance parameters for selected design storms

Number of creek culverts is approximate as a modeled creek culvert may actually represent two or more culverts

Table 3. Creek culverts exceeding performance parameters by creek basin

Creek Name	Creek culverts exceeding performance parameter											
	5YR			10YR			25YR			50YR		
	Count[a]	Total length (ft)	Percent by length[b]	Count[a]	Total length (ft)	Percent by length[b]	Count[a]	Total length (ft)	Percent by length[b]	Count[a]	Total length (ft)	Percent by length[b]
South Creek Basins												
Longfellow	0	0	0	0	0	0	0	0	0	1	133	2
Puget	1	768	17	1	768	17	1	768	17	1	768	17
Mount Baker	0	0	0	0	0	0	2	358	59	2	358	59
Taylor	1	91	25	1	91	25	1	91	25	1	91	25
Thornton Creek Basin												
Thornton, Mainstem	1	18	9	2	35	17	2	35	17	2	35	17
Thornton, N Branch	1	87	5	1	87	5	2	258	16	2	258	16
Thornton, S Branch	5	189	25	6	363	48	6	363	48	6	363	48
Hamlin	1	40	1	2	347	10	5	893	26	7	1211	35
Littles	1	419	20	1	419	20	1	419	20	1	419	20
Mock	0	0	0	1	47	3	1	47	3	1	47	3
Matthews	0	0	0	0	0	0	0	0	0	1	323	13
Littlebrook	4	836	38	4	836	38	5	1,165	53	5	1,165	53

Table 3. Creek culverts exceeding performance parameters by creek basin

Creek Name	Creek culverts exceeding performance parameter											
	5YR			10YR			25YR			50YR		
	Count[a]	Total length (ft)	Percent by length[b]	Count[a]	Total length (ft)	Percent by length[b]	Count[a]	Total length (ft)	Percent by length[b]	Count[a]	Total length (ft)	Percent by length[b]
Maple	0	0	0	1	40	100	1	40	100	1	40	100
North Creek Basins												
Piper's - Trib H	1	44	100	1	44	100	1	44	100	1	44	100
Yesler	0	0	0	0	0	0	3	1,151	20	9	1,844	33
Licton Springs	6	930	18	7	1,165	22	9	1,219	23	12	1,369	26
Total	**22**	**3,422**	**6.7**	**28**	**4,241**	**8.3**	**40**	**6,850**	**13**	**53**	**8,466**	**17**

a. *The count indicates the number of modeled creek culverts exceeding the performance parameter; a modeled creek culvert may represent one or more SPU-owned creek culverts.*

b. *Percentage provided is the total length of culverts exceeding the performance parameter divided by the total length of modeled creek culverts.*

3.2.4 Storage Ponds

A stormwater storage pond, which is modeled as a storage node, overtops when the water depth exceeds the top of the node, as shown in Figure 15. However, stormwater storage facilities may comprise various other infrastructure in addition to the storage ponds, such as flow control structures, weirs, orifices, paths for overland flow, berms, etc.

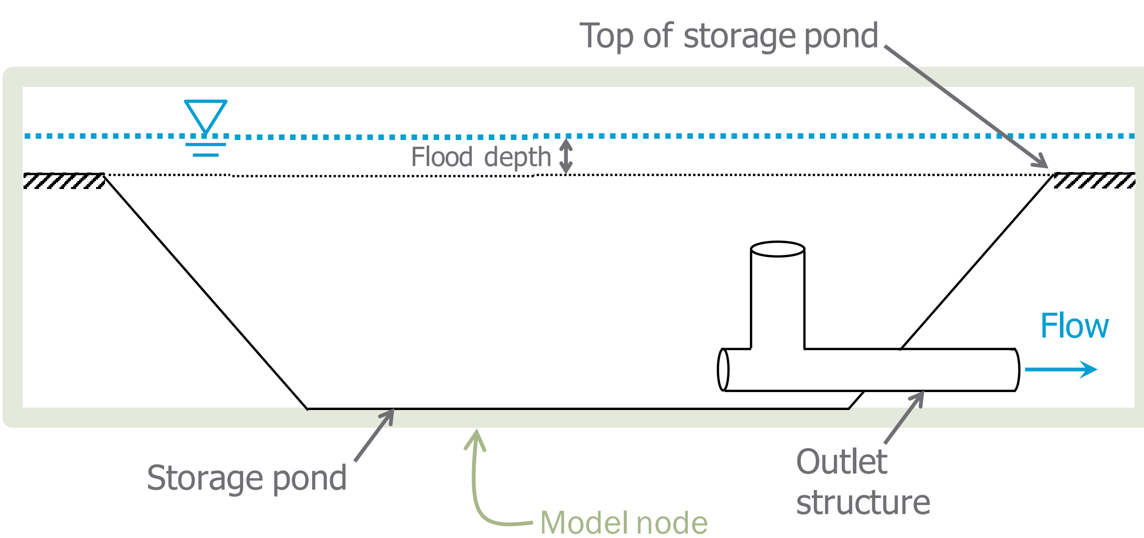

Figure 15. Schematic profile for a storage pond

The City owns and operates 12 stormwater ponds that provide flow control. Out of these, 10 ponds are included in the City's drainage system models, as shown in Table 4. Because of the complexity of the storage facilities and how they are configured in the models, each storage facility was evaluated individually, and the flooding threshold for potential impact evaluated based on site-specific information (Appendix D). Table 4 summarizes the performance parameters and modeling results for the design storms.

Table 4. SPU Owned and Operated Stormwater Ponds

Facility name	Flooding performance parameter	Modeled as under capacity			
		5YR	**10YR**	**25YR**	**50YR**
Ashworth Pond	Sum of flooding volume at 4 modeled storage nodes is larger than 125,000 ft^3	no	no	yes	yes
Blue Dog Pond[a]	Flooding at the modeled storage node is larger than 0 ft^3	no	no	no	no
East John Pond	Flooding at the modeled storage node is larger than 0 ft^3	no	no	no	no
Genesee Pond	Not modeled	not available			
Jackson Park Pond	Sum of flooding volume at 3 modeled storage nodes is larger than 0 ft^3	no	no	no	no
Lake City (35th Ave) Pond	Sum of flooding volume at 2 modeled storage nodes is larger than 0 ft^3	no	no	no	no
Littles Creek Pond	Flooding at the modeled storage node is larger than 0 ft^3	no	no	no	no
Meadowbrook Pond	Flooding threshold at the modeled storage node is larger than 0 ft^3.	no	no	yes	yes
Midvale Pond	Sum of flooding volume at 4 modeled storage nodes is larger than 400 ft^3	no	yes	yes	yes
Olson Pond	Not modeled	not available			
Stone Pond	HGL >365 feet in the conduit that conveys overland flow	no	yes	yes	yes
Webster Pond	Flooding at the modeled storage node is larger than 0 ft^3	no	no	no	no
Summary – total number of ponds		0	2	4	4

a. Modeling for Blue Dog Pond completed by SPU.

b. Based on SPU's current understanding that Meadowbrook Pond was designed for a 25-year event.

Midvale and Stone ponds exceeded their flooding performance parameter for the 10-, 25-, and 50-year storms. Ashworth Pond flooded at the 25- and 50-year storms only. Meadowbrook Pond exceeded the flooding performance parameter for all four storm events. However, SPU determined that the model was inaccurate in the vicinity of Meadowbrook Pond. SPU's current understanding is that Meadowbrook Pond was designed for a 25-year event. For these purposes, SPU decided to apply the flooding performance parameter to the 25- and 50-year design storms only and exclude results below 25-year design storm.

3.3 Performance Thresholds Selection

Three workshops were held with SPU and the Consultant to discuss the approach to select the Performance Threshold and review the modeling results. These workshops were held on August 14, 2018; February 28, 2019; and May 2, 2019. The Consultant presented mapped, tabulated and summarized capacity results (similar to those shown in Section 3.2) that corresponded to the selected performance parameters and range of design storms. During the third workshop, the team reviewed the WWSA-modified equity toolkit for selecting a Performance Threshold (SPU 2019). The team discussed how the goals and outcomes of the WWSA equity toolkit are very similar for selecting the DSA Performance Thresholds. We then compared the drainage system results and developed a pro/con table for each Performance Threshold.

After the third workshop, the SPU task lead:

- Held meetings with SPU staff members who were unable to attend the third workshop
- Followed up with all SPU workshop participants to solicit more feedback on the Performance Thresholds
- Solicited additional input, revised, and finalized the pro/con table (Appendix E)

The following considerations supported the recommendation of selecting the 25-year, 24-hour design storm that delivers 4.0 inches of rain in 24 hours for the Performance Thresholds:

- Affordability to meet each Performance Threshold was discussed as we talked though the WWSA equity toolkit. It was recognized that this storm event could result in higher rates than if a smaller event was selected, but that was not the most important factor. Other valid considerations included the fact that a larger number of customers would have to pay high upfront costs if a smaller storm event was selected, given that fewer drainage capacity problems would be addressed by SPU.
- The 25-year average recurrence interval is in line with the Design Standards & Guidelines (SPU 2018), which requires public storm drains to be designed for full gravity peak flow (with some surcharge) with a 4 percent annual exceedance probability (25-year average recurrence interval). Selecting the design storm that delivers 4.0 inches of rain in 24 hours will help identify where the system is not functioning as intended when it was designed.
- The ISP will identify projects and programs to address drainage capacity issues over a 50-year planning horizon. The 25-year, 24-hour storm event is robust in that it includes rainfall intensities for several durations, which are based on historical data from 1977-2017 from all of SPU's rain gages. SPU believed that this storm event was a good measure for use in DWW long-term planning.

The drainage system Performance Thresholds recommendations shown in Table 5 were presented to the DWW LOB Deputy Director and Division Directors on May 23, 2019. The Performance Thresholds recommendations were presented to and approved by the Planning Management Team[3] on May 31, 2019.

[3] Planning Management Team consisted of Ben Marré, Rose Ann Lopez, and John Holmes.

Table 5. Drainage System Performance Goals and Thresholds	
Performance goal	**Performance thresholds[a]**
Provide adequate capacity in the public drainage system to minimize the risk of flooding onto private property	Adequate capacity is defined as the following for the storm event that delivers 4.0 inches of rain in 24 hours: • Piped systems: maintenance hole flooding greater than 2,400 ft^3 • Creek culverts: HGL in a creek cross section greater than 1 foot above the crown of the culvert inlet or no surcharging (creek overtopping) at inlet when modeled with a ditch-like cross section upstream • Ditches: no overtopping • Culverts: no surcharging at the inlet • Ponds: pond-specific criteria
Provide adequate capacity in the public drainage system to minimize the risk of flooding in the public ROW	Adequate capacity is defined as the following for the storm event that delivers 4.0 inches of rain in 24 hours: • Piped systems: maintenance hole surface flooding greater than 400 ft^3 • Creek culverts: HGL in a creek cross section greater than 1 foot above the crown of the culvert inlet or no surcharging (creek overtopping) at inlet when modeled with a ditch-like cross section upstream • Ditches: no overtopping • Culverts: no surcharging at the inlet • Ponds: pond-specific criteria

a. Performance Thresholds were developed for this citywide modeling analysis; they are not design standards.

4. Capacity Evaluation

The Consultant team performed hydraulic modeling simulations and used the selected Performance Thresholds to evaluate the capacity of the drainage system to collect and convey runoff. Modeling results were used to identify drainage assets where the Performance Thresholds are exceeded under existing conditions. This section summarizes the results of the existing-conditions capacity evaluation.

In addition, the Consultant team developed future conditions models for the 2035 planning horizon and ran simulations to evaluate the potential changes in flooding caused by changes in impervious cover, stormwater code compliance, sea level rise, and more frequent extreme rainfall events.

A modeling methodology was developed for SPU to estimate future flows accounting for redevelopment and climate change – both sea level rise and changes to precipitation patterns (Osborn Consulting Incorporated 2018). These factors are anticipated to impact future drainage system flows in the following ways:

- Redevelopment can result in additional impervious areas which can increase peak flows and affect conveyance capacity. Due to the City's stormwater code requirements, new or replaced impervious areas associated with development may require flow control, which mitigate the increased flows and sometimes decrease existing flows.
- While sea level rise will not increase flows, it will increase the HGL at outfalls to Puget Sound. A higher HGL could result in backups upstream of the drainage outfalls.

- Changing precipitation patterns can result in increased precipitation, increasing peak flows in the conveyance system.

Appendix C summarizes the drainage model updates for future conditions using the future flow methodology.

Citywide results for existing and future conditions are presented, in the following sections, by system/asset type with summary data including the number, length, and percentage of modeled infrastructure shown to exceed the Performance Threshold. Maps of model results are provided Appendix F.

The Consultant team has developed geographic information system (GIS) datasets for the capacity modeling results described herein. These data are stored in two geodatabases, one for existing conditions and one for future conditions. SPU will use the assets that exceed the Performance Thresholds for the existing conditions to delineate drainage system capacity risk areas. This process and the identified risk areas will be described in a separate document: *Risk Area Prioritization TM*.

4.1 Pipes, Ditches and Culverts

This section summarizes the location, number, and length of under-capacity drainage pipes, ditches and culverts for the existing and future conditions analyses. Citywide results for pipes are summarized in Figure 16, which shows the number and total length of pipes that are under capacity, based on the Performance Thresholds. For existing conditions, a total of 674 pipes and 26.5 miles (approximately 6 percent of the total length of modeled pipes) are shown to be under capacity based on the selected Performance Thresholds. The results for future conditions increased to a total of 951 pipes or 36.9 miles—an increase of approximately 2 percent over existing conditions.

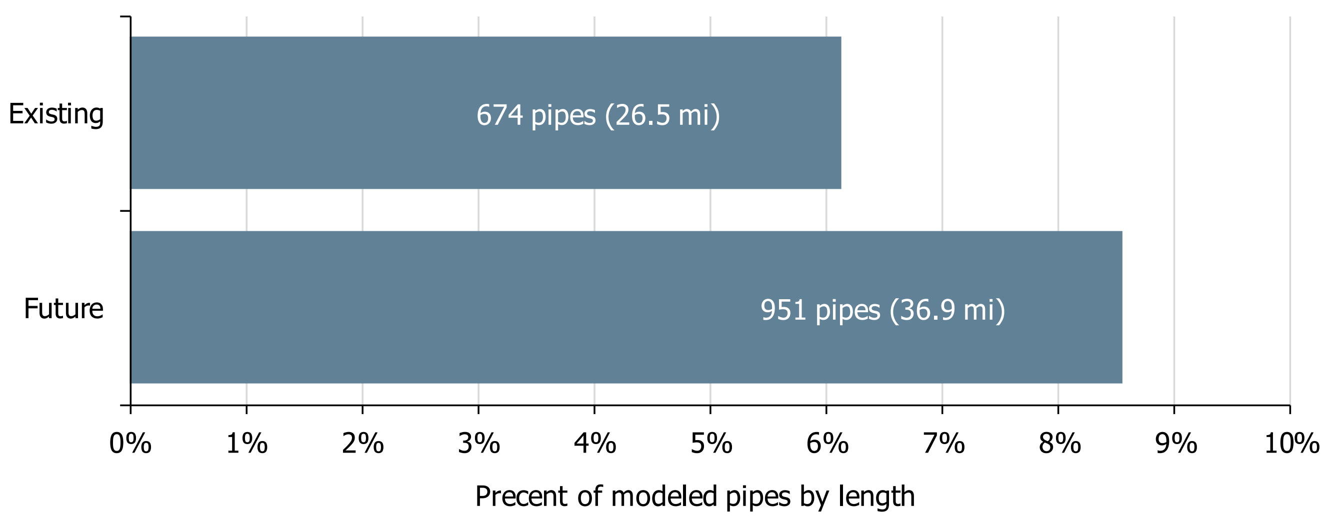

Figure 16. Percentage of under-capacity pipes (by length) for existing and future conditions

Citywide results for ditches and culverts are summarized in Figure 19, which shows the number and total length of ditches and culverts that are under capacity, based on the Performance Thresholds. For existing conditions, a total of 298 ditches and culverts and 8.4 miles (approximately 18 percent of the total length of modeled pipes) are under capacity. The results for future conditions increased to a total of 234 ditches and culverts or 5.8 miles—an increase of approximately 1.2 percent over existing conditions.

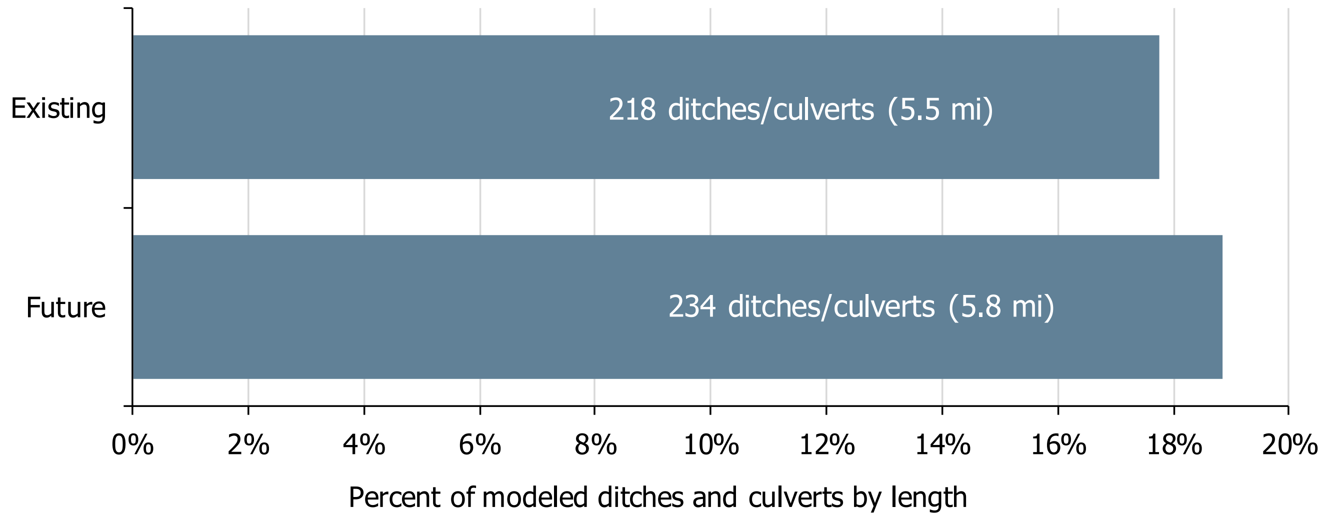

Figure 17. Percentage of under-capacity ditches and culverts (by length) for existing and future conditions

Citywide mapped results are provided in Appendix F. Figure 18 provides an example of the mapped results in the southeast area of the city.

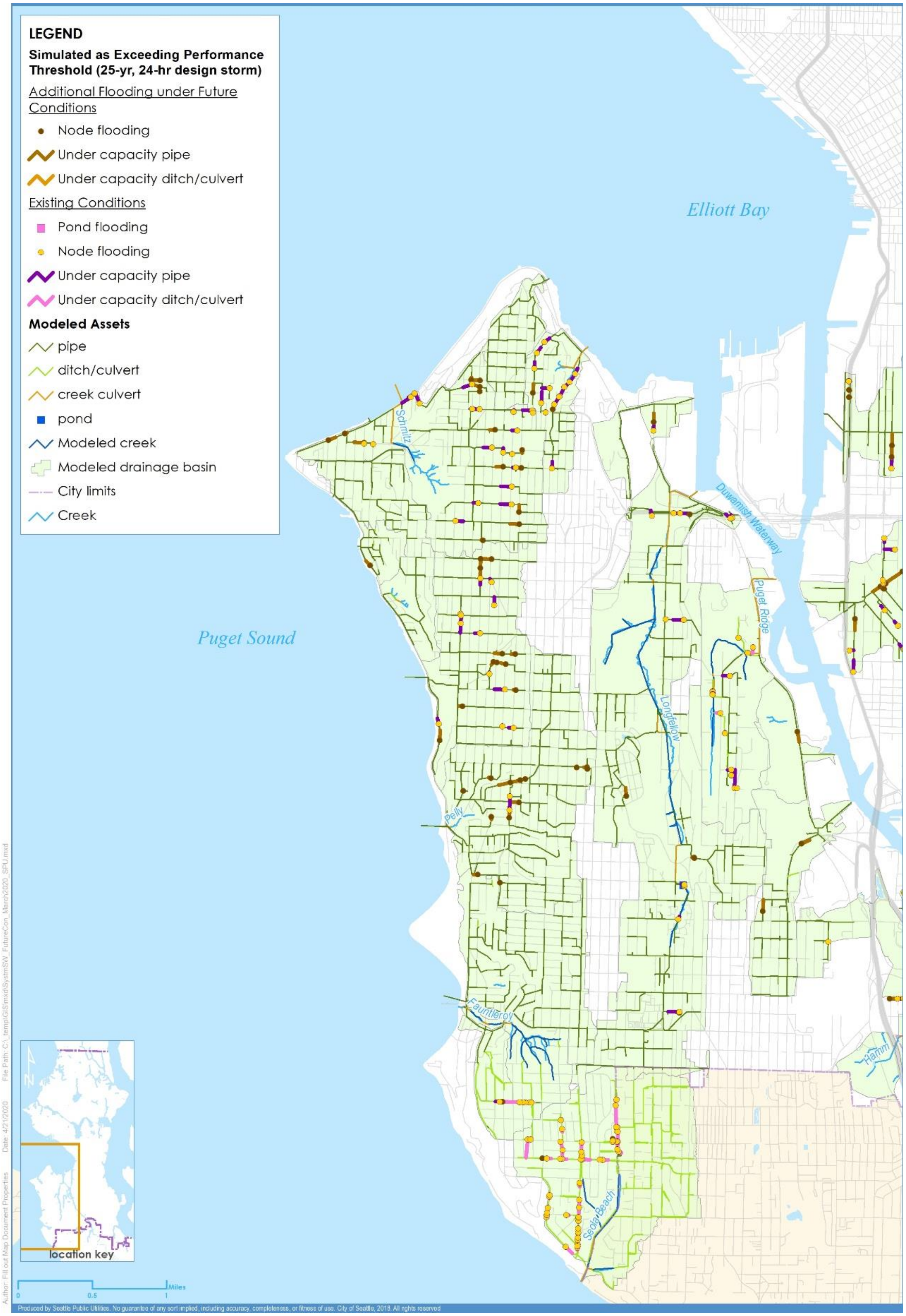

Figure 18. Example map of under-capacity pipes, ditches and culverts for existing and future conditions

4.2 Creek Culverts

This section summarizes the location, number, and length of under-capacity creek culverts for the existing and future conditions analysis. Figure 19 shows the number and total length of creek culverts that are under capacity based on the Performance Thresholds. Figure 19 summarizes the results by creek modeled and shows little change in the future conditions.

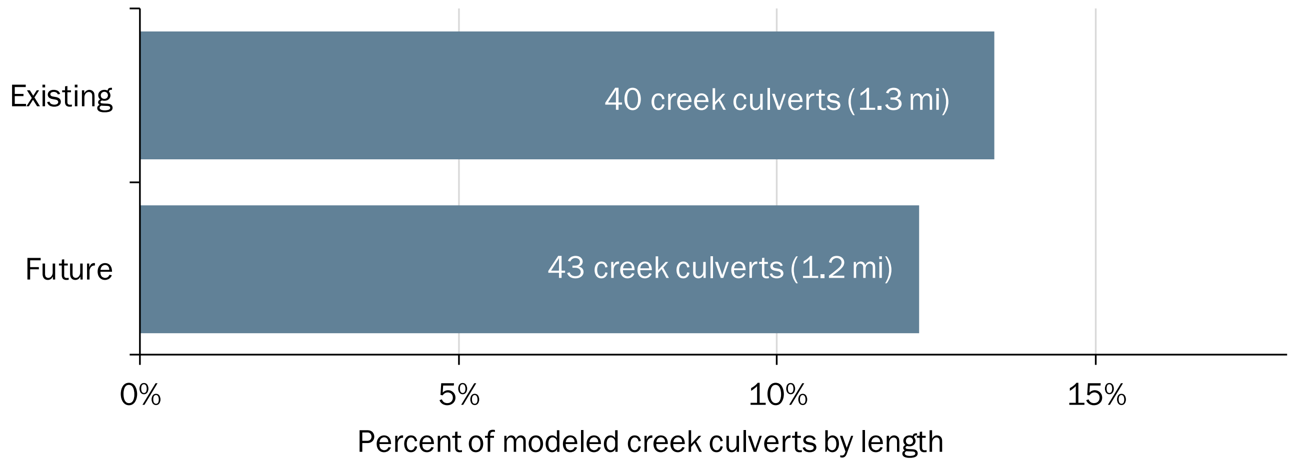

Figure 19. Length and percentage of under-capacity creek culverts for existing and future conditions

Table 6. Under-capacity Creek Culverts by Creek Basin

Creek Name	Existing		Change with future conditions	
	Count[a]	Length (%)[b]	Count[a]	Length (%)[b]
South Creek Basins				
Longfellow	0	0 (0%)	no change	
Puget	1	768 (17%)	-1	-768 (-17%)
Mount Baker	2	358 (59%)	no change	
Taylor[c]	1	91 (25%)	no change	
Thornton Creek Basin				
Thornton - Mainstem Trib E	2	35 (17%)	no change	
Thornton - N Branch	2	258 (16%)	no change	
Thornton - S Branch	6	363 (48%)	no change	
Hamlin	5	893 (26%)	+1	+17 (0%)
Littles	1	419 (20%)	no change	
Mock	1	47 (3%)	no change	
Matthews	0	0 (0%)	no change	
Littlebrook	5	1,165 (53%)	no change	
Maple	1	40 (100%)	no change	
North Creek Basin				
Piper's - Trib H	1	44 (100%)	no change	
Yesler	3	1,151 (20%)	no change	
Licton Springs	9	1,219 (23%)	+3	+150 (3%)

a. Number of creek culverts is approximate as a modeled creek culvert may represent two or more culverts.

b. Percent (by length) is measured by dividing the length of under-capacity creek culverts by the total modeled length of creek culverts for each stream.

c. A project to replace this Taylor Creek culvert is currently in progress.

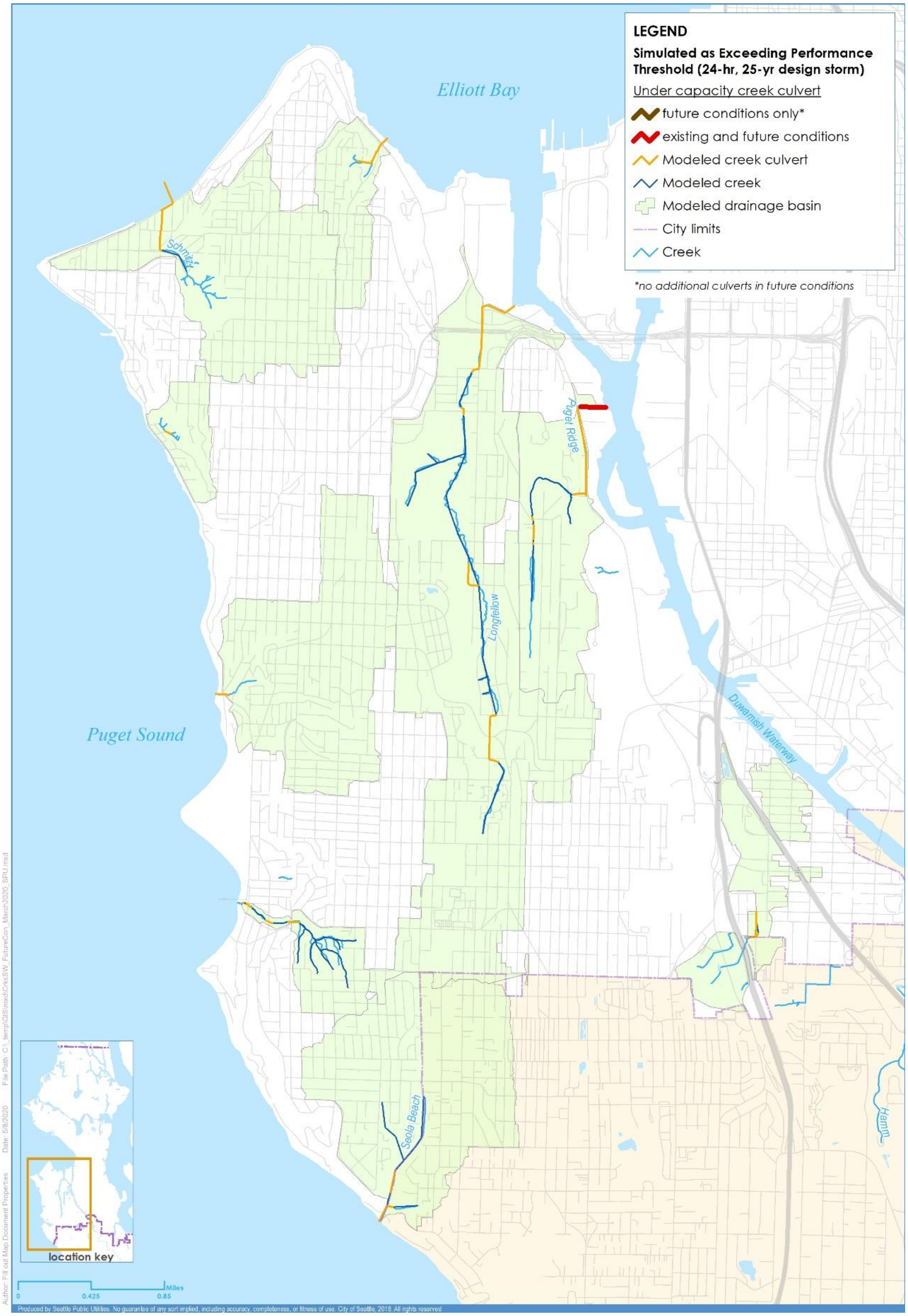

Figure 20. Example map of under-capacity creek culverts for existing and future conditions

4.3 Pond Flooding

Modeling showed that four of SPU's managed stormwater ponds (Ashworth, Midvale, Stone, and Meadowbrook Ponds) exceeded the Performance Threshold for existing conditions. The future conditions modeling results shows no additional ponds would overtop.

4.4 Summary

In summary, the modeling analysis shows a modest increase, from existing to future conditions, in the percent and number of assets that exceed the Performance Thresholds (Table 7).

Table 7. Summary of Existing and Future Conditions Model Results

Asset	Extent of system modeled	Assets that exceed the performance threshold	
		Existing conditions	Future conditions
Drainage pipes	432 miles (92%)	26.5 miles (6%)	37 miles (8.2%)
Ditches and culverts	31 miles (15%)	8.4 miles (18%)	9 miles (19.2%)
Creek culverts	303 creek culverts (65% by count)	40 creek culverts (13%)	43 creek culverts (14%)
Storage ponds	10 ponds	4 ponds	4 ponds

4.5 Limitations of Results

System capacity modeling was performed to evaluate performance parameters for different types of drainage assets to support risk area identification and the development of the ISP. Use and interpretation of the results requires an understanding of the assumptions and limitations associated with the analysis. As planning progresses and focuses more narrowly on specific areas of interest, drainage assessments may need to be more advanced and refined. The following key assumptions and limitations have been identified:

- **Not all areas of the city have been covered by detailed modeling of the drainage systems.** Combined sewer areas were covered by the WWSA. Most separated drainage systems were covered by this DSA capacity analysis. However, there are a few areas of the city that weren't modeled because they contain limited or no drainage assets, only private drainage systems, or drainage systems owned by other entities. Similarly, not all drainage assets were modeled in the areas served by ditches and culverts. These gaps—however limited—should be acknowledged when considering citywide results. For example, it has been noted that some of these gaps fall within the "lowest" or "second-lowest" areas of disadvantage according to the City's Race and Social Equity Composite Index. To address such gaps, SPU has conducted targeted outreach in those areas.
- **Some drainage basin models, or portions of drainage basin models, were not calibrated.** Uncalibrated models are not as accurate as calibrated models. While the Consultant team analyzed relationships between calibrated hydrologic parameters and citywide mapping of soil properties, the parameters did not exhibit strong correlations. Alternatively, the Consultant team translated calibrated parameters to uncalibrated areas using generally averaged sets of calibrated parameters for pervious

and impervious areas. While these adjustments are considered an improvement over the use of default parameters, full calibration should be considered for more focused studies.

- **Models developed for areas served primarily by ditches and culverts are based on limited data.** Detailed surveys do not exist for many of the ditches and culverts. Only 15 percent of ditches and culverts are represented in the drainage models, and those drainage networks were often developed using approximations for shapes, dimensions, elevations, roughness, and slopes. Simplifications and limited network resolution may lead to large contributing areas and greater runoff inflows to some portions of the system.
- **Peripheral storm drain inlets and catch basins are not included in the drainage models.** Inlets, catch basins, and appurtenant connecting pipes are not explicitly represented in the drainage models. When originally designed and constructed, the number of inlets and sizing of appurtenant structures are likely to have been based on conservative methods using short duration peak rainfall intensities for the design event. However, flooding may occur if inlet capacity is exceeded, and that would not be reflected in this analysis.
- **Future drainage conditions reflect assumptions regarding new development densities and continued application of current stormwater development code.** Impervious cover for model subcatchments was adjusted using a combination of zoning data and estimated redevelopment rates for specific areas. Imperviousness percentages were increased where redevelopment leads to new impervious areas, and subsequently decreased where stormwater code compliance leads to impervious areas that are managed for flow control. Best available estimates for redevelopment rates, locations and densities were used at the time of this analysis, but these factors are very hard to accurately predict. Variances or revisions to the estimated redevelopment rates, densities, or stormwater code in the future would alter the assumptions and change the simulated runoff rates.
- **The future conditions precipitation intensity and frequency should be viewed within the context of climate change and substantial uncertainty.** Best available estimates for climate change impacts to precipitation intensity and frequency were used at the time of this analysis, but these estimates are very hard to accurately predict. The recurrence intervals for the existing-conditions design storms are based on IDF curves developed by Tetra Tech (2017) using historical data. However, Tetra Tech (2017) found statistically significant positive trends in extreme precipitation metrics and studies by Mauger (2015) and Warner et al. (2015) suggest significant increases in atmospheric river events and heavy rainfall in the coming decades. While the 25-year design storm was increased by a scaling factor of 1.055 to simulate future conditions, the following must be considered:
    - The scaling factor is based on a "business as usual" scenario, where greenhouse gas emissions continue without significant reductions in current rates. While this is commonly viewed as a conservative scenario, it is not a worst case.
    - The scaling factor is based on a median value taken from an ensemble of climate projections for the year 2035. In other words, this is a central value within a range of values projected for 2035; and projected increases may be greater for years beyond 2035.

  - The scaling factor is based on projections for daily data and applied uniformly over the 24-hour storm duration. Changes in sub-daily rainfall intensities (e.g., over durations of 5 minutes, 15 minutes, or 1 hour) are unknown and may vary from this uniform assumption.
- **Buildings are not modeled as separate impervious subcatchments in some areas.** To assist with runoff parameter development, drainage model subcatchments were divided into building areas, right-of-way areas, and "other" (i.e., all remaining areas). However, some drainage basin models do not have separate subcatchments for buildings (South Park, Longfellow, Ballard, North Beach, Blue Ridge, Pipers Creek). In those areas, modifications to imperviousness percentages were only made to the "other" portions of the subcatchment, without special adjustments to account for the buildings. For these areas, when redevelopment estimates are high and the stormwater code requires flow control, runoff can be overestimated since reducing building impervious area was the flow control mechanism prescribed by the future flow method.
- **Future drainage conditions for areas served by ditches and culverts were not converted to more formal pipe networks.** SPU's current policy is to replace existing drainage assets with in-kind, or equivalent, assets, systems or services. Under this policy, ditches and culverts would not be converted to other asset types, even as future improvements are implemented. If this policy were to change, more formal and structured piped assets may be installed, which could change conveyance rates and the overall efficiency of the drainage system.
- **Low-lying areas with tidally influenced outfalls may have flap gates at unknown locations.** Flap gates are often installed to prevent high tide waters from backing up into the drainage system. The location of all flap gates within SPU's drainage systems were not identified for this effort. In the Diagonal Basin model, 21 flap gates were added to accommodate for an inaccuracy in the model. In those 21 cases, flap gates were assumed to be located along secondary branch pipes leading to the mainline drainage pipe that discharges to the Duwamish Waterway. The inaccuracy of the model should be considered when using the modeling results in the area.
- **Accuracy of the drainage system representation varies amongst the models**. During this effort, two models were identified to having several inaccuracies that may impact the results; the impacts, however, are not well known. The inaccuracies of the model should be considered when using the modeling results. While these are likely not the only models, they include below since they are known issues.
  - Diagonal Basin model. Flap gates are often installed to prevent high tide waters from backing up into the drainage system. The location of all flap gates within SPU's drainage systems were not identified for this effort or previous model build efforts. The Diagonal Basin model includes 21 flap gates to accommodate for an inaccuracy in the model. In those 21 cases, flap gates were assumed to be located along secondary branch pipes leading to the mainline drainage pipe that discharges to the Duwamish Waterway.
  - Longfellow Creek model. This model was developed several years ago and has not been updated recently. It includes a simplistic representation of the creek and drainage system ponds. It is also lacking several creek culverts and a creek bypass. Last, stormwater discharge locations to the creek are inaccurate.

- **Performance parameters are approximations for identifying impacts.** While there is a physical basis for the performance parameters for the drainage system, the selected values represent a rough metric for conditions or incidents that could result in impacts to customers. The conditions at which flooding impacts occur depend on many site-specific factors such as the elevation and location of a structure relative to the point of discharge. Furthermore, discharges from the drainage system may flow down gradient and combine or accumulate in low-lying areas, potentially yielding greater flood volumes.
- **24-hour design storms are well suited for evaluating conveyance in urban drainages but are less suited for evaluating storage.** Design storms are characterized by, and constructed around, short-duration (i.e., sub-daily) rainfall intensities that heavily influence peak discharges to be conveyed by the drainage systems. Ditches, culverts, and pipes are generally sized to meet conveyance requirements, while ponds are generally sized to meet storage requirements. The performance of storage ponds depends on the volume of runoff over consecutive days, as well as how the facility is operated to capture and release flow. As the ponds are examined in more detail, SPU should consider using long-term continuous simulations to evaluate pond performance.
- **The exceedance probability of rainfall is not necessarily equivalent to the exceedance probability of flooding.** In addition to storm events, several other factors affect the magnitude and frequency of flooding, such as antecedent moisture in the watershed at the onset of a storm.

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Appendix A: DWW Level of Service Policy, Phase I: DWW LOS Framework

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Memorandum

Seattle Public Utilities

Date: **12/22/16**

To: Ben Marre, DWW Planning and Program Management Division Director
Madeline Goddard, DWW LOB Deputy Director

From: Leslie Webster
Core Team: Lilin Li, Liz Anderson, Brian Landau, Holly Scarlett, Don Anderson

Re: Policy Recommendation - DWW Level of Service Policy, Phase I: DWW LOS Framework

The DWW Level of Service Policy Project Team is seeking your approval to present the attached DWW LOS Framework to the General Manager and CEO of SPU, Mami Hara, for discussion and identification of next steps.

DWW Level of Service Policy, Phase I: DWW LOS Framework

12/22/16

1. Project Overview

Levels of Service (LOS) state the desired system performance that SPU's Drainage and Wastewater (DWW) Line of Business (LOB) provides that are high priority to our customers or required by our regulators. Levels of service are the commitments made to our customers – they convey what quality of service customers should receive in exchange for their rates. Where possible, LOS are presented as specific, measurable actions to be achieved either now or at some date in the future. The duty of the utility is to select the appropriate service level commitment while balancing financial, social, and environmental responsibilities.

Seattle Public Utility's (SPU) DWW LOB provides drainage and wastewater collection and conveyance services for the City of Seattle. SPU currently has established DWW service levels that are memorialized in the SPU Strategic Business Plan (SBP) and other previous system plans (see Appendix A: Summary of Existing DWW Levels of Service). There is currently a lack of clarity about what SPU's established levels of service mean and how they should be used for system planning, operations and maintenance planning, and setting criteria for capital improvements.

To address this issue, staff have initiated development of this DWW Level of Service Policy. The objective for the DWW LOS Policy is to set level of service terms, categories, goals, and performance targets for DWW services that improve the clarity and consistent use of levels of service in the DWW LOB. The focus of this project is on developing technical service levels to guide SPU staff, projects, and programs. This Policy is it is not focused on developing "customer facing" service levels.

Phase I of the DWW LOS Policy is this DWW LOS Framework, which defines Level of Service terms, categories, and goals. Phase I also includes potential performance targets for each level of service goal that have been discussed, but <u>the potential performance targets included below are not proposed for adoption with this Framework</u>. Greater vetting is necessary at the staff level prior to adoption of the potential performance targets.

Phase II of the DWW LOS Policy will further develop and finalize the Potential Performance Targets and provide guidance on the application of the Level of Service goals and final Performance Targets within SPU. For more information on the DWW LOS policy development project, please see the Project Management Plan and the Policy Objective Memo.

2. Policy Context

One of the goals of the DWW LOS Policy is to ensure that there is a direct relationship between the final policy and SPU's mission, vision, and values and the DWW LOB goals, which are included below.

SPU Strategic Business Plan Framework:

- **Mission:** Providing efficient and forward-looking utility services that keep Seattle the best place to live
- **Vision:** Our customers will see how their utility dollars sustain and improve their quality of life
- **Strategic Role:** Solving problems at the source
- **Values:** Customer focus, Safety, Innovation, Inclusion, Value for money

Drainage and Wastewater Line of Business Goals[1]:

- Collect and convey wastewater in our public sanitary and combined sewer systems to protect public health and the environment by preventing sewer back-ups and overflows.
- Manage stormwater and drainage from the public system to reduce flooding, protect and improve receiving water and sediment quality, public safety and the environment.

3. Guiding Principles

Based on a review of the existing and past SPU Levels of Service as well as relevant examples of Levels of Service from peer utilities, the following guiding principles for the development of the DWW LOS Policy were determined. See the Precedent Catalogue and Recommendations Memo and its appendices for more information.

DWW LOS Policy development guiding principles:

1. LOS should be organized in a straightforward manner; LOS Categories should be simple; and LOS Goals should be understandable statements.
2. LOS Performance Targets should be limited in number.
3. Each LOS Goal needs to have a measurable Performance Target (aka performance 'measure' or 'metric').
4. LOS Goals and Performance Targets should focus on things that SPU has a high level of influence over and is willing and able to measure.
5. SPU's DWW adopted LOS Policy should include LOS Goals.
6. Some LOS Categories should be set for SPU as a whole, not by the LOB.
7. LOS Goals should strive to be based on what AMC and Water LOB have already developed.
8. LOS Goals and Performance Targets should include regulatory compliance minimums.
9. LOS Goals should strive to cover all DWW systems.
10. Clarification is needed between DWW LOS and SPU design standards in the LOS Policy.
11. Service equity should be considered in the development of LOS Goals and Targets.

4. Terms

Below are terms and definitions for use in the DWW LOS Framework.

Level of Service (LOS) Performance Target: Statements of the desired system performance that SPU's Drainage and Wastewater (DWW) Line of Business (LOB) provides that are high priority to our customers or required by our regulators. Where possible, LOS are presented as specific, measurable actions to be achieved either now or at some date in the future.

[1] The DWW LOB Goals were presented by Madeline Goddard, SPU Drainage and Wastewater LOB Deputy Director, at the quarterly LOB All-Staff meeting in January, 2016.

Level of Service Goal: General statement of service levels SPU strives to achieve through management of the public drainage and wastewater sewer systems and towards which effort and actions are directed.
Public Wastewater System, or Sewer System: Sewer system operated and maintained by the City of Seattle which carries wastewater and flows to a publicly owned treatment works which may or may not also carry stormwater. For the purposes of this framework, this term includes three system types – combined, partially separated, and separated sanitary sewer systems).
Public Drainage System: Drainage system operated and maintained by the City of Seattle which carries stormwater only (equivalent to Seattle's Municipal Separate Storm Sewer System, or MS4).

5. Recommended DWW Levels of Service Framework

The table below shows the proposed DWW Level of Service Framework. The existing SPU DWW LOS are included in Appendix A. Potential Performance Target's that are shown in *grey italics* are equivalent to existing SPU DWW Levels of Service (See Appendix A: Summary of Existing DWW Levels of Service).

Table 1. Draft DWW System Performance Level of Service Framework

Category	Level of Service Goal	Potential Level of Service Performance Target	
Regulatory Compliance	Meet or exceed regulatory requirements	*Limit SPU related sewer overflows (SSOs) to no more than 4 per 100 miles of pipe per year on average.*	WW
		Limit storm-driven sewer overflows to an average of 1 untreated discharge per permitted overflow site per year by 20XX.	
		Eliminate dry-weather overflows from permitted overflow sites.	
		Meet or exceed NPDES municipal stormwater permit requirements.	D
Public Health, Safety and Property	Minimize public wastewater system backups into private property	Limit sewer backups into private property caused by inadequate capacity of public wastewater system the to no more than X% of our customers during and up to the storm event that delivers x inches of rain in x hours, by 20XX.	WW
	Minimize the impact of flooding from the public drainage system into private property	Limit interior flooding caused by inadequate capacity of public drainage system to no more than X% of our customers during and up to the storm event that delivers x inches of rain in x hours, by 20XX.	D
	Minimize the impact of overflows from the public wastewater system into the public right-of-way	Limit sewer overflows in streets caused by inadequate capacity of the public wastewater system to no more than X% of the system during and up to the storm event that delivers x inches of rain in x hours, by 20XX.	WW

	Minimize the impact of flooding from the public drainage system into the public right-of-way	Limit flooding in arterial streets and emergency routes caused by inadequate capacity of the public drainage system that impacts safe mobility[2] to no more than X% of the system during and up to the storm event that delivers x inches of rain in x hours, by 20XX.	D
		Limit flooding in non-arterial streets caused by inadequate capacity of the public drainage system that impacts safe mobility to no more than X% of the system during and up to the storm event that delivers x inches of rain in x hours, by 20XX.	
Environment	Minimize the impact of discharges from the public wastewater and drainage systems into receiving waters	Reduce stormwater volume by XX gallons in Seattle's creek basins by 20XX.	D
		Reduce stormwater volume by XX gallons in Seattle's combined sewer system basins by 20XX.	WW
Problem Response	*Respond quickly and effectively to problems with potential health and safety consequences*	*Respond to 90% of high priority wastewater problems within 1 hour*	D/ WW
		80% of safety-related wastewater problems resulting in a service interruption will have service reinstated within 6 hours	D/ WW

6. Areas for Further Development

Below is a list of acknowledged areas that may warrant further development either prior to or following the adoption of this recommended DWW LOS Framework.

- Although it may be aspirational to meet a LOS Performance Target for some portions of the City, the potential LOS Performance Targets in this Framework assume that SPU wishes to continue to make citywide service level commitments to our customers. Significant revision would be required if management wishes to set different service level commitments for different geographic areas of the City.
- The audience of this DWW LOS Framework was primarily intended to be SPU staff and management. The primary objective of this project, as noted in the Overview section above, is to improve the clarity and consistent use of DWW levels of service for system planning, operations and maintenance planning, and setting criteria for capital improvements. Therefore, the potential performance targets, other than those already adopted in the SBP, are not written in a customer focused way. The translation of this DWW LOS Framework for a more customer focused audience is a potential area for future development.
- The team recognizes that further guidance will need to be developed to apply the LOS Goals and Performance Targets adopted in the final DWW LOS Policy more consistently. This is an area that warrants further development in the future.

[2] "Safe mobility" on a street means the street is passible and accessible for vehicles.

- Most of the potential Performance targets commit to a future date for when the Target will be achieved. The benefit of this approach is that it allows SPU to set LOS Performance Targets that are not currently being met. Those Targets guide investments in system improvement over a specified timeframe. However, there are cost implications and significant uncertainties including a changing climate that could impact SPU's ability to achieve a future date commitment. This decision warrants further study.
- Many of the LOS Performance Targets include a service level commitment up to a specified storm event. This approach is typical of the LOS from many of precedents reviewed for this project. This approach allows a utility to make different service level commitments during less extreme storm events vs. more extreme storm events. In this DWW LOS Framework, the storm event is described consistently as "*the storm event that delivers x inches of rain in x hours*." The benefit of this choice is that as the return frequency of this specific storm event changes in the future due to climate change, the service level commitment is not affected. However, this is not how SPU has referred to storm events in our existing LOS and therefore will impact how the utility currently plans and designs system improvements. This decision warrants further study.
- For the purposes of regulatory compliance, a Sewer Overflow (or SSO) includes both sewer backups and sewer overflows in the public ROW. Currently, DWW has one level of service that applies to SSOs: "*Limit SPU-related sewer backups to no more than 4 per 100 miles of pipe per year*." In this DWW LOS Framework, multiple Performance Targets describe system deficiencies that cause SSOs. This was done so that the utility could commit to different service level performance targets for sewer backups and for sewer overflows in the street. However, this choice should be further discussed with management and SPU wastewater regulatory compliance program leads.
- The team focused on revising or adding new LOS Goals only if they were specific to services that the DWW LOB provides (as opposed to the whole utility). Therefore, LOS Goals for service areas like affordability and equity were discussed be the project team but were not included in this Framework. The project team determined that these types of LOS should be set for the whole utility. This is an area that warrants further development in the future.
- The project team focused on revising or adding new LOS Goals only if they were describing system performance and if they were measurable. Therefore, LOS Goals for service areas like climate adaptation/resiliency, response to catastrophic events, and odor were discussed but not included because the project team was not able to develop a measurable performance indictor for Goals related to these services. This is an area that warrants further development in the future.
- Most of the LOS goals use the term "minimize." However, the precedents reviewed during the development of this framework did not use this term. Some members of the project team advocated to instead use "protect" or "prevent" because these words better align with the DWW LOB goals, are more aspirational, and may mean more to our customers. Management input on the use of "minimize" is desired.

Appendix A: Summary of Existing DWW Levels of Service

The table below shows the existing DWW Levels of Service, as memorialized in the 2015 SPU Strategic Business Plan (SBP), the 2004 Drainage Comprehensive Plan (DCP), and the 2006 Wastewater System Plan (WSP). *Grey and Italic* items included below have been carried over to this recommended DWW LOS Framework with minimal revisions. In the case where service level goals in the SBP were redundant with service level goals in either of the DCP or the WSP, only the service level goal from the SBP was included in this table. The SBP and the DCP did not have Level of Service Goals. The WSP included three service level goals:

Service level goals from the 2006 Wastewater System Plan (WSP)

- Customers in all areas of the City shall be well served by the SPU sewer system, and should not experience frequent sewer backups.
- Meet the overflow limits on SPU's combined sewer system as required by its NPDES permit and state and federal CSO regulations.
- *Respond quickly and effectively to problems with potential health and safety consequences.*

Table 2. Existing DWW Levels of Service

Category	Recommended service level/Target	LOB	Source
All Drainage Services	Construct, maintain and operate SPU's drainage infrastructure according to asset management principles in order to minimize risks to city property, promote environmental protection, and ensure long-term viability of city assets.	D	DCP
	Support drainage improvements that contribute to citywide objectives or community expectations based on an evaluation of social, economic, and environmental benefits.	D	DCP
Protection of public safety and property	Manage stormwater runoff within the public right-of-way to protect public safety and buildings (e.g., residences and businesses) from flooding, up to and including runoff from the 25-year, 24-hour design storm event.	D	DCP
	Manage stormwater runoff within the public right-of-way to allow access to and functionality of critical services such as hospitals, fire stations, and schools up to and including runoff from the 100-year, 24-hour design storm event.	D	DCP
	No critical services are inaccessible due to flooding, except during extreme storm events (i.e., events exceeding the 25-year, 24-hour design storm event)	D	SBP
	Manage stormwater runoff within the public right-of-way to protect public safety and support mobility on major transportation routes (i.e., arterial roads) up to and including runoff from the 25-year, 24-hour design storm event.	D	DCP
	Manage stormwater runoff within the public right-of-way to protect public safety and support mobility on residential roads (i.e., nonarterial roads) up to and including runoff from the 5-year, 24-hour design storm event.	D	DCP

	Protect drainage system facilities and infrastructure within landslide-prone areas, and mitigate the direct effects of drainage system operations that are contributing to landslide-prone conditions.	D	DCP
	Limit SPU drainage system-related interior flooding to 0.1% of customers	D	SBP
Service Provision	Fewer than 1% of customers will experience a backup in any year caused by a problem with the SPU sewer system.	WW	WSP
	By 2020, there will be no more than one backup in 5 years, on average, at any location, caused by a problem with the SPU sewer system.	WW	WSP
	Limit SPU-related sewer backups to no more than 4 per 100 miles of pipe per year	WW	SBP
Protection and improvement of key aquatic resources	Protect and improve, where possible, creek, shoreline, and lake aquatic receiving waters from the direct impacts of SPU's drainage system, using science-based projects and programs.	D	DCP
	Provide aggressive pollution prevention programs such as business inspections, source control, and public outreach programs.	D	DCP
	Operate a robust water quality monitoring program to identify problem areas and evaluate the effectiveness of management decisions in protecting and enhancing aquatic resources.	D	DCP
Regulatory requirements	*Eliminate dry-weather sewer overflows by 2014.*	WW	SBP
	Limit storm-driven sewer overflows to an average of one untreated discharge per overflow site per year	WW	SBP
	Meet NPDES municipal stormwater permit requirements.	D	SBP, DCP
Problem Response	*Respond to 90% of high priority wastewater problems within 1 hour*	D, WW	SBP
	80% of safety-related wastewater problems resulting in a service interruption will have service reinstated within 6 hours	D, WW	SBP

Appendix B: List of SPU Drainage Models

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Table B-1. List of SPU Drainage Models			
No.	**Model Name**	**Previous Name**	**Calibration Status**
1	Alki	D053-111	Not calibrated
2	Ballard[a]	D011-012	Calibrated
3	Blue Ridge	Blue Ridge	Calibrated
4	Bryant	D025-019	Not calibrated
5	Columbia City	D059-187_D060W-020	Calibrated
6	Densmore	Densmore	Calibrated
7	Diagonal	Diagonal	Calibrated
8	E Fremont	D022-155	Calibrated
9	E Highland Park	D070-164	Not calibrated
10	E Madison Park	D032-089	Not calibrated
11	E Magnolia[b]	D026-153	Calibrated
12	E Montlake	D031-004_057	Not calibrated
13	Fauntleroy Creek	Fauntleroy Creek	Calibrated
14	Fremont	D022-184	Not calibrated
15	Gatewood	D068-040	Calibrated
16	Green Lake	Green Lake	Not calibrated
17	Henderson - Mapes	Henderson_Mapes	Calibrated
18	Highland Park	D070-029	Calibrated
19	Industrial Dist	D049-023	Not calibrated
20	Interbay	Interbay	Calibrated
21	Lander	Lander	Calibrated
22	Laurelhurst	D025-059	Not calibrated
23	Leschi	D046-030_038	Not calibrated
24	Longfellow Creek	Longfellow Creek	Calibrated
25	Madison Valley	Madison Valley	Not calibrated
26	Minor Ave	Minor Ave	Calibrated
27	N Admiral E	D048-142	Not calibrated
28	N Admiral W	D047N-026	Not calibrated
29	N Alki	D053-024	Not calibrated
31	N Fauntleroy - Arbor Heights	D075-136	Not calibrated
32	N Leschi	D042-173	Not calibrated
33	N Madison Park	D032-037_068	Not calibrated
34	N Madrona	D038-072	Not calibrated
35	N Magnolia	Magnolia	Calibrated
36	N Mt Baker	D046E-031	Not calibrated

Table B-1. List of SPU Drainage Models			
No.	**Model Name**	**Previous Name**	**Calibration Status**
42	N Rainier Valley	D074-053_D081-011	Calibrated
37	N Seward Park	D059-244_D060W-021	Calibrated
38	Norfolk	Norfolk	Not calibrated
	North Beach	North Beach	Calibrated
39	Pipers Creek[c]	Pipers Creek	Calibrated
40	Puget Creek	Puget Creek	Calibrated
41	Rainier Beach	Rainier Beach	Not calibrated
43	Ravenna	D024-025_026_027	Calibrated
44	Riverview	D063-018	Not calibrated
45	Roosevelt	D005-060	Not calibrated
46	S Alki	D060-128	Not calibrated
47	S Leschi	D046-083_059_014	Not calibrated
48	S Madison Park	D038-032	Not calibrated
49	S Madrona	D042-093	Not calibrated
50	S Mt Baker	D059-157	Not calibrated
51	S Seward Park	D074-083_092_097	Not calibrated
52	Seaview	D060-030	Not calibrated
53	Seola Beach Creek	Seola Beach Creek	Calibrated
54	Seward Park 1	D067-021_042_056	Not calibrated
55	Seward Park 2	D067-137	Not calibrated
56	South Park	South Park	Calibrated
57	Taylor Creek	Taylor Creek	Calibrated
58	Thornton Creek	Thornton Creek	Calibrated
59	U District	D023-154	Calibrated
60	View Ridge	D008-208	Not calibrated
61	W Fremont	D021-086	Not calibrated
62	W Madison Park	D032-001	Not calibrated
63	W Montlake	D031-077	Not calibrated
64	W Seattle	D047-016_039	Not calibrated
65	W U District	D023-041_197	Not calibrated
66	Windermere	D017-117	Not calibrated

a. *Includes E (D021-001) and W Ballard (D011-103) drainage basins*
b. *Includes Magnolia (D026-058) drainage basin.*
c. *Includes Broadview drainage basin*

Appendix C: Drainage Model Development and Calibration

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Appendix C
Drainage Model Development, Calibration, and Updates

This appendix provides some background about the development and calibration of SPU's drainage models. In addition, the appendix outlines the parameter and storm event updates that the Consulting team performed to simulate existing and future conditions and generate the results presented in Sections 3.2 and 4.

1. Drainage Model Development

The capacity of the drainage system was evaluated based on modeling results for 66 drainage basin models (see Appendix B). This section provides background on the City's drainage basin models that were used as the basis for evaluating the City's drainage system capacity.

The drainage basin models were originally developed by Aqualyze, Inc., for SPU in 2010 as part of SPU Drainage System Model Development project (Aqualyze, Inc. 2010). The SWMM models were initially developed by converting SPU's Geographic Information Systems (GIS) data into SWMM software and delineating the areas contributing to the stormwater network. Since 2010, model calibration for these basins have been ongoing through various modeling on-call contracts with SPU. Prior to calibration, models were reviewed for hydraulic updates, such as adding pipes, MHs, ditches, culverts, creek cross sections, and special structures based on new and more reliable data sources, such as surveyed data, record drawings, data collected during flow metering, plan set drawings, SPU side sewer cards, and updated GIS data.

A summary of the updates is included below:

- In 2014, the Aqualyze-led team, including Brown and Caldwell and other sub-consultants, started working on refining and calibrating the individual drainage system models. Two phases of initial model calibration (work assignments [WA] 1 and WA 1.1) between 2014 and 2016 consisted of calibrating the Ballard, E Ballard, W Ballard, Longfellow Creek, Piper's Creek, North Beach/Blue Ridge, Interbay, Lander, Magnolia, N Magnolia, and E Magnolia basin models (Aqualyze, Inc. 2015), (Aqualyze, Inc. 2016a). Concurrent project work resulted in calibration of Densmore (Kennedy Jenks 2016) and Taylor Creek basins models (Osborn Consulting Incorporated 2016).
- In 2016, under WA 1.2, all the drainage models were prioritized using a ranking matrix that considered a variety of factors (Aqualyze, Inc. 2016b). The highest-priority models were refined in June 2016 using GIS data provided by SPU. The high-priority models were also validated against areas of known flood complaints.
- In 2017 and 2018, under WA 1.3, 15 highest-priority models were updated and calibrated. The hydrologic parameters were revised, based on updated GIS overlays, in an additional 39 uncalibrated drainage basin models (Aqualyze, Inc. 2018b). Concurrent project work resulted in calibration of the South Park basin model (Osborn Consulting Incorporated 2018).

Although the intent of the DSA was not to update or calibrate these models, some updates to these models were warranted to ensure that the objective of selecting a Performance Threshold and assessing the drainage capacity of the city was being evaluated correctly. Further information on how these models were updated for the DSA is discussed in the subsequent sections.

2. Review of Model Calibration and DSA Model Updates

This section summarizes the general methodology for calibrating drainage basin models, which were performed as part of modeling on-call contracts with SPU prior to the DSA. No additional calibrations were done as part of the DSA.

Drainage models were calibrated based on flow and depth meter data collected at various locations. Historical rain data gathered from SPU's rain gages were used in conjunction with the monitoring data to run the model simulations. Calibration was typically based on three to five significant storm events where a period before and after the storm event was included to assess the antecedent and recession conditions.

Once the model was run and significant storm events were selected, calibration parameters were adjusted in two key steps—surface water runoff response calibration and groundwater response calibration. Surface water runoff response parameters, also known as impervious response parameters, represent parameters that contribute to the peak flows of the basin, such as hydraulic conductivity, depression storage, and sub-area routing. Groundwater response parameters include aquifer bottom elevation, lower groundwater loss rate, and groundwater flow equation coefficients that contribute to groundwater response in the basin. Once these parameters were adjusted, calibration statistics were generated on an event basis to compare to the calibration criteria described in Chapter 7 of SPU's Drainage Standards and Guidelines (SPU 2018). These criteria include allowable variance between observed and modeled values for peak flow, flow volume, and surcharge depth.

3. Existing Conditions Model Setup

Drainage basin model development and calibration, as described in the previous section, spanned several years. To maintain consistency across models for the DSA project, a uniform set of model setup criteria were developed and applied as described below.

3.1. Model Parameter Updates

Hydrologic and hydraulic input parameters were updated for 39 uncalibrated drainage basin models to create consistent parameters based on hydrologic and hydraulic characteristics across the city. Previously calibrated basins were used as a basis to evaluate the parameters for the uncalibrated basins. The following calibration parameters were evaluated for impervious response and groundwater response:

- Sub-area routing (percent routed)
- Subcatchment soil hydraulic conductivity (inches/hour)
- Impervious depression storage (inch)
- Pervious depression storage (inch)
- Aquifer depth (feet)
- A1 and B1 power of the groundwater aquifer equation
- Porosity (percent)
- Field capacity (fraction)
- Lower groundwater loss rate (inches/hour)

The ranges and distribution of the above parameters were extracted from the calibrated areas and compared against basin attributes, such as land-use, percent of impervious surfaces, geographic location relative to the closest rain gage, and basin size. No clear correlations, however, were observed for the calibration parameters and the basin attributes. This was true for both surface runoff and groundwater contribution parameters. Groundwater parameters were not assigned to the uncalibrated basins, as groundwater is only assigned to an area based on flow monitoring data and is not present in every calibrated drainage basin. In general, groundwater does not typically make up a large component of the hydrograph for the calibrated drainage basins, so adding groundwater in the model to the uncalibrated models was not evaluated further.

Since there were no clear correlations, the impervious response parameters, such as percent routed, impervious depression storage, pervious depression storage, and hydraulic conductivity, were assigned area-weighted mean values of the calibrated basins. In addition, uncalibrated basins were updated with the following global average parameters calculated using data from calibrated areas:

- For all building subcatchments, approximately 49.8 percent of the runoff was assumed to be routed to the pervious area within the subcatchment. In the SWMM models, this translated to setting all the building subcatchments' pervious sub-area routing to a value of 49.8 percent.
- For all other subcatchments, approximately 51.8 percent of the runoff was assumed to be routed to the pervious area within the subcatchment. In the SWMM models, this translated to setting all the remaining subcatchments' pervious sub-area routing to a value of 51.8 percent.
- Impervious depression storage was set to 0.07 inches for impervious areas, and 0.16 inches for pervious areas.
- Green-Ampt infiltration conductivity for all the subcatchments was set to 0.59 inches/hour.

Time-step analysis was also done for all the uncalibrated models, and the routing timesteps were updated to minimize the routing error.

To validate the adjustments made, calibrated and uncalibrated models were run to get discharge per unit area for a 25-year, 24-hour design storm. Peak runoff (cubic feet per second per acre [cfs/acre]) was plotted against the percent imperviousness, and then compared between the calibrated, uncalibrated, and the uncalibrated adjusted basins (Figure C-1). The results presented in Figure C-1 suggested that the adjustment brought uncalibrated basins in line with the calibrated basins in that the runoff response is reasonably consistent across all drainage basins.

The need to adjust parameters for uncalibrated portions of calibrated basin models was also evaluated, but as there was no systematic bias in the peak runoff, the parameters were not adjusted.

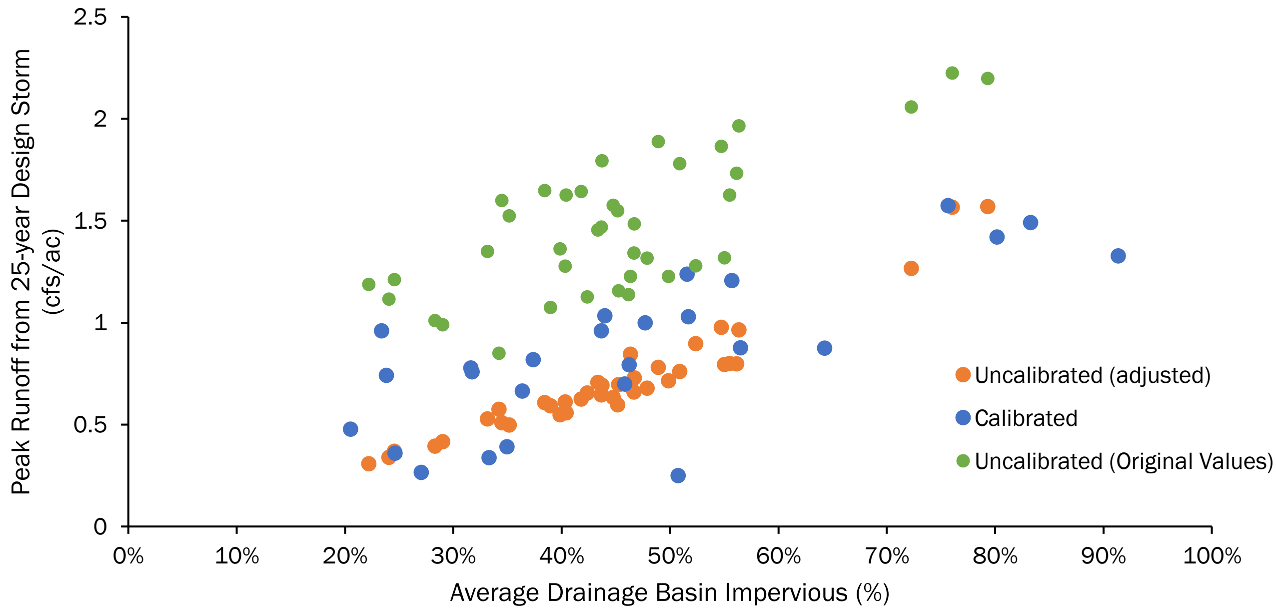

Figure C-1. Peak runoff relationship with percent imperviousness for calibrated and uncalibrated basins

3.2. Boundary Conditions

For SPU's drainage system, receiving waterbody downstream boundaries include both freshwater and marine outfalls. For assessing the existing conditions of the drainage system against the selected Performance Threshold design storm, fixed values were used for boundary conditions rather than using time series data. The three main types of receiving waters and the corresponding boundary conditions assigned for each are as follows:

- Lake Washington and Lake Union levels were set to be at the highest operating level of 18.5 feet at Ballard Locks.
- Puget Sound levels were set to be at mean high higher water (MHHW) level data of 9.02 feet of North American Vertical Datum of 1988 (NAVD88) that represents the average of the higher high-water height of each tidal day observed over the National Tidal Datum Epoch. This value was further adjusted for salinity gradient using the unique outfall invert elevations as follows (Pang 2012):

$$New\ Tide\ Level = \frac{Density\ of\ Saltwater\ (64.0\ \frac{lb.ft}{ft^3})}{Density\ of\ Fresh\ Water\ (62.4\ \frac{lb.ft}{ft^3})}(Tide\ - Invert\ ) + Invert\ Elevation$$

- Creeks were set to have a free outfall consistent with previous modeling efforts.

3.3. Evaporation

Average monthly evaporation data developed as part of the WWSA were used for the DSA (Aqualyze, Inc. 2018a). Monthly averages were calculated based on the data from January 2012 to March 2018 from the Seattle, King County WSA AgWeatherNet weather station. The data are summarized in Table B-1, and show the highest evaporation is calculated to be in June and lowest in December.

Table C-1. Average Monthly Evaporation	
Month	**Average Evaporation (inches)**
January	0.014
February	0.029
March	0.053
April	0.088
May	0.123
June	0.147
July	0.163
August	0.137
September	0.085
October	0.039
November	0.018
December	0.012

3.4. Combined Sewer Model Inflow

There are several locations within the city where combined sewers can overflow into the drainage system. A total of 14 locations were identified by the City to have inflows from the combined system to the drainage system during an overflow as shown in Table C-1. Not all the previous drainage modeling projects had explicitly modeled the combined sewer overflows as inflows to the drainage system. At the 14 locations, inflow hydrographs were exported from combined sewer models used for WWSA.

Although the hydraulics for drainage basin models were largely used “as is”, updates were made in Madison Valley and Diagonal models to represent where combined sewer inflow can occur into the system.

Table C-2. Location of CSO Inflows Added in Drainage Basin Models

Model Name	Maintenance Hole ID
Bryant	D016-049
Riverview	D063-059
Diagonal	D056-126
	D057-131
	056-365
Henderson Mapes	D081-029
	D081-042
Interbay	D028-224
	D028-005
Longfellow Creek	D069-088
	D055-184
	D076-094
Norfolk	D305-037
Rainier Beach	D081-100

4. Future Conditions Model Setup

In addition to simulating existing conditions, the Consultant team used the Future Flow Methodology (Osborne Consulting Incorporated 2018) to simulate future conditions. The methodology was designed to estimate future flows for the 2035 planning horizon for the drainage system based on changes in impervious cover, stormwater code compliance, sea level rise, and more frequent extreme rainfall events. Updates to the SWMM models consisted of:

- Updating impervious cover for model subcatchments using a combination of zoning data and estimated redevelopment rates for specific areas. Depending on the development patterns and code requirement, imperviousness of a subcatchment could increase or decrease. The imperviousness was adjusted for drainage model subcatchments that represent building areas, right-of-way areas, and "other" (i.e. all remaining areas) separately. For those subcatchments that do not have separate building areas, adjustments were made using factors for "other" portions of subcatchments and separate factors for building areas were not made. Figure C-2 shows the mapped changes in imperviousness.
- Increasing boundary conditions at tidally influenced outfalls by adding 11.3 inches to fixed stage values.
- Using a 25-year, 24-hour design storm with increased rainfall intensities to account for climate change. The existing conditions design storm was multiplied by a scaling factor of 1.055 (+5.5 percent) based on the 24-hour rainfall scaling factor used in *Combined Sewer Overflow Sizing Approach Implementation: Perturbing Precipitation Time Series to Future Climate Conditions* (CH2M, 2017).
- For models that have CSO inflow locations – Bryant, Riverview, Diagonal, Henderson Makes, Interbay, Longfellow Creek, Norfolk, and Rainier Beach – inflow hydrographs exported from combined sewer models run using 25-year, 24-hour design storm with increased rainfall intensities were used.

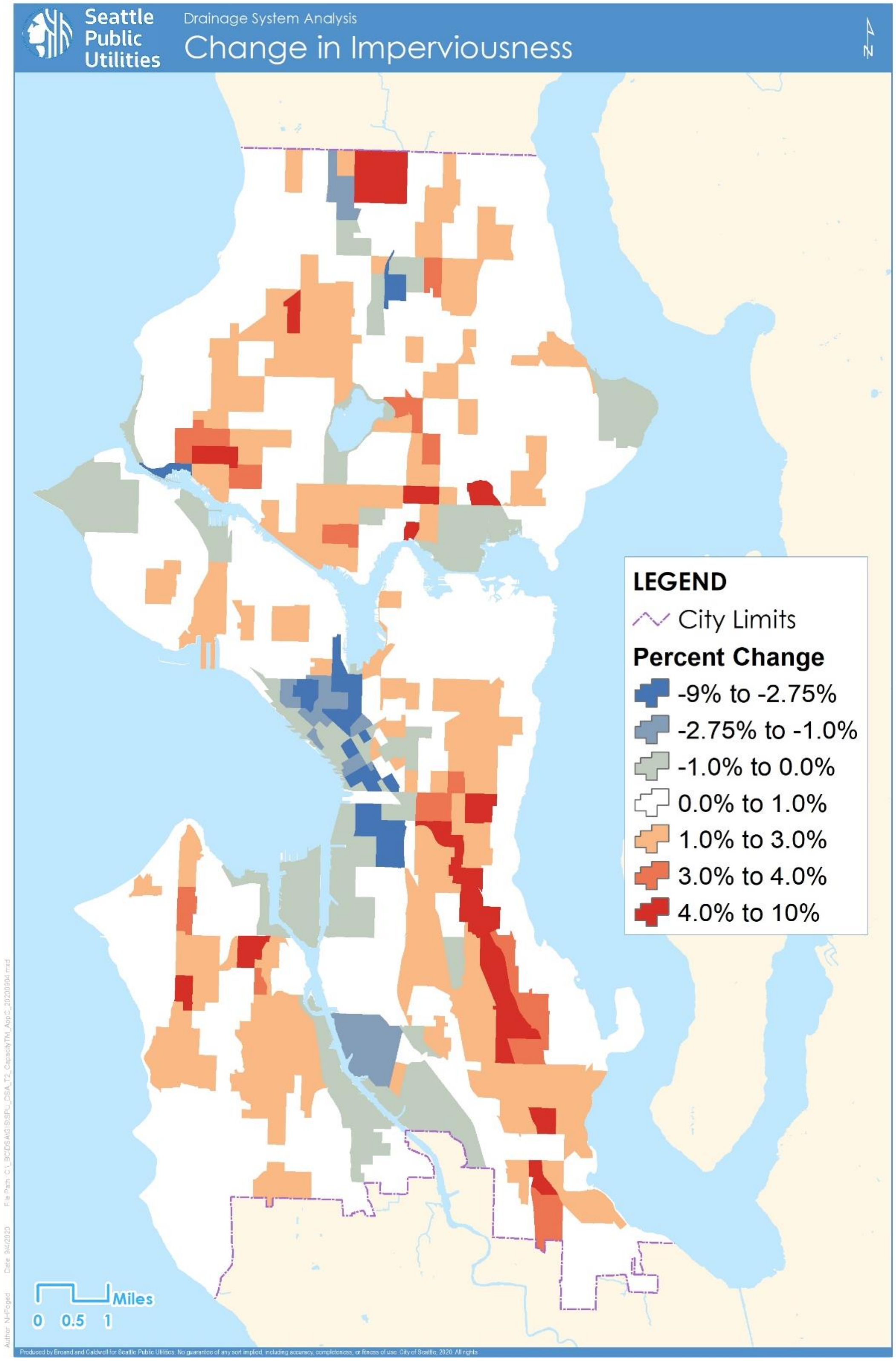

Figure C-2. Change in percent imperviousness from existing to future conditions

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Appendix D: Impact Thresholds for Ponds

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Seattle Public Utilities

Memorandum

Date: 8/17/20

To: Project File

From: Colleen O'Brien

Re: Drainage System Analysis Pond Flooding Thresholds for Potential Impacts

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This memorandum describes the basis of the selection of Drainage System Analysis (DSA) performance parameters for stormwater ponds included in SPU's drainage system models. A performance parameter is a set flood volume or hydraulic grade line (HGL) that defines when simulated flooding represents a potential flooding impact. When combined with a design storm (a specific amount of rainfall distributed over time and space), a performance parameter is used to determine if a Performance Threshold has been exceeded. A Performance Threshold defines adequate capacity for the purposes of the citywide modeling analysis, completed during the DSA, to identify drainage system capacity risk areas.

Each pond is uniquely represented in the models. The most simplistic representation is a single storage node with a single drainage pipe conveying flow into the node and a single drainage pipe conveying pond outflow. Ponds with multiple cells and flow control structures have more complex model representations. They can include several storage nodes, multiple drainage pipes conveying flow into the nodes, weirs and orifices representing flow control structures, and multiple drainage pipes conveying pond outflow or overflow.

Preliminary modeling, using a conservative method of determining pond overtopping, indicated that several ponds did not overtop for the range of storms being evaluated for the DSA. The conservative method was defined as: if there was any simulated flooding volume (simulated flooding > 0 cubic feet [ft^3]) for any of the storage nodes used to represent the ponds, then the pond was considered to have overtopped.

For ponds that simulated as overtopping, performance parameters of overtopping that could result in impacts to right-of-ways or private property were developed based on site-specific information. The performance parameters are summarized in Table 1 and the locations of all modeled ponds are shown on Figure 1. Table 1 indicates the three ponds where performance parameters were developed, as initial modeling indicated the pond overtopped. The sections following the table explain how the performance parameters were developed.

There are two ponds owned or managed by SPU that were not included in this effort as they are not represented in the drainage system models: Genesee Pond (which was not included when the Longfellow Creek model was initially developed) and Olson Pond (which is in a relatively small drainage basin not currently modeled.).

Table 1. Stormwater Pond Performance Parameters

Pond Name	Flooding Performance Parameter	Approach to Selecting Performance Parameter
Ashworth	Sum of flooding volume at 4 modeled storage nodes is larger than 125,000 ft^3.	Site specific – see description below
Blue Dog	Flooding at the modeled storage node is larger than 0 ft^3.	Simulated flooding at any of the storage nodes representing the pond (initial approach).
East John	Flooding at the modeled storage node is larger than 0 ft^3.	Simulated flooding at any of the storage nodes representing the pond (initial approach).
Jackson Park	Sum of flooding volume at 3 modeled storage nodes is larger than 0 ft^3.	Simulated flooding at any of the storage nodes representing the pond (initial approach).
Lake City (35th Ave)	Sum of flooding volume at 2 modeled storage nodes is larger than 0 ft^3.	Simulated flooding at any of the storage nodes representing the pond (initial approach).
Littles Creek	Flooding at the modeled storage node is larger than 0 ft^3.	Simulated flooding at any of the storage nodes representing the pond (initial approach).
Meadowbrook	Not applicable	SPU reviewed the model in the vicinity of the pond and determined improvements were needed to better represent the flows into the pond. The pond was assumed to exceed the Performance Threshold, which has a design storm of 25-year, 24-hour event, based on the understanding that the pond was designed for a 25-year event and if it were to overtop, impacts could be immediate to residents to the west.
Midvale	Sum of flooding volume at 4 modeled storage nodes is larger than 400 ft^3.	Site-specific – see description below
Stone	Hydraulic grade line is greater than 365 feet NAVD88 in the model conduit (model ID StonePond_Overland) representing overland flow from the pond.	Site-specific – see description below
Webster	Flooding at the modeled storage node is larger than 0 ft^3.	Simulated flooding at any of the storage nodes representing the pond (initial approach).


Seattle Public Utilities
Drainage System Analysis
Figure 1. Stormwater Ponds Evaluated
LEGEND
pond
Modeled drainage basin
Littles Creek Pond
Jackson Park Pond 1
Ashworth Pond
Stone Pond
Lake City (35th Ave) Pond
Midvale Pond
Meadowbrook Pond
East John Pond
Blue Dog Pond
Webster Pond
Green Lake
Union Bay
Lake Union
Elliott Bay
Puget Sound
Lake Washington
Miles
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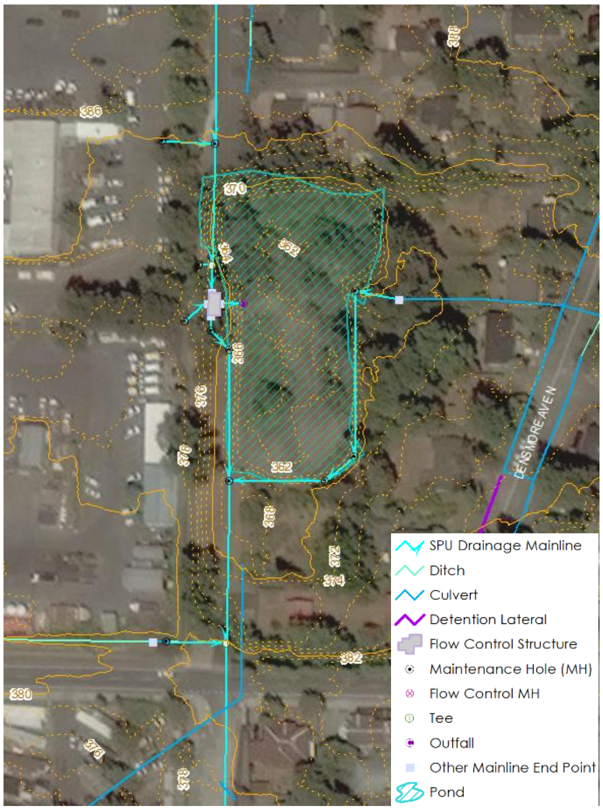
Ashworth Pond

When Ashworth Pond overtops, stormwater is believed to first impact buildings to the east and southeast, approximately at elevation 371 feet NAVD88. The pond overtops at elevation 368 feet. The volume of flooded water between these elevations is approximately 125,000 ft^3, based on the average area of the contours, as determined in GIS, multiplied by the difference in elevation. The performance parameter used was: sum of flooding volume at the four modeled storage nodes is larger than 125,000 ft^3.

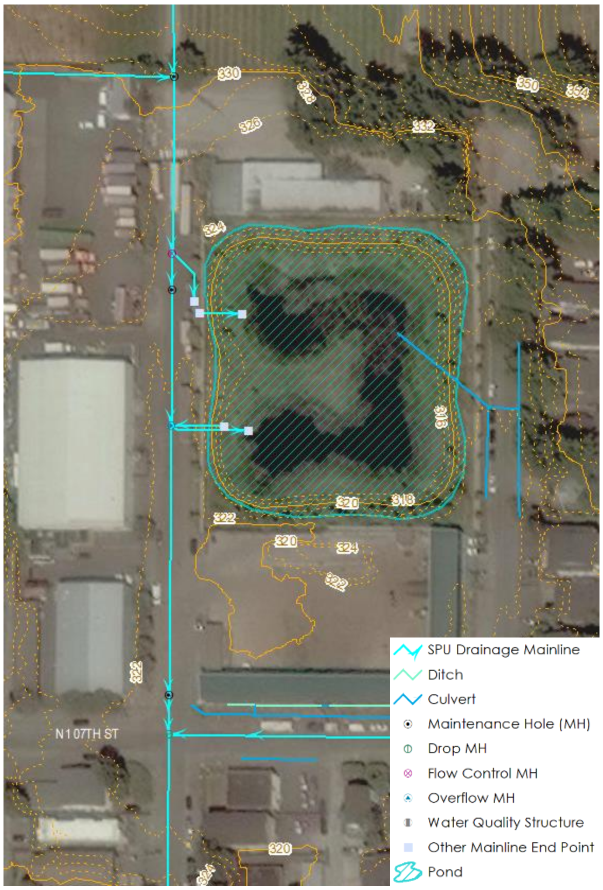


Drainage System

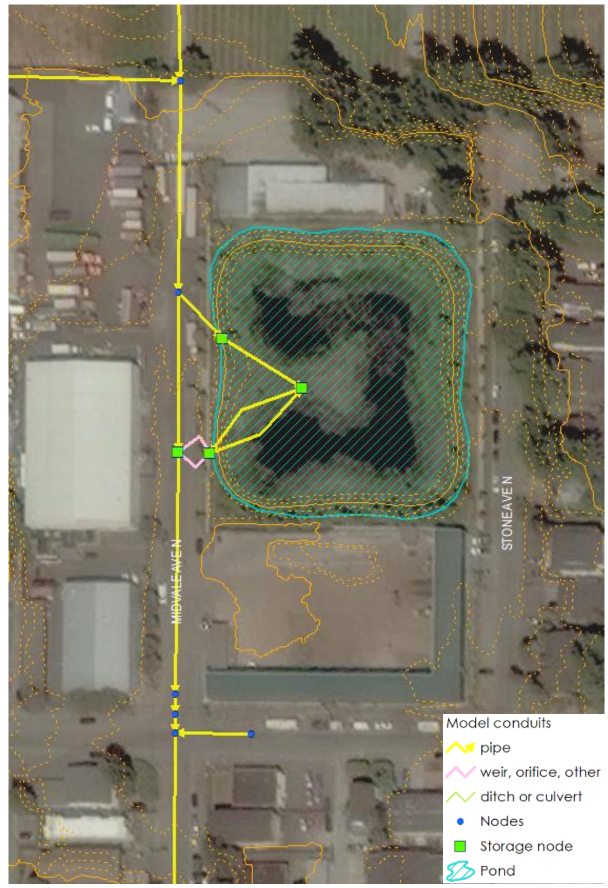
Model Representation

Midvale Pond

When Midvale Pond overtops, it can impact roadways to west and east and properties to the north and south. The performance parameter for right-of-way impacts (simulated flooding volume = 400 ft^3) was used. The pond was considered to have exceeded the Performance Threshold if, between any of the storage nodes representing the pond, the volume was exceeded.



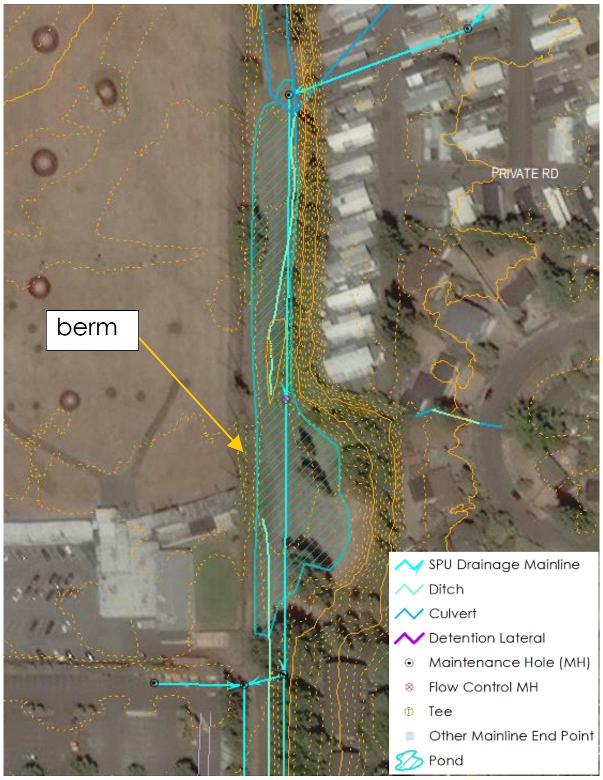
Drainage System



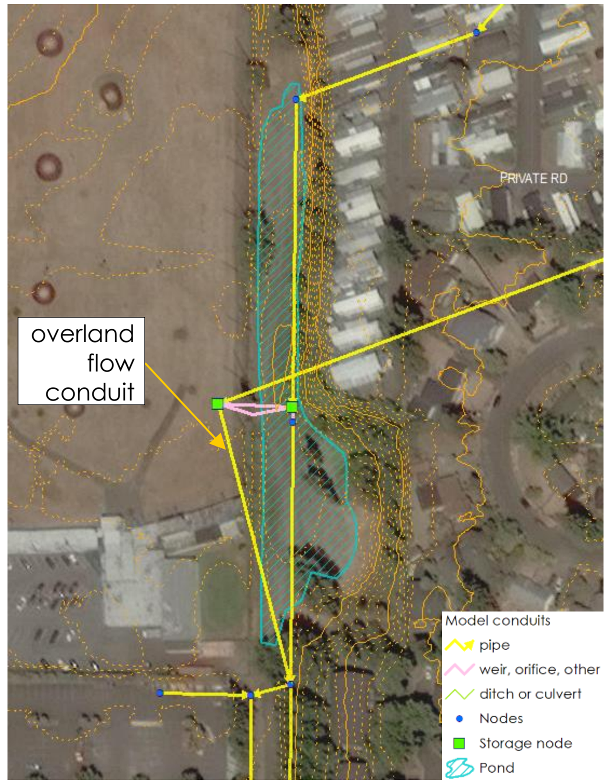
Model Representation

Stone Pond

When Stone Pond overtops, water flows west over a berm. The elevation of the berm is 365 feet NAVD88. If the hydraulic grade line in the model conduit representing the overland flow pathway exceeded 365 feet, the Performance Threshold was considered exceeded.



Drainage System



Model Representation

Appendix E: Design Storm Event Pro/Con Table

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Table D-1. Design Storm Event Comparison to Support Selection of Performance Threshold		
Storm Event	**Pros**	**Cons**
2.7 inches in 24 hours (5-year, 24-hour)	• Could result in smaller rates for our customers • The same storm event selected for the wastewater system Performance Threshold • Fewer areas to address in the near term	• Less protective for our customers • Less inclusive of problems to prioritize • Lower than existing levels of service • Customers will have to handle more problems on their own • Harder to justify to our customers • Harder for internal buy-in
3.2 inches in 24 hours (10-year, 24 hour)	• More inclusive of problems to prioritize than the 2.7 inches in 24 hours event • Parallels the Interim Conveyance Design Criteria for DWW Capital Projects for residential streets	• Different from the Interim Conveyance Design Criteria for DWW Capital Projects for arterial streets • Different than the design storm event selected for the wastewater system Performance Threshold
4.0 inches in 24 hours (25-year, 24 hour)	• More inclusive of problems to prioritize than the 3.2 inches in 24 hours event • Parallels the Interim Conveyance Design Criteria for DWW Capital Projects for arterial streets • In line with Design Standards & Guidelines (DS&G) and will help identify where the system is not functioning as designed	• Different from the Interim Conveyance Design Criteria for DWW Capital Projects for residential streets • Different than the storm event selected for the wastewater system Performance Threshold
4.7 inches in 24 hours (50-year, 24 hour)	• Most inclusive (of the storm events evaluated) of problems to prioritize • Most protective for our customers; customers will have fewer problems to deal with on their own • Since most protective, aligns with climate resiliency • Gives the opportunity to capture a problem that might be significant from the critical-facility standpoint	• Higher standard than SPU has had. Higher than standards of peer utilities reviewed as part of the DWW LOS policy work (12/22/16). Potentially harder to garner internal buy-in. • Could result in higher rates for customers • Might identify a problem with something recently designed according to the DS&G • Might identify more risk areas than SPU can address in the near term • Might create future liability issues if risk areas identified are based on this event. • Different than the storm event selected for the wastewater system Performance Threshold

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Appendix F: Simulation Results Quadrant Maps

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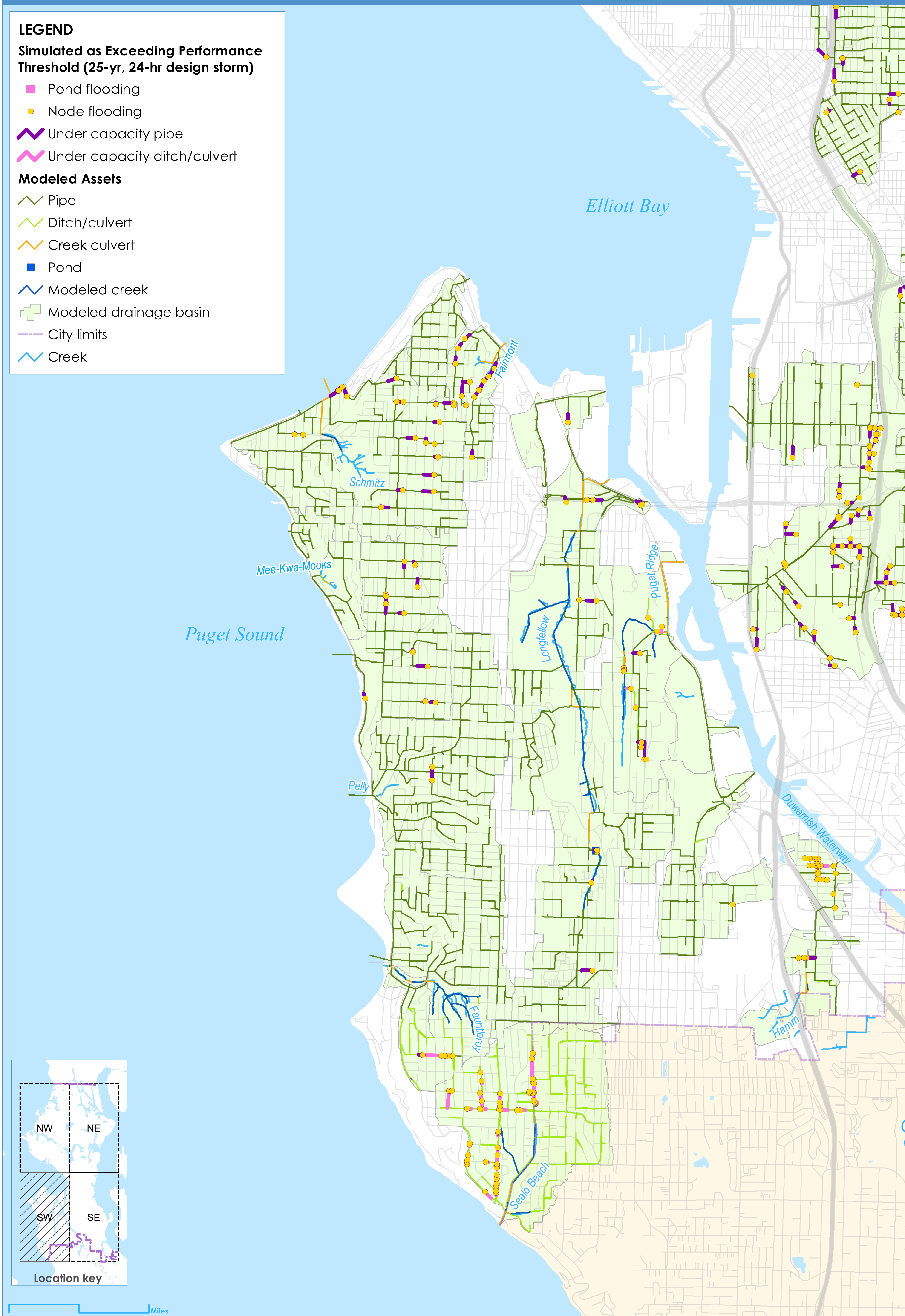
Seattle Public Utilities

Drainage System Analysis

Simulated Flooding under Existing Conditions

southwest

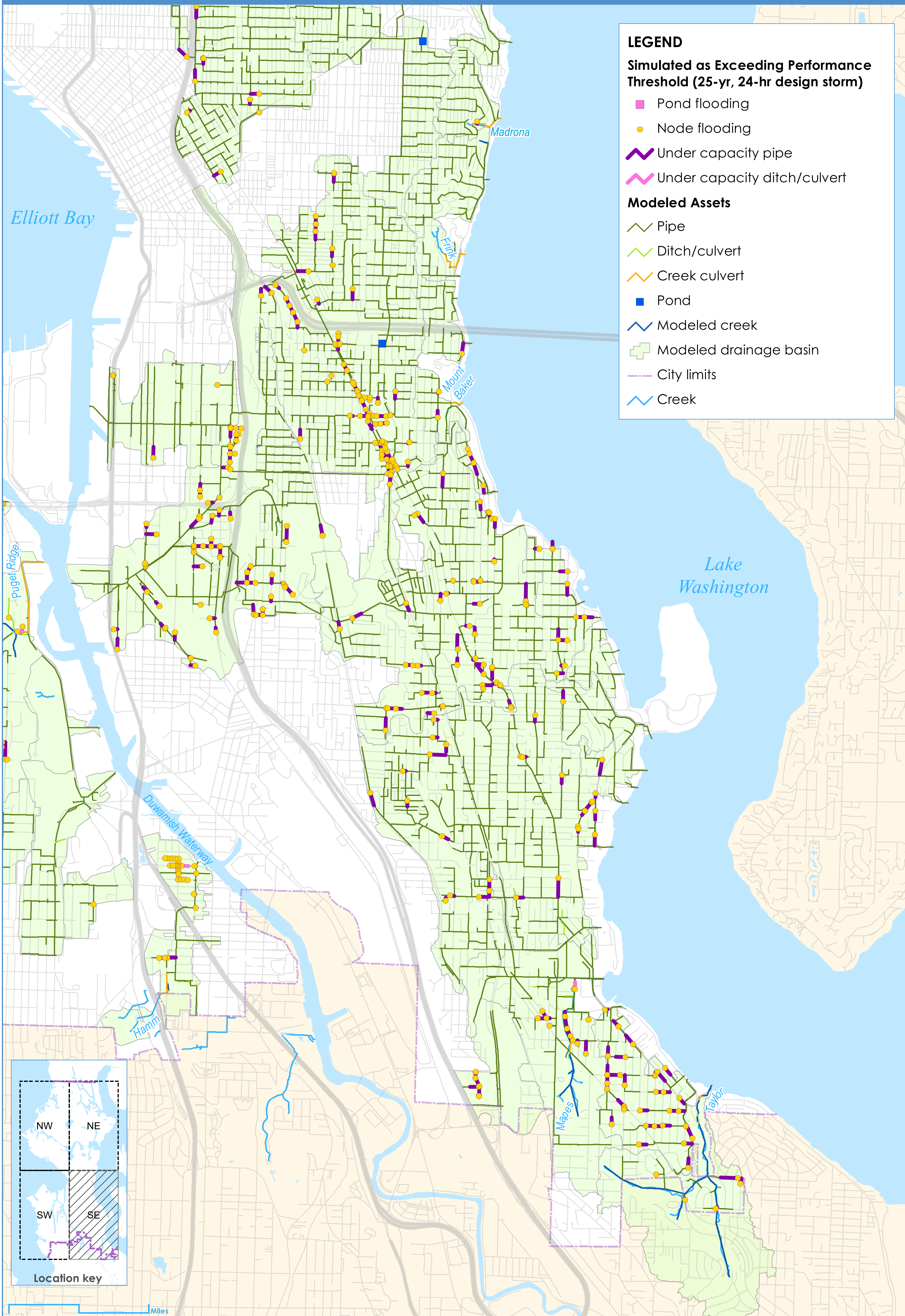


Seattle Public Utilities

Drainage System Analysis

Simulated Flooding under Existing Conditions

southeast



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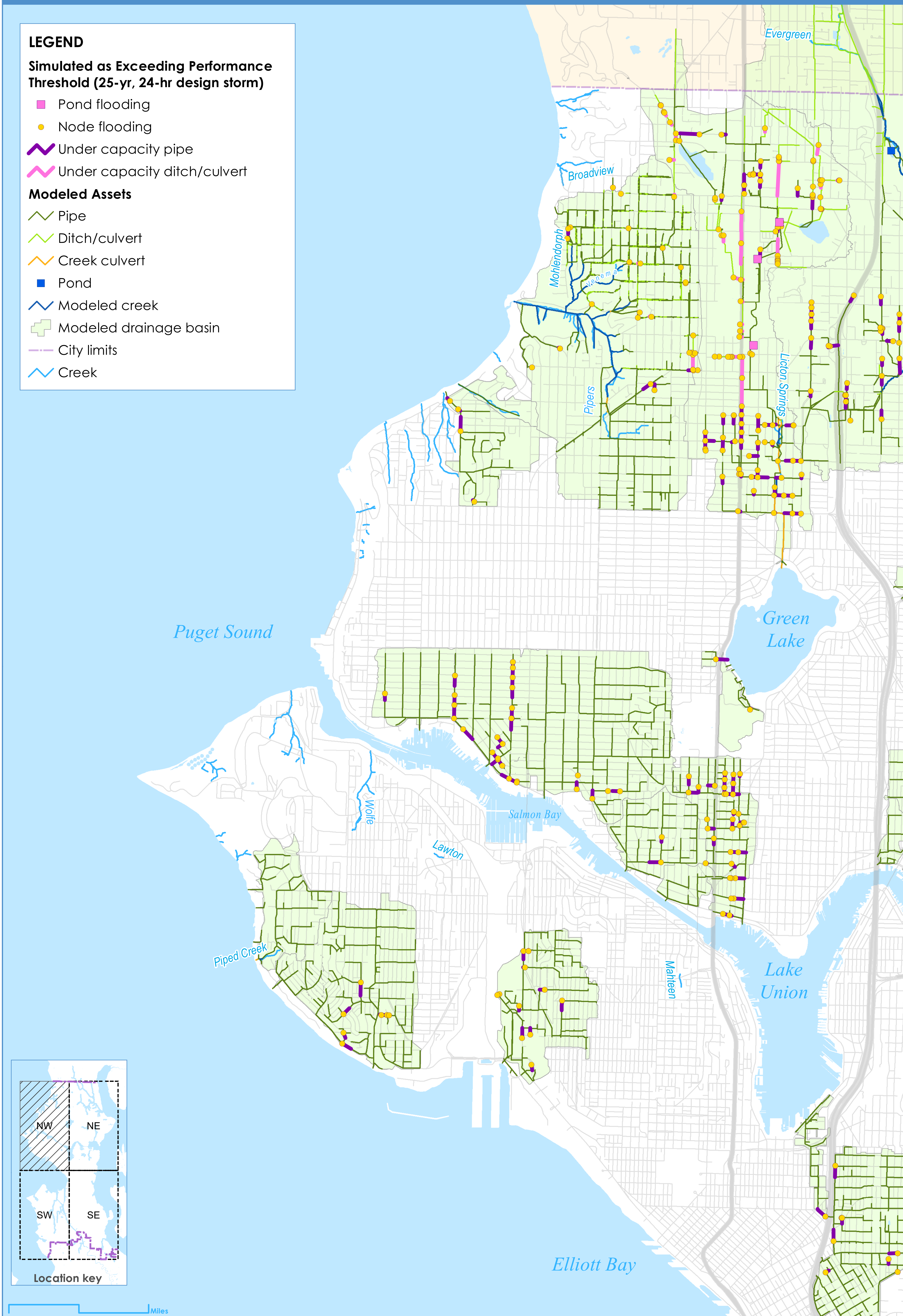
Seattle Public Utilities

Drainage System Analysis

Simulated Flooding under Existing Conditions

northwest



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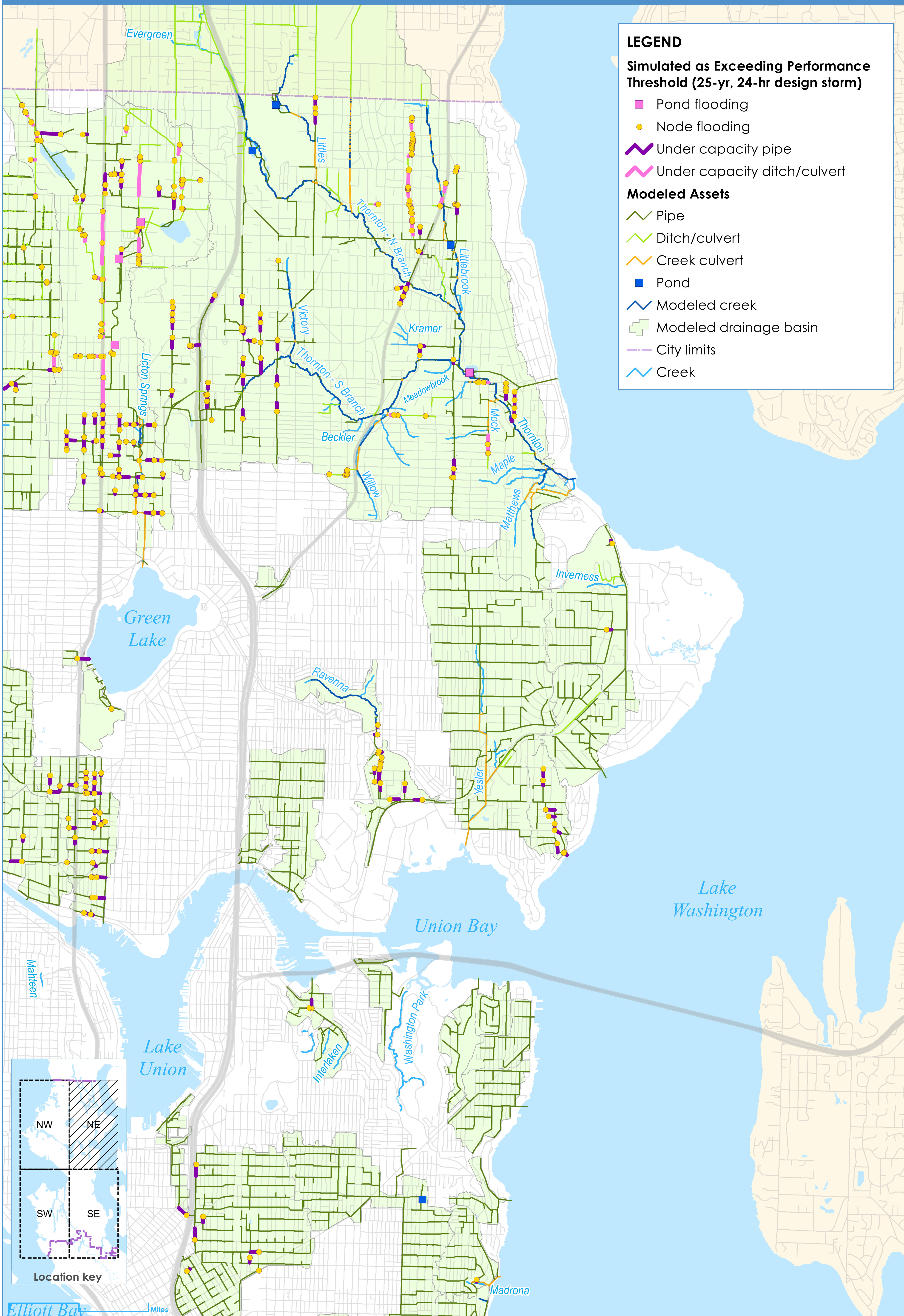
Seattle Public Utilities

Drainage System Analysis

Simulated Flooding under Existing Conditions

northeast



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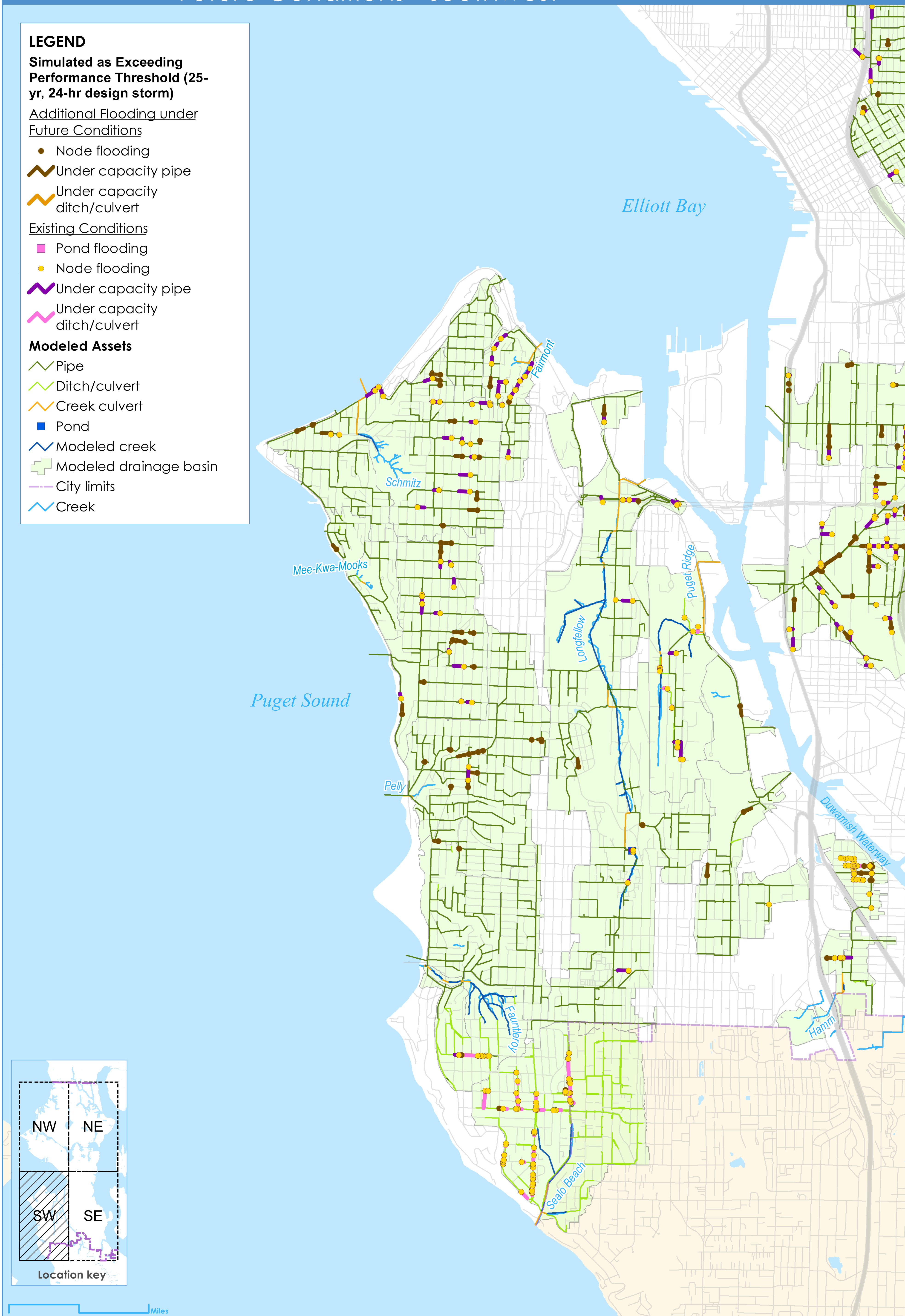
Seattle Public Utilities

Drainage System Analysis

Comparison of Simulated Flooding in Existing and Future Conditions - southwest



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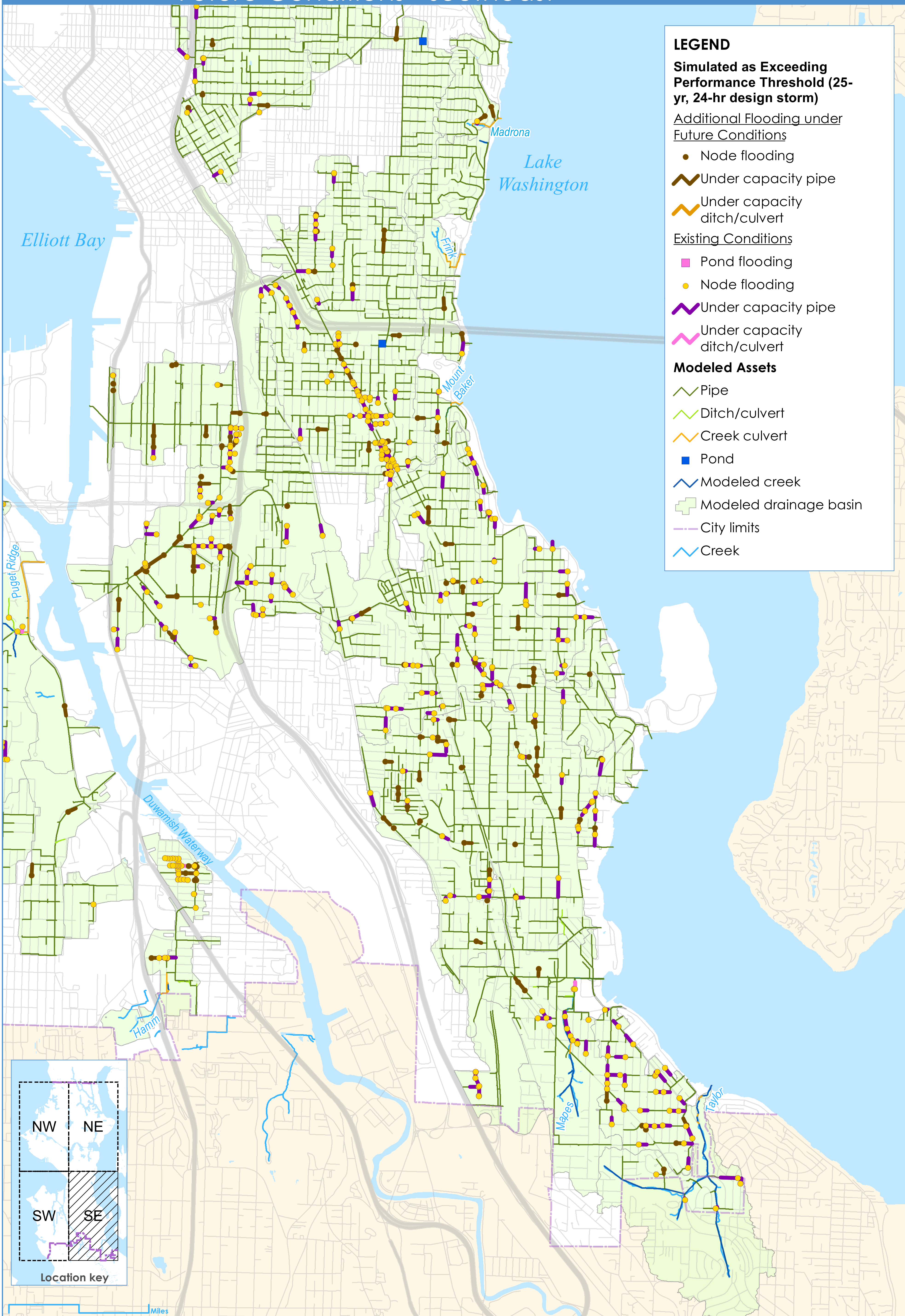
Seattle Public Utilities

Drainage System Analysis

Comparison of Simulated Flooding in Existing and Future Conditions - southeast



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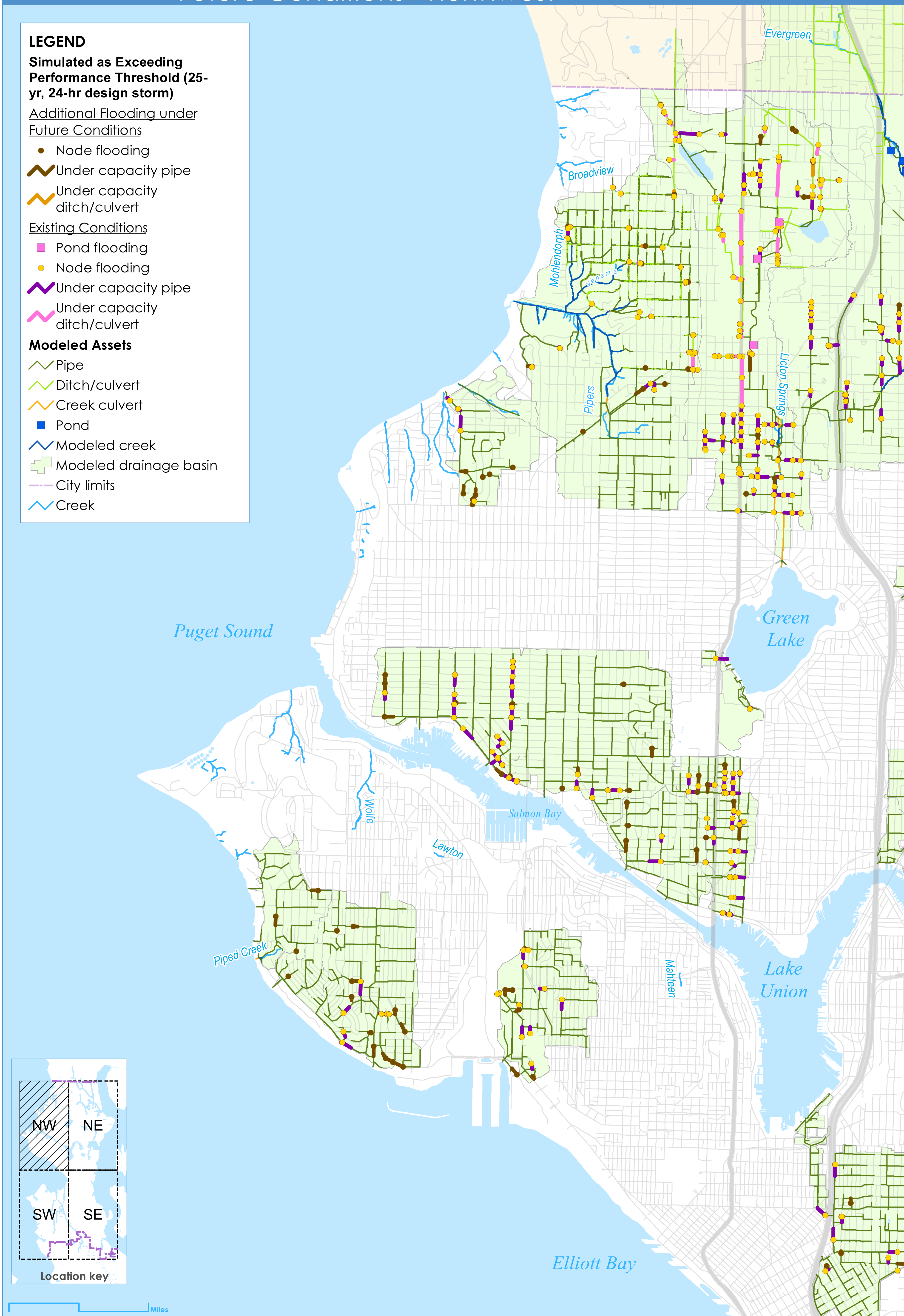
Seattle Public Utilities

Drainage System Analysis

Comparison of Simulated Flooding in Existing and Future Conditions - northwest



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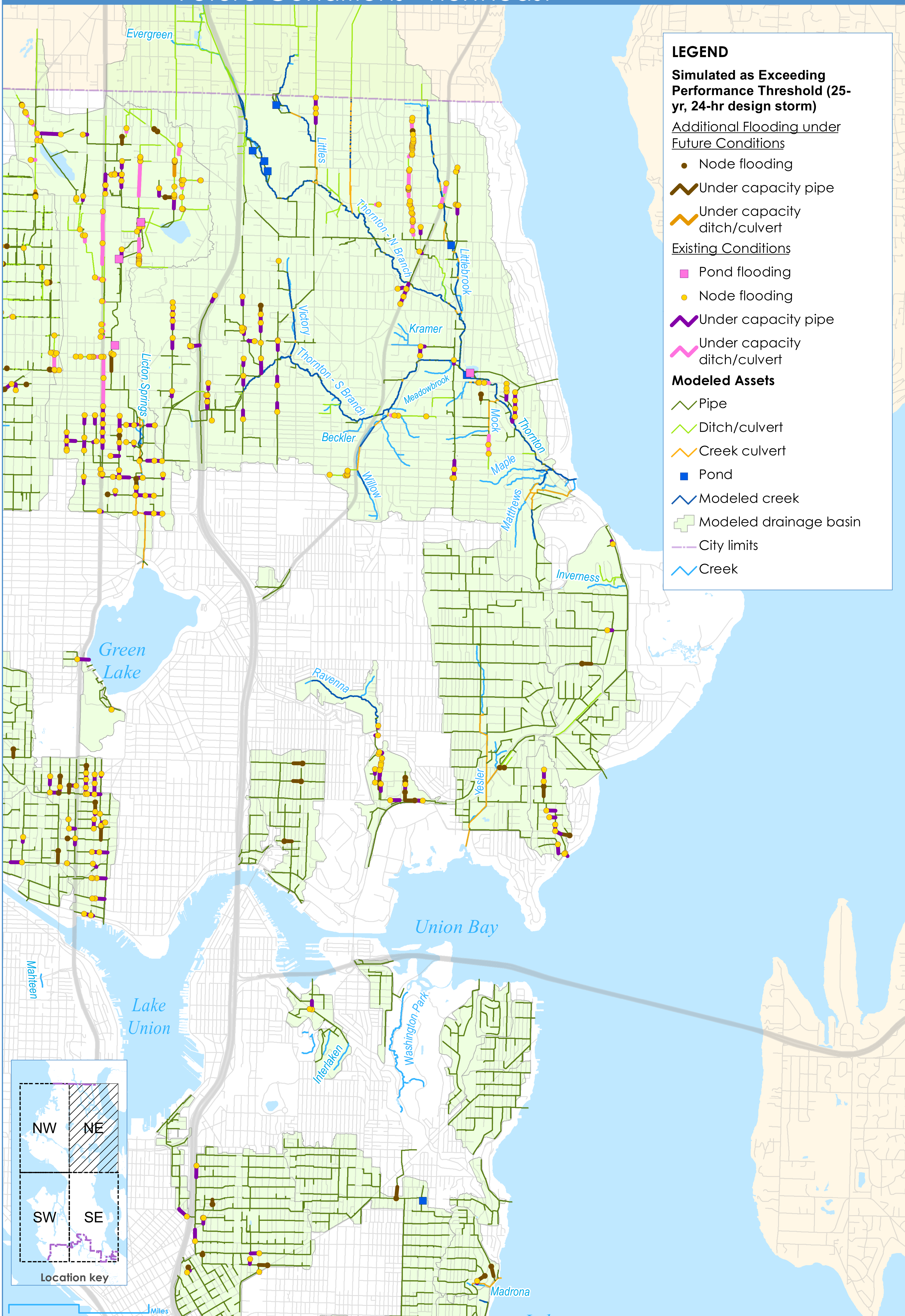
Drainage System Analysis

Comparison of Simulated Flooding in Existing and Future Conditions - northeast



Seattle Public Utilities

Drainage System Analysis

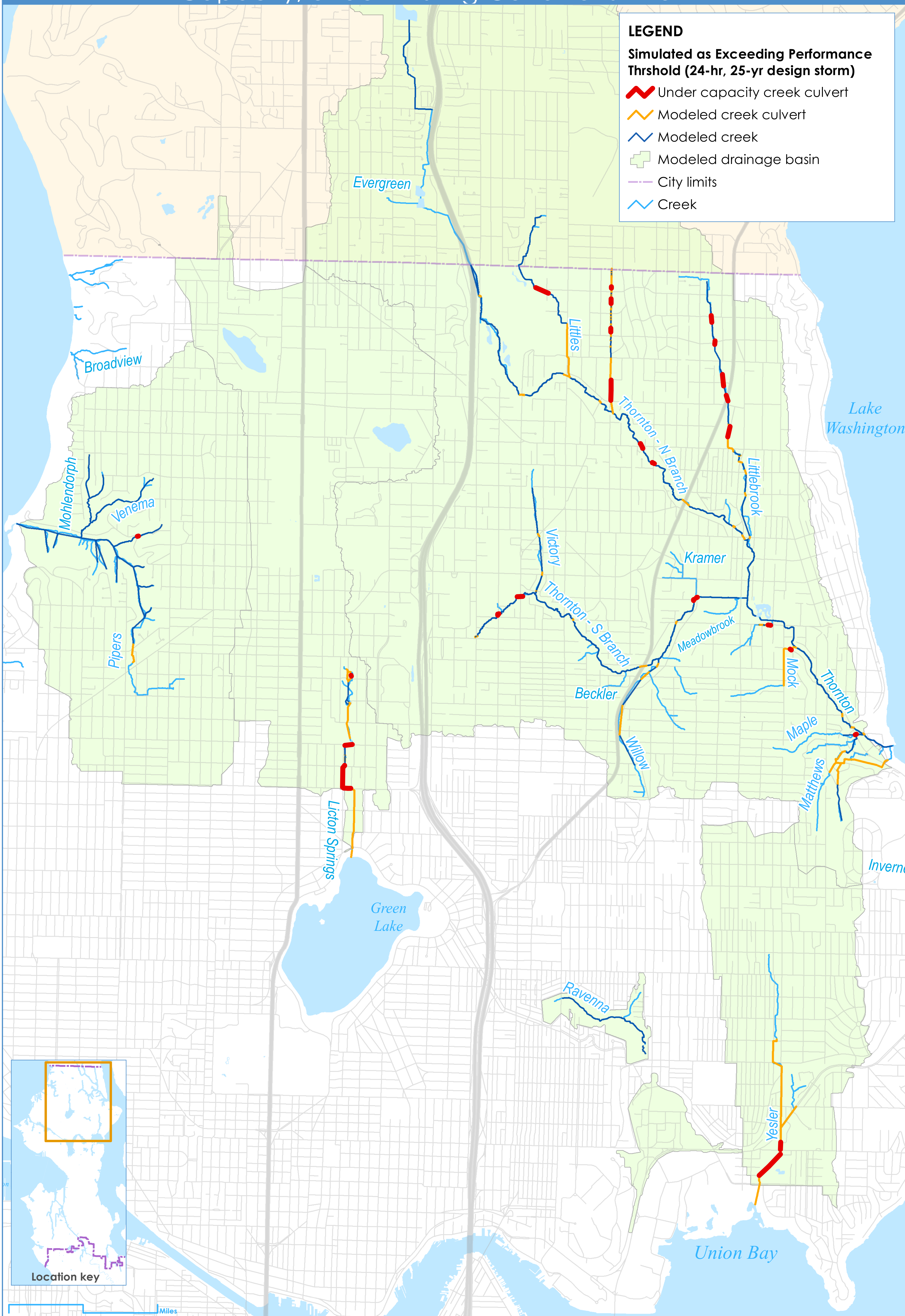
Simulated Flooding caused by Creek Culvert Capacity, under Existing Conditions - southwest

Author: Fill out Map Document Properties Date: 9/4/2020 File Path: P:\Seattle Public Utilities\152220 SPU Drainage System Analysis\Task 2 Flooding\500 Deliverables\010 Working\2.4 Drainage Capacity\Capacity Evaluation TM Final\GIS Quad maps\BC Maps\Maps\CrksSW_ExistCon.mxd

Seattle Public Utilities

Drainage System Analysis

Simulated Flooding caused by Creek Culvert Capacity, under Existing Conditions - north



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Seattle Public Utilities

Drainage System Analysis

Simulated Flooding caused by Creek Culvert Capacity, under Existing Conditions - se, e and w

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Seattle Public Utilities

Drainage System Analysis

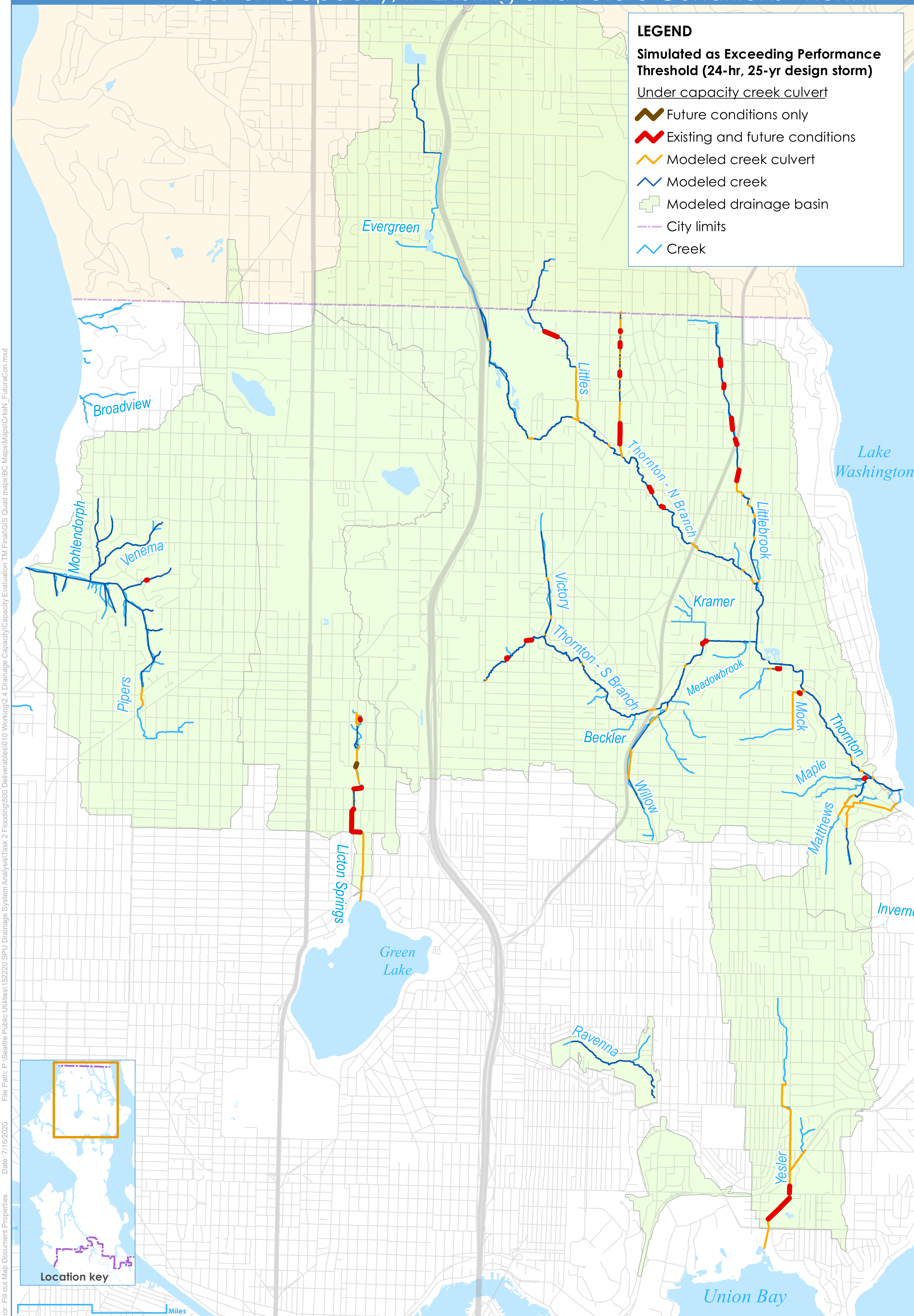
Comparison of Simulated Flooding caused by Creek Culvert Capacity, in Existing and Future Conditions - sw

Author: Fill out Map Document Properties Date: 9/4/2020 File Path: P:\Seattle Public Utilities\152220 SPU Drainage System Analysis\Task 2 Flooding\500 Deliverables\010 Working\2.4 Drainage Capacity\Capacity Evaluation TM Final\GIS Quad maps\BC Maps\Maps\CrksSW_FutureCon.mxd

Seattle Public Utilities

Drainage System Analysis

Comparison of Simulated Flooding caused by Creek Culvert Capacity, in Existing and Future Conditions - north

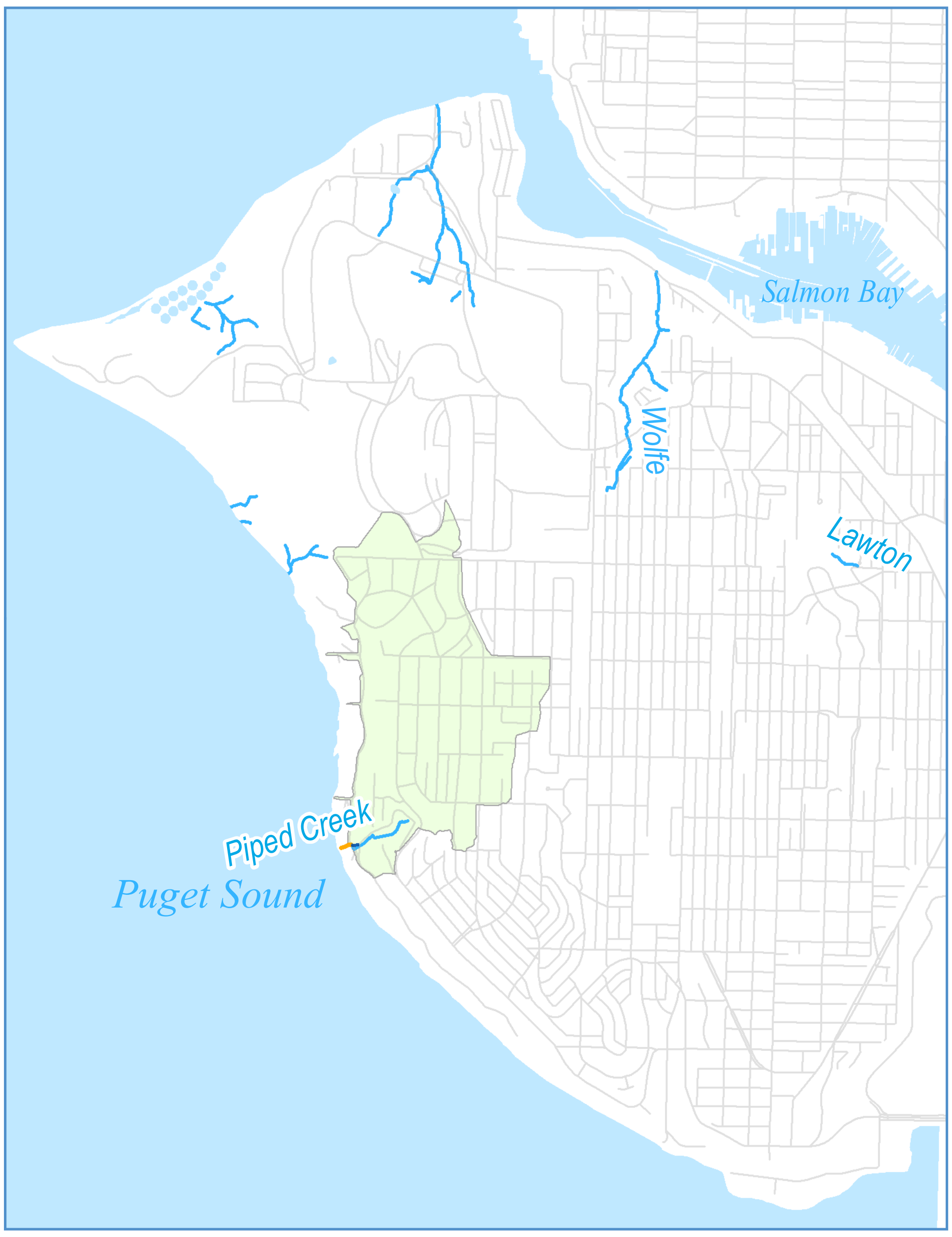


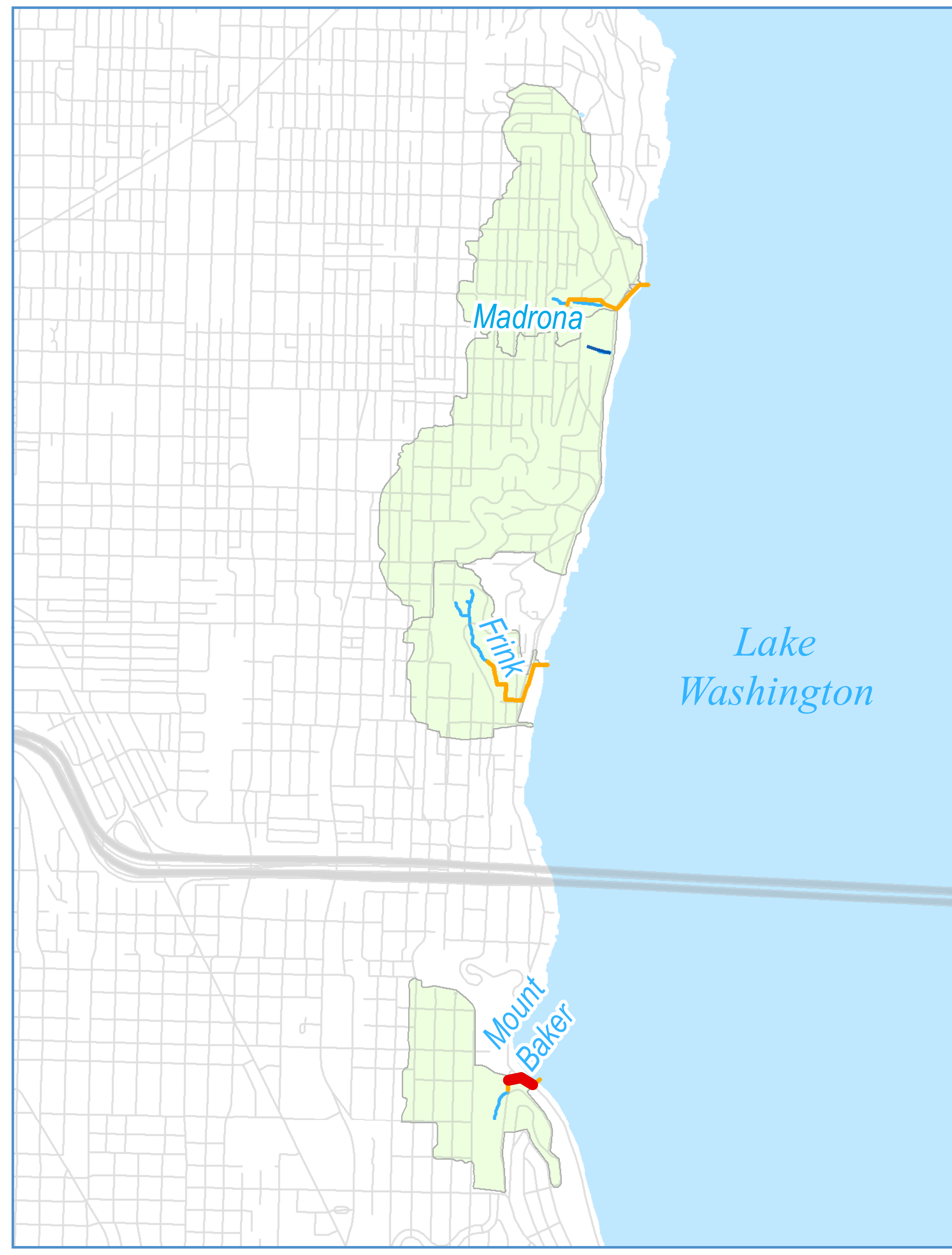
Seattle Public Utilities

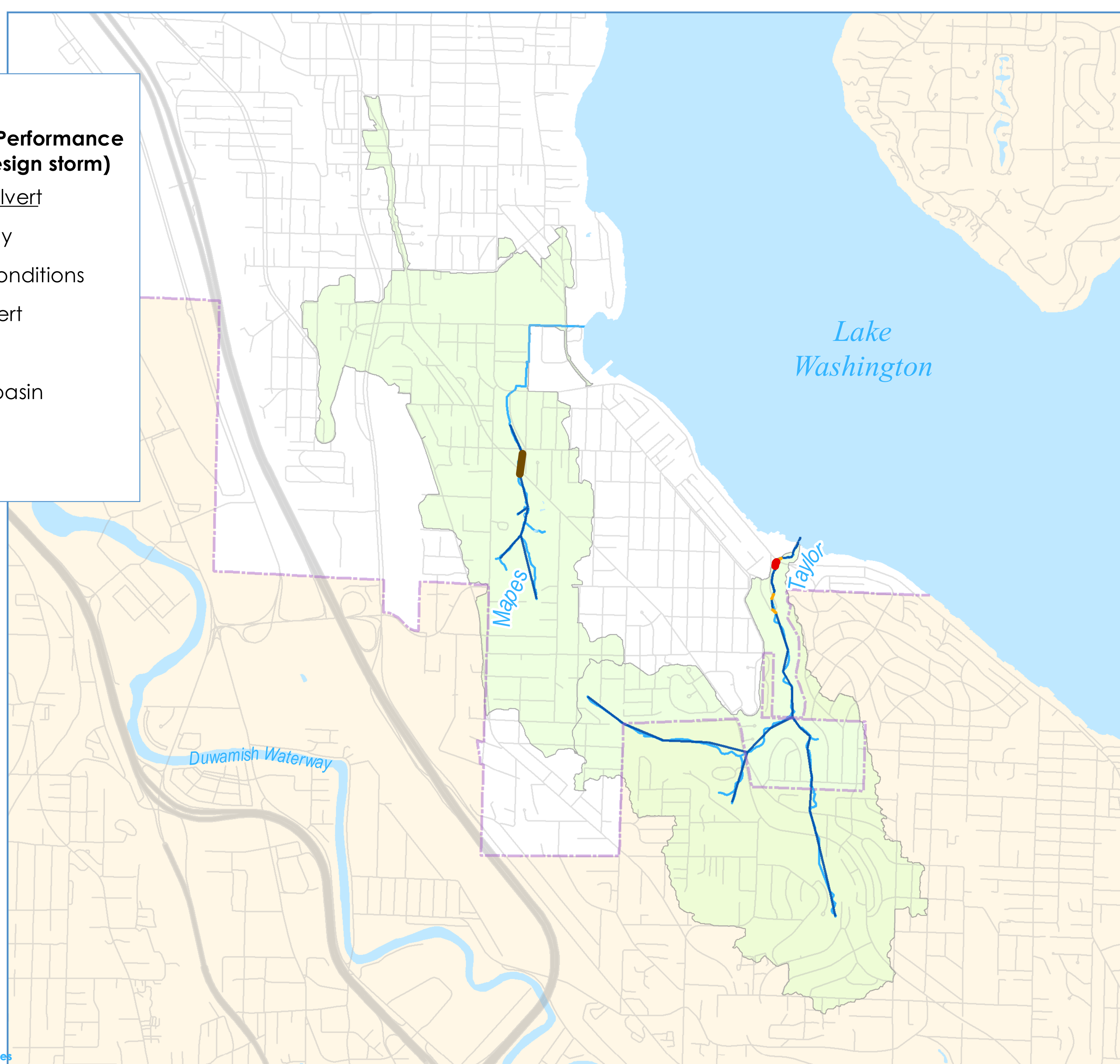
Drainage System Analysis

Comparison of Simulated Flooding caused by Creek Culvert Capacity, in Existing and Future Conditions - se, e and w

N





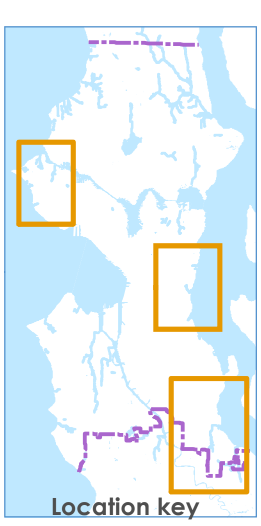


LEGEND

Simulated as Exceeding Performance Threshold (24-hr, 25-yr design storm)

Under capacity creek culvert

- Future conditions only
- Existing and future conditions
- Modeled creek culvert
- Modeled creek
- Modeled drainage basin
- City limits
- Creek



0 0.425 0.85 Miles

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