DRAINAGE SYSTEMS ANALYSIS

Flooding Topic Area | Creek Flow Metric

December 2020

Seattle Public Utilities

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Salmon in Longfellow Creek, Seattle. Holli Margell, 2009. http://nativelightphoto.com/

Thornton Creek Confluence Restoration, Seattle. Natural Systems Design, 2014. http://naturaldes.com

Flooding in South Park, Seattle. Sheila Harrison, Seattle Public Utlities, 2009.

Lake Union, Seattle. Seattle Public Utilities Photo Archive, date unknown.

Flooding Topic Area

Technical Memorandum

Title: Creek Flow Metric

Task No.: 2 (Subtask 2.7)

To: Holly Scarlett, SPU Project Manager

From: Tony Dubin, Senior Engineer
Urban Tech Systems

Date: December 21, 2020

Copy to: Colleen O'Brien, Seattle Public Utilities
Nathan Foged, Brown and Caldwell

Prepared by: ____
Tony Dubin, P.E., Senior Engineer, WA License #38770, April 1, 2021
Urban Tech Systems

Approved by: Leslie Webster (Dec 23, 2020 14:52 PST) 12/23/2020
Leslie Webster, Planning Program Manager, SPU

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Abbreviations

ac	acre
B-IBI	benthic index of biological integrity
BLD	Building
City	City of Seattle (organization)
city	city of Seattle (place)
cfs	cubic feet per second
CSO	combined sewer overflow
DCIA	directly connected impervious area
DSA	Drainage System Analysis
DWW	Drainage and Wastewater
GIS	geographic information system
GSI	green stormwater infrastructure
GW	groundwater
HSPF	Hydrologic Simulation Program-Fortran
IMP or imp	impervious
LTS	long-term simulation
MS4	Municipal Separate Storm Sewer Systems
QA/QC	quality assurance and quality control
Q2	Two-year flow; the flow rate that is equaled or exceeded on average once per two years
SPU	Seattle Public Utilities
SWMM	Storm Water Management Model
TM	technical memorandum
WADNR	Washington State Department of Natural Resources
WWHM	Western Washington Hydrology Model

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 *Shape Our Water Plan* (formerly the *Vision Plan* and *Integrated System Plan)* for the Drainage and Wastewater (DWW) Line of Business. 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 flooding topic area. The Consultant is working with SPU staff (collectively, the DSA Team) to complete several analyses for the flooding topic area. Key objectives of the flooding topic area include:

- Develop a prioritized inventory of drainage system 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 (the subject of this document), to prioritize areas for runoff reduction to improve the creek flow regime and better support creek aquatic health.

The primary goal of the analysis described in this technical memorandum (TM) is to calculate flow metrics in creek watersheds, based on changes in runoff due to development and the corresponding creation of a storm drainage system, and to describe how these results can be integrated with other watershed characteristics to prioritize areas that would have the most impact on reducing the impacts of high creek flows. The analysis covers the watersheds of the five major creeks within the city: Fauntleroy Creek, Longfellow Creek, Taylor Creek, Piper's Creek, and Thornton Creek. Key objectives include:

- Calculate a creek flow metric (ratio of 2-year peak flow for existing conditions to undeveloped, pasture conditions) for several sub-basins within each creek watershed.
- Evaluate inter- and intra-basin metric variations to identify areas where development is more impactful to the creek flow metric and why.
- Identify where, in a watershed, a measure could have the most impact on reducing the creek flow metric.
- Prepare maps of the flow metrics for the basins in each of the Seattle's five major creek watersheds.

This TM describes technical methods and summarizes the results of the analyses conducted by the DSA Team. Section 2 describes the background information used for this analysis. Section 3 describes the methods. Section 4 summarizes the results. Section 5 describes the limitations of the analysis.

2. Background Information

Seattle's creek watersheds have been altered by the process of urbanization for the past 100+ years. These alternations have affected every watershed in the city through the process of property platting and regrading, adding streets, sidewalks, housing, and other impervious surfaces, building drainage and wastewater infrastructure, and making instream alterations, including straightening, ditching, and piping natural surface water channels.

These alterations of Seattle's creek watersheds have increased the level of hydrologic flashiness (rapid flow peaks in response to rainfall) and brought about a decline in watershed health that is characterized by an increase in pollutants (e.g., metals), nutrients, stream channel incision, and a reduction in stream channel/floodplain connectivity and biological diversity (e.g., reduction in benthic index of biological integrity [B-IBI] values). The City of Seattle (City) has aggressively sought to reduce the impact of development on our creeks with stormwater code provisions and by promoting restoration and retrofit measures, such as the implementation of green stormwater infrastructure (GSI) and floodplain reconnection (e.g., Knickerbocker floodplain reconnection in the Kingfisher Natural Area on Thornton Creek).

2.1 Background Reports

Two studies and one technical paper were reviewed in preparation for this analysis:

- *State of the Waters* (City of Seattle, 2007)
- Piper's Creek Flow Control Plan (SvR, 2014)
- Hydrologic Metrics for Status-and-Trends Monitoring in Urban and Urbanizing Watersheds (Booth and Conrad, 2017)

The ***State of the Waters*** report represents a substantial effort by City staff to characterize stream hydrology, water quality, key pollutants, fish habitat, barriers to fish passage, and other factors that contribute to overall stream health in the Fauntleroy, Longfellow, Piper's, Taylor, and Thornton Creek watersheds. This report noted the following:

> "Flows in Seattle watercourses appear to be flashy, with sudden high peak flows, although additional flow data are needed to provide a more accurate picture over time. High peak flows are major causes of poor instream habitat, and the adverse impacts are compounded by buildings and armoring along stream banks."

In the stream flow summary section, Figure 35 summarizes the flow increases in each creek by computing the ratio of the two-year flow rate (Q2) for existing and undeveloped, forested conditions. At the time the report was developed, the regional target for protection of creek health was established as the pre-development forested condition, which was also the required target condition established in the Department of Ecology's municipal separate storm sewer systems (MS4) requirements. The *State of the Waters* report found that Thornton Creek, which is the largest watershed, had the smallest increase in flow from undeveloped to developed conditions. The Consultant's analysis was performed at finer spatial scale than the one used in *State of the Waters* report because SPU wants to be able to prioritize areas within creek watersheds and their SWMM hydrologic and hydraulic models allow for the calculation of stream flow within each stream reach and at significant locations, such as downstream of stormwater outfalls.

The Piper's Creek Flow Control Plan helped further evaluate what was an appropriate restoration flow control target for highly impacted urban watersheds, and what actions could be taken within the watershed to achieve that flow objective. Restoration activities included a comprehensive suite of proposed approaches, including a combination of retrofit projects, stormwater code-revisions, education and voluntary actions, and policy updates to reduce flow flashiness within the Piper's Creek watershed. The plan considered a variety of flow metrics such as pulse counts, peak flow ratios, changes in Q2, and changes in flow durations. The report noted that flow metrics incorporating base flow are less suitable for evaluating urbanization impacts in the Piper's Creek watershed, because of the underlying geology, shallow groundwater table, and strong base flow component to stream hydrology. The expert panel convened for the project agreed that a variety of metrics are valuable for assessing the effects of urbanization on hydrology and overall stream health. The panel's consensus was that the following metrics would be mostly valuable when considering the beneficial effects of retrofit projects:

- High pulse counts
- High pulse range
- Ratio of Q2 to wintertime base flow
- Percent change in Q2
- Changes in springtime base flow

The report also notes that modeling base flows for baseline and existing conditions is challenging (due to a lack of baseline, undeveloped flow monitoring) and therefore can introduce high levels of uncertainty into the results.

Combining findings from the *State of the Waters* and the Piper's Flow Control Plan, SPU worked with the Department of Ecology to adjust the MS4 required flow control target for Seattle's highly urban creeks to a pre-development pasture condition (these creeks are identified in Seattle's stormwater code as "Non-listed creeks", and include Fauntleroy, Longfellow, Piper's, and Thornton). The pre-developed pasture flow control target is still considered conservative, , as at the time scientists were unable to identify any impacted urban creeks that had watershed conditions fully restored to any variation of a less urbanized state. Regardless of the ultimate restoration flow control-based performance objective, metrics identified above had consensus as the parameters most impacting creek health.

The Hydrologic Metrics research paper described methods for identifying trends and key hydrologic changes due to urbanization. The paper considers a variety of pulse count metrics, flow reversals, and ratios of high flows to base flows. The analysis looked at watersheds with long-term monitoring histories and increasing levels of urbanization to identify which of the metrics is more suitable for spotting trends. One challenge of applying these results is the need for long-term monitoring that begins prior to watershed build-out. Additionally, the reliance on metrics with base flows limits its applicability to urban modeling analyses.

2.2 Selected Flow Metric

SPU considered the metrics presented in the Piper's Creek Flow Control Plan and reached out to expert panel members from the Piper's Creek Flow Control Plan for input on which metric should be evaluated for this effort, which allowed for the calculation of a single metric. The list was subsequently reduced to two, with the recommendation to use both the ratio of Q2 to wintertime base flow and high pulse count. Completing the modeling to calculate the ratio of Q2 to wintertime base flow would also provide the data to calculate high pulse count. Therefore, SPU selected the ratio of Q2 to wintertime base flow for this Consultant effort, with the option to calculate high pulse count at a later date.

The pasture condition models showed little variability in area-weighted wintertime base flow averages. The lack of variability appeared to be tied to model construct and not watershed conditions, as existing monitoring data showed considerable variation in base flow magnitudes among watersheds. For example, monitoring data show that the Fauntleroy Creek and Taylor Creek watersheds have similar wintertime base flow values even though the Taylor Creek watershed is more than four times larger. This suggests local geological conditions are substantially influencing wintertime base flow rates. Appendix A provides more information on the estimation of wintertime base flows. Additionally, relatively small wintertime base flows and uncertainty in the metric's denominator limited the modeler's ability to identify trends in the modeling results.

The combination of watershed-to-watershed variation in existing conditions base flow and uncertainty in the wintertime base flow computed by the pasture conditions models created challenges when interpreting the model results. Because the existing conditions base flow variability is not duplicated by the model, watersheds with relatively high existing base flow (e.g., Fauntleroy) produce "existing to pasture" ratios. Additionally, because base flow values are small (relative to Q2 values) and appear in the denominator of the Q2 / winter base flow equation, any uncertainty in these base flows can provide wide swings in the computed index. For these reasons, a comparison of Q2 was completed instead, and the calculation of high pulse count at a future date is still possible. This approach is similar to the State of the Waters report, which also included comparison of Q2 values, and the Piper's Creek Flow Control Plan, which evaluated the percent change in the 2-year flow magnitude.

This TM calculates the ratio of existing and undeveloped pasture condition 2-year peak flows at locations throughout the five watersheds:

$$Creek\ Flow\ Metric = \frac{Q2_{existing\ conditions}}{Q2_{undeveloped,pasture\ condtions}}$$

The calculation locations (see Section 3.4) were selected to characterize the effects of urbanization (contributing impervious area), watershed position (upper versus lower basin), and storm drainage network configuration on the creek flow metric.

2.3 Models and Data Sources

This analysis was conducted using the following hydraulic models and datasets:

- Calibrated SWMM models of the Fauntleroy, Longfellow, Piper's, Taylor, and Thornton Creek watersheds were used for existing conditions and to produce pasture conditions SWMM models.
- MGS Flood and WWHM hydrology models were used to prepare hydrographs and flow statistics that aided in the development of the SWMM pasture conditions models.

- GIS data supported the model development and results presentation (key datasets: DWW pipes, DWW maintenance holes and point structures, watershed boundaries, LiDAR topography, surficial geology, urban watercourses, and race and social equity mapping layers).
- Flow monitoring data, collected by SPU and King County, were used to assess existing conditions base flows produced by the SWMM models (see Appendix A for list a of monitoring sites).

Previously developed model calibration reports and hydrographs were consulted to verify existing conditions model results.

3. Method

This section describes the hydraulic modeling process used to evaluate the effects of urbanization on stream flows. The effort included running long-term simulations for existing conditions and undeveloped, pasture conditions models, calculating a creek flow metric that is a ratio of the 2-year flow rates, and then comparing the metric along different reaches of each creek, from the upper to the lower watershed.

Figure 3-1 presents an overview of the modeling and analysis process, and Table 3-1 lists the modeling period and time series data sources used to run the existing conditions and pasture conditions models. Key modeling elements of the process are described in greater detail later in this section.

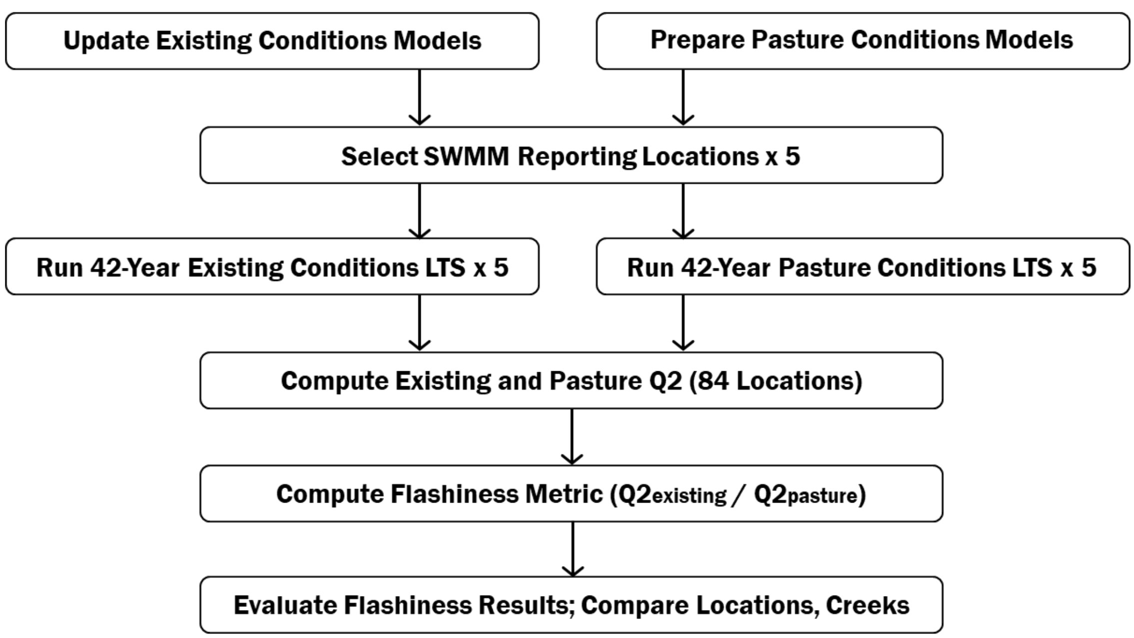


Figure 3-1. Modeling Process Overview

Table 3-1. Existing Conditions and Pasture Conditions Modeling Process Summary		
Model Item	**File Name[a]**	**Comment**
SWMM model file	WATERSHED_Dev_LTS.inp or WATERSHED_UnDev_LTS.inp	Modeling period=1978 through 2019 (42 years)
Rainfall data	RGxx.dat where xx is the SPU rain gage number	Nine rain gages used across the five watersheds. SPU-provided data were unadjusted. List of RGs by model: • Fauntleroy: RG05 • Longfellow: RG05, RG14, RG15, RG17 • Piper's: RG01, RG07 • Taylor: RG10_30 • Thornton: RG01, RG02, RG04
Evapotranspiration data	ETo_2019.12.31.dat	Daily time series data from WSU-Puyallup until 6/1/2017 and WSU-Seattle afterward. SPU-provided data were unadjusted.
Boundary condition data	LW_WL_9.1.77-12.31.19.dat or NOAA_Seattle_Tide_NAVD_ft_ 1977-20200101_WATERSHED.dat	• Taylor, Thornton=Lake Washington as measured at Chittenden (Ballard) Locks. SPU-provided data were unadjusted. • Fauntleroy, Longfellow, Piper's=Puget Sound corrected for salinity above elevation of outfall (portion of tide above the outfall invert elevation were multiplied by 1.026 to account for salinity)

a. WATERSHED=the name of each of the creek watersheds evaluated.

3.1 Update Existing Conditions Models

SPU provided calibrated SWMM hydraulic models for the Fauntleroy, Longfellow, Piper's, Taylor, and Thornton Creek watersheds to the Consultant for the DSA. These models were updated and used by the Consultant for other DSA Flooding Topic Area analyses (Brown and Caldwell, 2020a and b). The updated models were used for this analysis. Only minor updates were performed for this assignment:

1. Time series data assignments (rainfall, evapotranspiration, and boundary condition data) were updated to run models from 1978 through 2019 (Table 3-1)
2. Combined sewer overflow (CSO) inputs were removed from the Longfellow Creek model (other creeks do not receive CSO discharges)

CSO inputs were excluded, because a) CSO flows represent the condition of the sewer system infrastructure, b) CSO flows are large enough to obscure the Longfellow storm drainage hydrology and the specific effects of development on flows, and c) future CSO projects should dramatically reduce the frequency and volume of discharges to the creek.

3.2 Prepare Undeveloped, Pasture Conditions Models

The existing SWMM models were modified to simulate baseline conditions (e.g., no impervious surfaces, pasture land cover). The models were simplified by removing built infrastructure (e.g., pipes, ponds), eliminating building (BLD) subcatchments and other impervious (IMP) areas (while preserving total contributing areas), and modifying subcatchment and groundwater (GW) parameters to represent pasture land cover.

Figure 3-2 summarizes the model revision process, and the subsections below describe key aspects of the model revisions in detail.

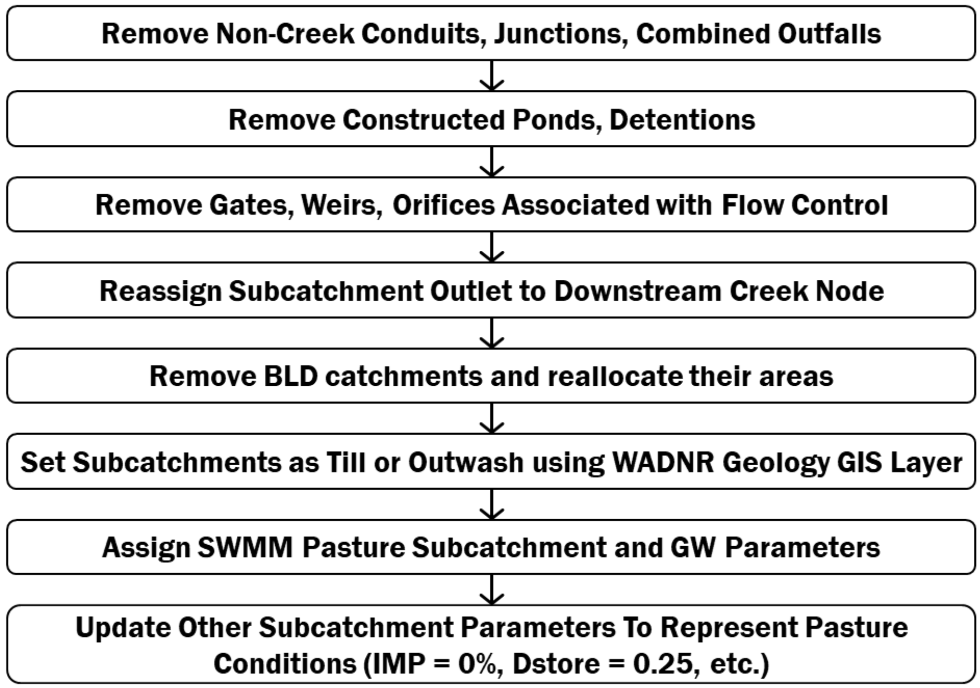


Figure 3-2. Preparing Undeveloped, Pasture Condition Models

3.2.1 Removing Built Infrastructure

The SWMM models use the TAG field for conduit and junction data to identify pipe, ditch, creek, and creek culvert infrastructure. In SWMM, the conduits and nodes were rendered to visually separate the “creek” and “non-creek” model conveyance elements. The “shape” of non-creek conduits upstream of the creeks was examined to identify any creek segments that could have been missed. This resulted in the classifying two additional trapezoidal channels as creeks in the Piper’s Creek pasture conditions model. Pipe and ditch elements upstream of the creek were removed to help create the “pasture” conditions.

Figure 3-3 shows an example for the Fauntleroy Creek model.

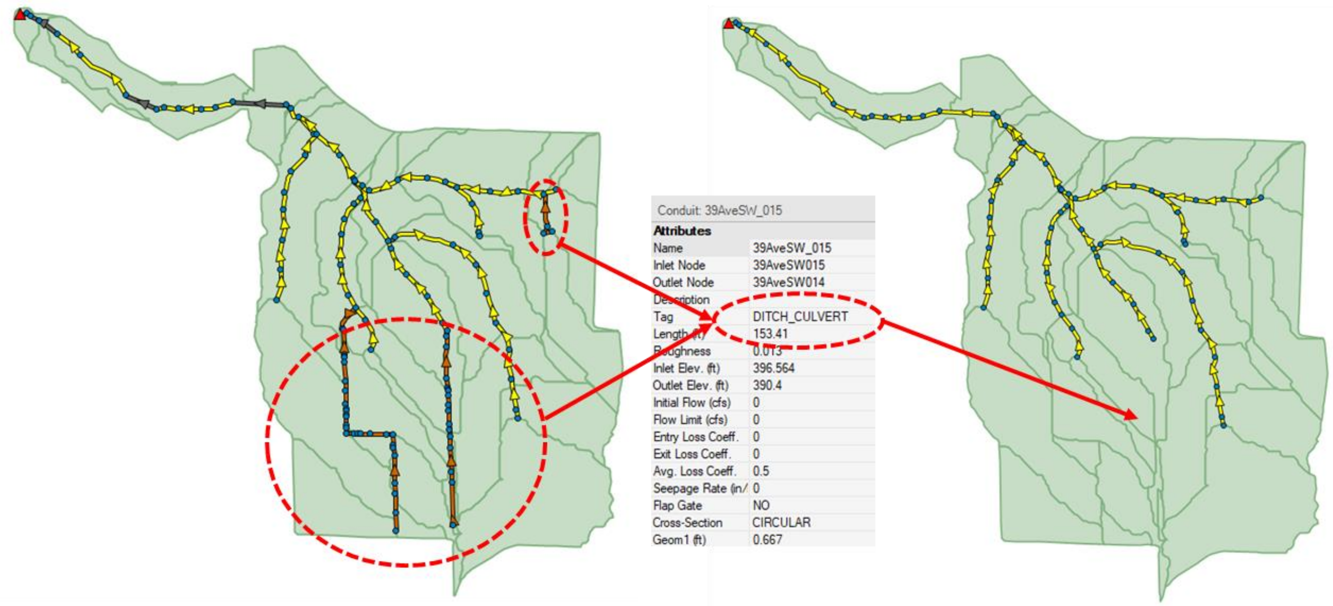


Figure 3-3. Example of Removing Built Infrastructure from the Pasture Conditions Model – Fauntleroy Creek

Creek segments in the models were not modified for the pasture conditions models. Therefore, any adaptations that have occurred within the channel during the process of urbanization (e.g., incision, straightening, armoring, floodplain disconnection), if present in the existing conditions model, are also present in the pasture conditions models. Additionally, piped, and culverted segments within a creek were left unmodified, and no new stream segments were added.

3.2.2 Baseline Pasture Conditions Hydrology

HSPF-based models, including WWHM and MGS Flood, are often used to model watershed hydrology in Western Washington, particularly in areas with limited development. HSPF's methods for computing interflow and groundwater contributions to creeks are particularly suited to Western Washington watersheds that generally exhibit a strong subsurface connection to creeks but little surface runoff in areas without storm drainage infrastructure.

Despite the common use of HSPF-based models, the use of SWMM for this analysis technically sound. SPU has developed SWMM hydrologic and hydraulic models for the five largest watersheds, and the models' combination of calibrated hydrology based on flow monitoring, detailed storm conveyance, and some surveyed stream cross-sections (Thornton and Taylor Creeks), culverts, and ponds makes them valuable tools for system analysis and project planning[1]. Developing the pasture conditions models in SWMM allows for the direct comparison of flows at multiple locations in each watershed, and SWMM's Green-Ampt infiltration and groundwater algorithms can be suitable for modeling Western Washington hydrology. The key for modeling watershed hydrology in SWMM is the replicate the interflow processes and extended hydrograph recessions that are common in Western Washington.

[1] See *DSA Creeks Analysis TM* (Brown and Caldwell, 2020a) for more information on creek representation in the models.

Because examples could not be found, the SWMM pasture hydrology was developed by modeling pasture conditions for till and outwash soils in MGS Flood and WWHM, and then iteratively adjusting SWMM's subcatchment and groundwater parameters until the SWMM flows reproduced the shape of the HSPF model hydrographs and approximated the seasonal peak flows. Without the benefit of predevelopment flow monitoring data for SWMM calibration, the MGS Flood and WWHM model hydrographs served as a target for the iteratively adjusted SWMM models.

Figure 3-4 and Figure 3-5 show examples of multiyear hydrographs for till and outwash soils, and Table 3-2 lists the specific subcatchment and groundwater parameter adjustments. The WWHM and MGS Flood models use SeaTac Airport rainfall whereas the SWMM models use local SPU rain gages, so the timing of the hydrograph peaks and magnitudes vary. However, the overall character of the hydrographs is similar, and the peaks are similar, which suggests the selected pasture parameters are suitable for modeling undeveloped conditions.

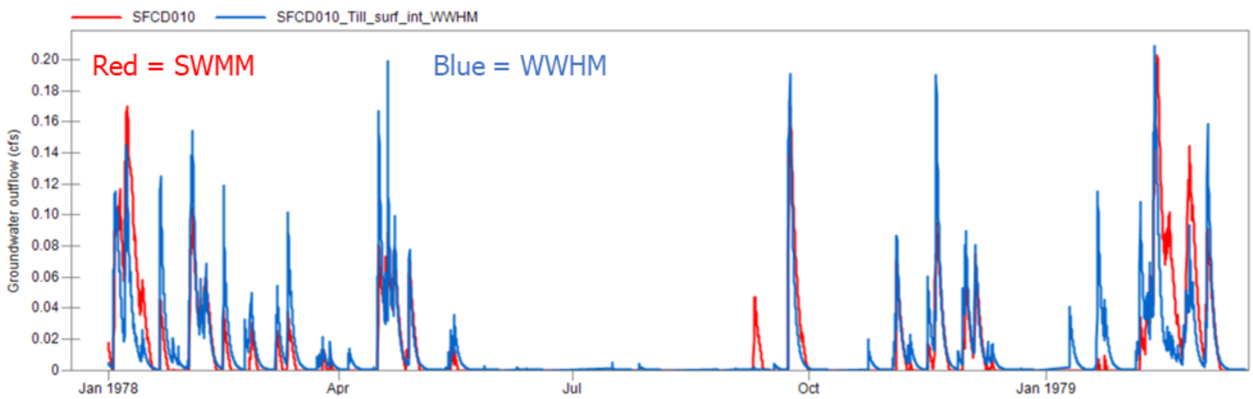


Figure 3-4. Till Soils, Pasture Land Cover Model Output Comparison

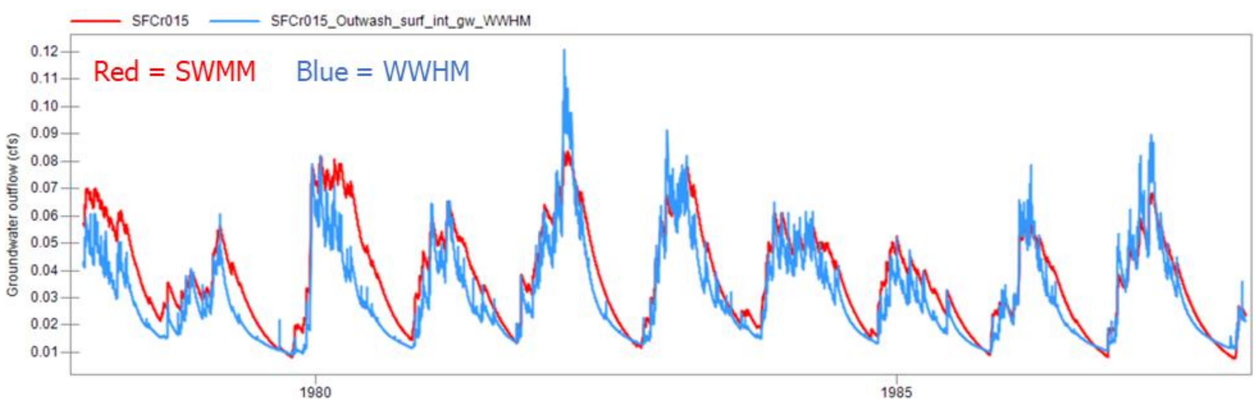


Figure 3-5. Outwash Soils, Pasture Land Cover Model Output Comparison

Table 3-2. SWMM Pasture Parameter Setup and Assignment	
Model Component	**Model Component Setup and Parameter Adjustment**
Groundwater setup	• All watersheds contain an outwash and a till aquifer. • Model aquifers setup with 10-foot thickness and flow engagement at 2 feet from bottom. This approach allowed for seasonal build-up and recession of aquifer levels: – Bottom elevation=98 feet – Surface elevation=108 feet – Water table threshold elevation=100 feet • Lower groundwater loss parameter was adjusted from existing conditions models, based on review of HSPF modeling • Other groundwater parameters were assigned based on values used by SPU for the till and outwash soil types
Subcatchment setup	• Buildings subcatchments combined into parcel subcatchments; total area preserved. • A1 coefficient, B1 exponent, outlet connection, and flow length parameters were adjusted. • Impervious value set to 0%. • Other subcatchment parameters based on values used in existing SPU SWMM models.
Outlet connection	• Removing built infrastructure from models (pipes, ditches) resulted in many subcatchments that were not directly connected to a model flow junction/conduit. • These subcatchment outflows were assigned to the junction where the existing conditions subcatchment currently enters the creek.
Flow length	• Removing built infrastructure creates longer flow travel pathways from many subcatchments to the closest downstream model conduit. • Updated flow lengths were computed in GIS to equal the distance between the subcatchment centroid and the model receiving node. • The flow lengths were then compared with the existing conditions models; the larger of the computed values and existing conditions values was used in the pasture conditions model (this step prevents the pasture model from having a quicker pathway that would generate faster responses than the existing conditions models).
Groundwater A1	• Parameter affects rate at which elevated groundwater flows into creek system (linear relationship between groundwater elevation and flow). – Till A1=0.0053 – Outwash A1=0.0007
Groundwater B1	• Parameter affects rate at which elevated groundwater flows into creek system (exponential relationship between groundwater elevation and flow). – Till B1=1.10 – Outwash B1=1.35
Lower groundwater loss parameter	• Parameter affects the seepage water from the active aquifer and therefore the portion of infiltrated water that is available/not available for creek flow. – Till lower groundwater loss=0.018 in/hr – Outwash lower groundwater loss=0.0017 in/hr

Please note, extensive research was conducted before developing the pasture parameter set to identify examples of SWMM watershed models for areas with limited storm drainage system development. The examples were few, and those examples used either RTK unit hydrograph or Soil Conservation Service curve number methods, and not the Green-Ampt infiltration and groundwater hydrology methods used by the SPU models.

3.3 Summary of SWMM Model Updates

The sections above describe the process of updating the existing conditions models and preparing the pasture conditions models. Table 3-3 provides a summary of the model revisions for this analysis.

Table 3-3. SWMM Model Revisions Summary and Comparison

Model Item	Existing Conditions	Undeveloped, Pasture Conditions
Subcatchment data	No revisions	• Impervious, groundwater, flow length parameters updated. • Flows produced by MGS Flood and WWHM used as guide for SWMM parameters.
Aquifer data	No revisions	• Calibrated, existing conditions aquifers removed. • All subcatchments assigned to "till" or "outwash" aquifer, based on WADNR surficial geology GIS provided by SPU. Appendix B provides maps of the soils assigned.
Conveyance data	No revisions	• Pipes, ditches, culverts tributary to creeks removed. • Creek culverts and piped sections within creeks unchanged.
Special structures data	No revisions	• Diversion structures and inline storage removed (Longfellow, Thornton). • Operating rules for Jackson Park ponds removed, along with the ponds (Thornton).
CSO flow inputs	Excluded (applies only to Longfellow Creek)	• Excluded (applies only to Longfellow Creek).

3.4 Model Reporting and Creek Flow Metric Calculation Locations

Creek flow metric calculations were performed for 84 creek segments across the five watersheds. Table 3-4 shows the number of locations by watershed and Figure 3-6 shows an example from the Taylor Creek model. Appendix C includes maps that show the location of all monitoring locations. These locations were selected to highlight how the process of urbanization affects a watershed and what factors produce higher levels of sensitivity. For example, the calculations include locations just downstream of storm drainage inputs, upstream and downstream of creek tributary confluences, and a variety of upper and lower basin locations. Trends within the modeling results can be coupled with stream condition data, restoration opportunities/open space data, and community partnering to help SPU develop goals and priorities for creek restoration, floodplain storage, and flow control activities.

Table 3-4. Creek Flow Metric Calculation Locations by Watershed

Watershed	Number of Locations
Fauntleroy Creek	12
Longfellow Creek	15
Taylor Creek	9
Piper's Creek	17
Thornton Creek	31

Total All Watersheds	**84**

Figure 3-6. Taylor Creek Flow Reporting and Creek Flow Metric Calculation Locations

3.5 Evaluating Long-Term Simulation Results

The long-term simulation results for each watershed were graphed and then separated into discrete flow events using SWMM. All flow events surpassing a 2- to 3-month magnitude were identified (with a minimum 24-hour period between events) and exported to Excel for further analysis.

In Excel, the flow events were ranked and assigned a recurrence (e.g., 6-month, 1-year, 2-year) using the Cunnane plotting position method. The 2-year flow rate for each reported creek segment was then computed for existing and pasture conditions. The ratio of these 2-year flows (existing/pasture) was the creek flow metric computed for this analysis. The results were then plotted to identify trends in the data (e.g., relationship between contributing area and creek flow metric) and mapped to identify where efforts to reduce flows would be impactful.

4. Results

This section describes the creek flow metric results within the Fauntleroy, Longfellow, Piper's, Taylor, and Thornton Creek watersheds. The discussion is divided into the following sections:

- **Summary** provides and overview of results with graphics across the five watersheds.
- **Discussion** highlights the key findings and trends among the results.
- **Recommendations** discusses how these results can be integrated with other creek and watershed information for future use.

4.1 Summary

This section presents information that demonstrates the range and distribution of creek flow metric values and how specific factors (e.g., location, upstream imperviousness) affect the metric's value within a stream reach. Appendix D lists the complete results for all 84 locations.

Each watershed has combinations of physical characteristics that contribute to the creek flow metric, as shown in Table 4-1. These physical characteristics can provide context when comparing modeling results among watersheds later in this section: area, % directly connected impervious, % till and % outwash. For example, basins with large directly connected impervious areas would exhibit higher Q2 values than basins with less impervious area and an informal drainage system. Basins with a large of outwash soil fraction would show a greater increase in flows relative to undeveloped, pasture conditions, because development converts low runoff surfaces to higher runoff surfaces. Conversely, larger basins should be less flashy due to attenuation within the conveyance system. Stormwater detention facilities and distributed GSI would also mitigate existing conditions storm flows.

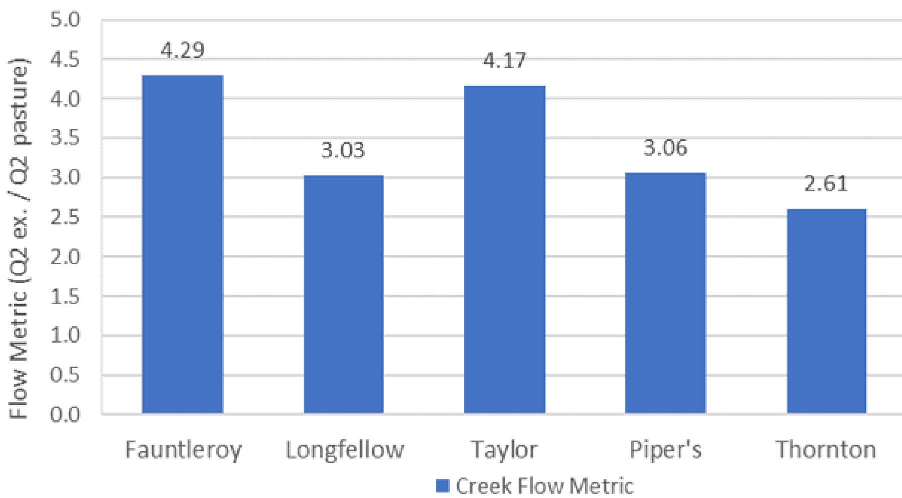
For this analysis, Taylor Creek has a relatively high impervious fraction, which suggests the watershed would have a high creek flow metric value. Longfellow Creek has similarly high levels of imperviousness and till soil fractions but is larger and contains more storm detention infrastructure., which suggests the creek flow metric for Longfellow Creek would be lower than Taylor Creek. The type of storm drainage conveyance should also influence the creek flow metric values. Informal drainage systems attenuate flows more than piped systems, and the ditch and culvert system in the Thornton Creek watershed should result in lower creek flow metric values.

Table 4-1. Watershed Physical Characteristics that Contribute to the Creek Flow Metric

Watershed	Area (ac)	% Directly Connected Impervious[a]	% Till	% Outwash
Fauntleroy	150	9.0%	60%	40%
Longfellow	1,717	20.1%	82%	18%
Taylor	643	19.8%	75%	25%
Piper's	1,450	16.0%	88%	12%
Thornton	6,797	14.8%	74%	26%

a. Directly connected impervious area (DCIA) percentages were computed from the calibrated SWMM models. For the Piper's model, the subcatchments that discharge to a conduit are considered directly connected. For the other models, the DCIA was computed as the portion subcatchment impervious area not "routed to pervious" in SWMM's "subarea routing" field.

Figure 4-1 shows creek flow metric values calculated in the lower portions of each watershed. The lower watershed creek flow metric values range from 2.61 to 4.29. The lowest values occur in the Longfellow, Piper's, and Thornton Creek watersheds, which are the largest by area. Longfellow Creek and Thornton Creek also have more flow detention facilities than the other three watersheds. Piper's Creek has some GSI retrofit facilities in upland areas and is susceptible to flooding in the lower watershed, which can attenuate the existing conditions flows and reduce the creek flow metric value. The values are generally consistent with those presented in the *State of the Waters* (see Appendix E).



Notes:
1. Lower basin SWMM model conduits: Fauntleroy = FC_Main002; Longfellow = D055-497_LF-032; Piper's = D223-006_PC-001; Taylor = CJ1317.1_2; Thornton = CJ7011.
2. Thornton Creek reporting location is just upstream of the Meadowbrook Pond. This location was selected instead of the creek mouth, because of the flow diversion at the pond substantially reduces the two-year flow to the creek mouth (for existing conditions) and would produce results that are not representative of the hydrologic changes brought about by urbanization.

Figure 4-1. Creek Flow Metric for Lower Watershed Locations

The distribution of creek flow metric values within each watershed provides additional insight into how stormwater discharges can influence the creek hydraulics and where efforts to mitigate the influences can be made. Figure 4-2 shows the flow metric as a function of tributary area within each watershed. All watersheds show a clear relationship between watershed position and creek flow metric value, as indicated by the slope of the linear regression line shown for each watershed. The lower basin (mainstem or lower position on large tributary) locations have lower metric values and upper watershed or tributary locations have higher values. The upper watershed and tributary locations show considerably more scatter among creek flow metric values, which indicates the degree that stormwater outfalls influence flows in smaller tributaries.

The has been annotated to explain the clusters of locations that fall above or below the expected flow metric value, based on watershed position (i.e., value relative to the plotted trend line). For example, the upper basin locations that plot above the regression line are generally downstream of stormwater outfalls whereas areas below the line are areas with limited directly connected contributing area or direct flow inputs from stormwater outfalls. The Longfellow and Thornton Creek plots show a clear influence of water control facilities. On Longfellow Creek, the cluster of reporting locations upstream of Webster Pond are significantly flashier than the reporting locations downstream. On Thornton Creek, the areas around Jackson Park and downstream of Meadowbrook Pond are considerably less flashy than other areas with similar watershed position and impervious tributary area.

Please note, the three most downstream reporting locations in the Longfellow Creek watershed are excluded from the results summary. These creek locations are tidally influenced, and the combination of tidally driven inflows and outflows overwhelm the influence of urbanization on the Q2 statistics.

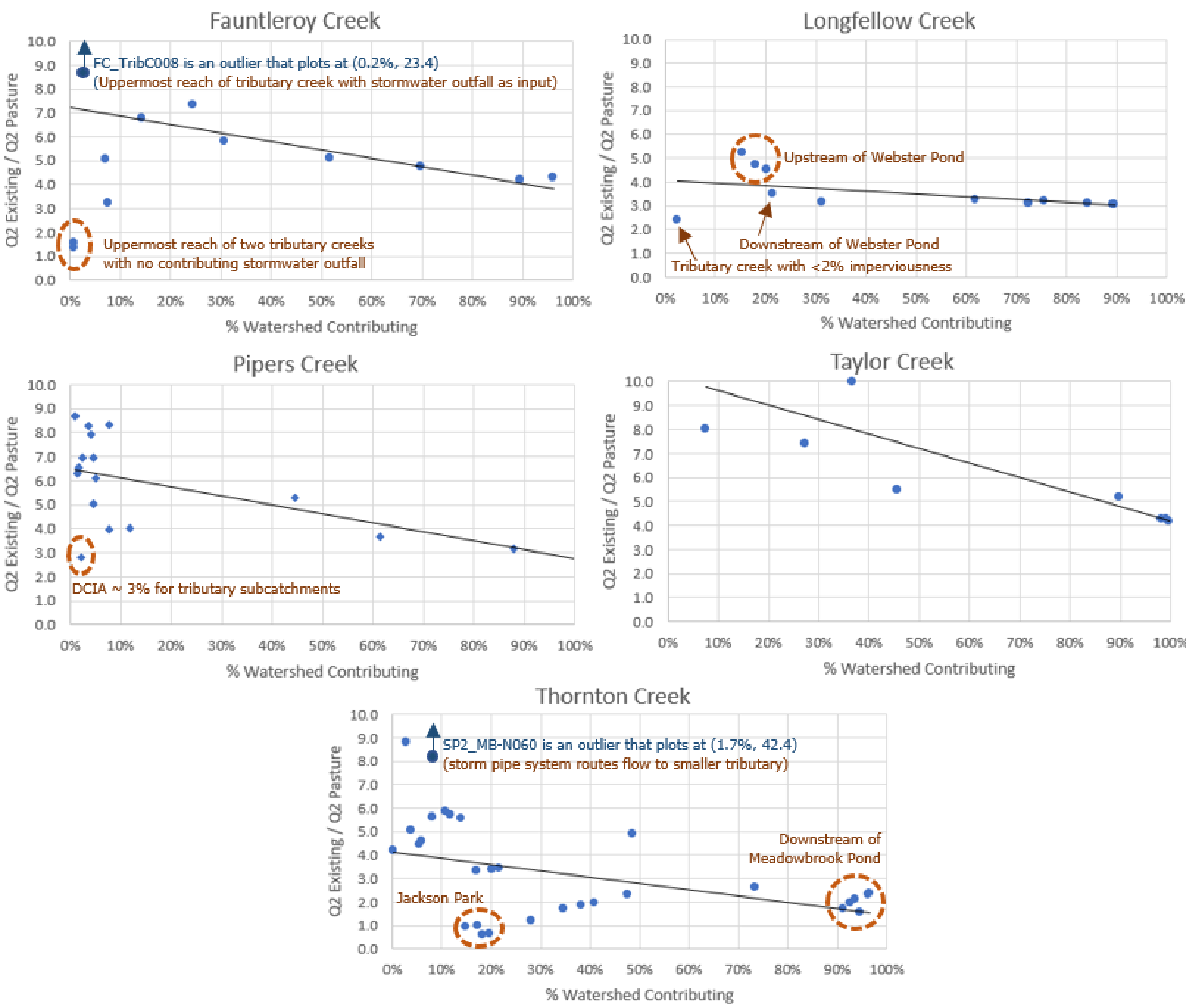


Figure 4-2. Relationship Between Creek Flow Metric and Watershed Contributing Area

Table 4-2 shows relative creek flow metric categories assigned from the overall spread of the creek flow metric values. These categories are not tied to specific geomorphic characteristics but are a useful method of identifying relative flashiness with the watersheds. Figure 4-3 shows the proportion of low, moderate, high, and very high creek flow metric values within each watershed.

Table 4-2. Relative Creek Flow Metric Categories and values

Creek Flow Metric Category	Flow Metric Value
Low	<2
Moderate	2-4
High	4-6
Very high	> 6

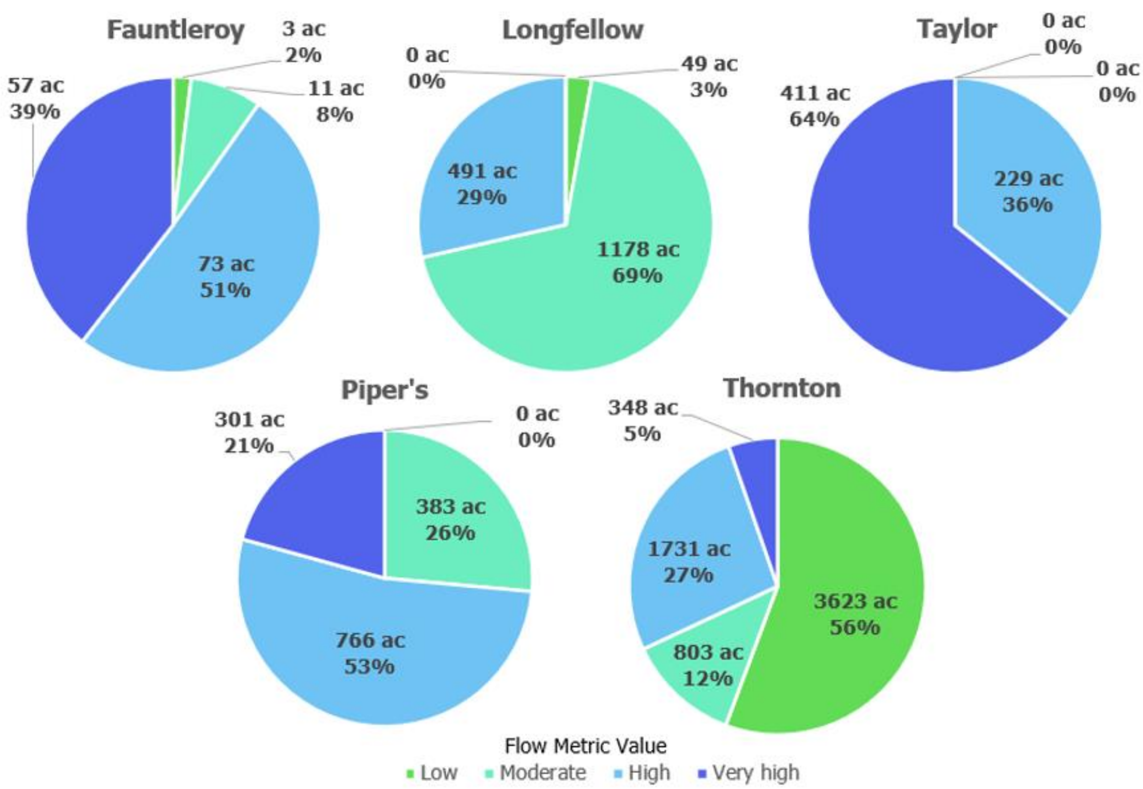


Figure 4-3. Low, Moderate, High, and Very High creek Flow Metric Values by Watershed

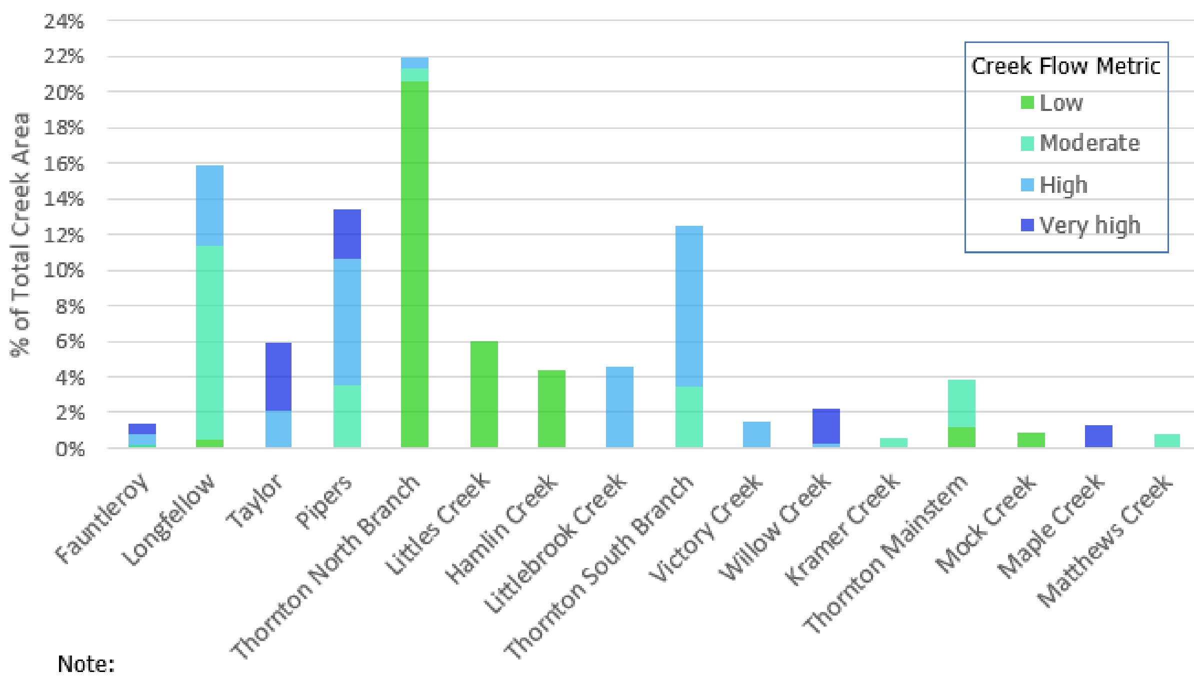
As the earlier discussion and graphics showed, the Fauntleroy and Taylor Creek watersheds have the highest proportion of areas with high and very high flow metric values. Conversely, more than two-thirds of Longfellow and Thornton Creek watersheds have low and moderate flow metric values. In addition to the relative proportion of low and high creek flow metric areas, the total areas listed in each pie chart can help guide SPU about the total quantity of upstream work that would be needed to reduce storm flows. For example, Fauntleroy has mostly high to very high creek flow metric values. However, because this watershed is relatively small, SPU could be lower the creek flow metric values into the low to moderate range with far fewer upstream retrofit projects than would be needed to accomplish the same reduction in the Piper's Creek watershed, which is much larger.

Figure 4-4 provides the distribution of low, moderate, high, and very high creek flow metric values across the five watersheds. The figure shows the area of each watershed and Thornton Creek sub-watershed relative to the total area of all five watersheds (e.g., Longfellow Creek is about 16 percent of the total area of the five watersheds). Further, the figure color codes each watershed (or sub-watershed) area, based on the relative creek flow metric categories.

The graphic shows the substantial variation in creek flow metric values among the Thornton Creek sub-watersheds:

- The mainstem and North Branch of Thornton Creek have lower creek flow metric values – this reflects the influence of the upstream storage projects.
- The South Branch of Thornton Creek has higher creek flow metric values – this reflects the lack of large flow control infrastructure.
- Among the smaller tributaries, Littlebrook Creek has a higher creek flow metric values – this reflects the high portion of directly connected imperviousness area and storm sewer buildout along Lake City Way.

Please note, the low creek flow metric values for Littles Creek and Hamlin Creek are a reflection of the model development and calibration process and how reporting locations were selected for the creek flow metric calculation. These creeks are largely piped. The process for creating the pasture models included removing built infrastructure, which eliminated these tributaries from the Thornton Creek pasture model. The nearest downstream reporting location used to compute the creek flow metric is located along the North Branch of Thornton Creek. Therefore, the Littles Creek and Hamlin Creek flow metric values reflect conditions in the larger North Branch, where flows are attenuated by the ponds at Jackson Park.



Note:
1) This graphic shows creek/tributary area relative to total watershed area (eg., Longfellow ~ 16% of total) and the portion of each watershed within each Creek Flow Metric value band.
2) Thornton North Branch and all creeks plotted to the right are within the Thornton Creek watershed.

Figure 4-4. Relative Creek Flow Metric Values

Summary maps showing flow metrics throughout each watershed are provided in Appendix F. Figure 4-5 shows an example for the Fauntleroy Creek.

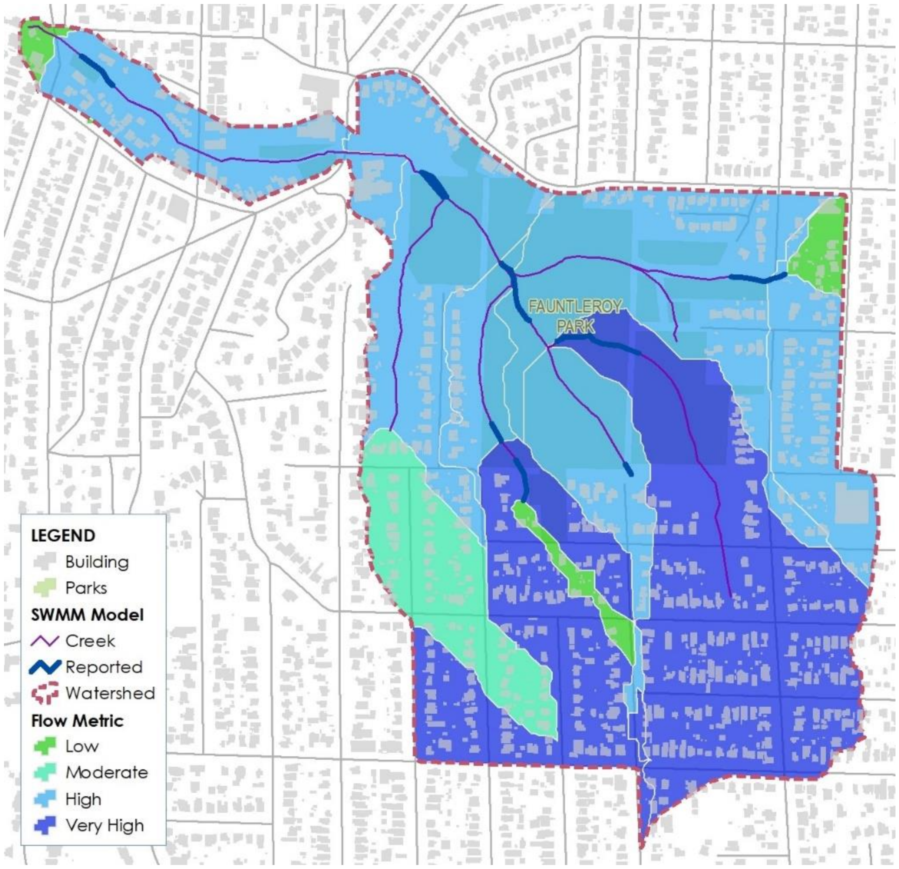


Figure 4-5. Fauntleroy Creek Watershed Flow Metric Map

4.2 Discussion

The section discusses:

1. How watershed characteristics and development patterns affect the modeling results used to calculate the creek flow metric.
2. How creek flow metric values overlay with Seattle's Race and Social Equity Composite Index - 2018.
3. How these results can help support SPU's future use.

4.2.1 Watershed Characteristics and Development Patterns

The hydrologic and hydraulic modeling analysis showed considerable variation in the creek flow metric values among the five watersheds and within each watershed. The lower basin creek flow metric values varied from 2.61 to 4.29 and middle and upper basin locations showed considerably more variation. The following factors appear to affect the flow metric:

- Watershed position. Upper watershed and upper tributary locations have flashier flows, because small creeks and tributaries are more sensitive to inflows from storm drainage outfalls. Mainstem and lower tributary basin locations (with larger tributary areas) are less flashy due to flow attenuation, flow control facilities, and potentially floodplain storage.

- Storm drainage infrastructure and connected imperviousness. The flow metric results show that the creek flow metric increases downstream of stormwater outfalls, and the increases are clearest in the upper watersheds where the existing drainage infrastructure substantially increases the directly connected imperviousness to the creek. Creek sections within densely developed areas served by piped drainage systems are more sensitive to stormwater discharges if the upstream system lacks stormwater control measures, such as ponds.
- Presence of flow control facilities. The major flow control facilities in the Longfellow Creek (Webster Pond) and Thornton Creek (Jackson Park, Meadowbrook Pond) watersheds have a very clear influence on creek flow metric values. The maps in Appendix F show the effects of these ponds.
- Underlying soil conditions. In areas with outwash soils, the conversion of pervious surfaces to impervious surfaces should result in flashier creek conditions. However, the modeling results did not show a clear soil type signature. This is likely due to the larger influence of the other factors mentioned above.

4.2.2 Race and Social Equity Composite Index

The results were also viewed within the context of race and social equity. Seattle Office of Planning and Community Development weighted factors including race, proportions of English language learners, foreign-born community members, socioeconomic disadvantage, and various measures of health disadvantages and combined them into a composite index that reflects relative levels of disadvantage and priority for each community. Figure 4-6 shows the five watersheds with the composite index.

The figures show a substantial degree of variation in the levels of disadvantage across the watersheds and within each watershed. The Longfellow and Taylor watersheds have the broadest extent of highest disadvantaged areas, but similar pockets exist within the watersheds. Factors that can commonly influence the data used to develop the composite index (e.g., density of development, extensiveness of impervious areas, quality, limited park and open space, and age/quality of infrastructure) can also affect creek flow metric values. However, the modeling results do not show a clear relationship between creek flow metric values and relative levels of disadvantage. The watershed characteristics affecting creek flow metric (e.g., watershed position, imperviousness, upstream flow control facilities) do not appear to be broadly correlated with community factors influencing the Race and Social Equity Composite Index - 2018.

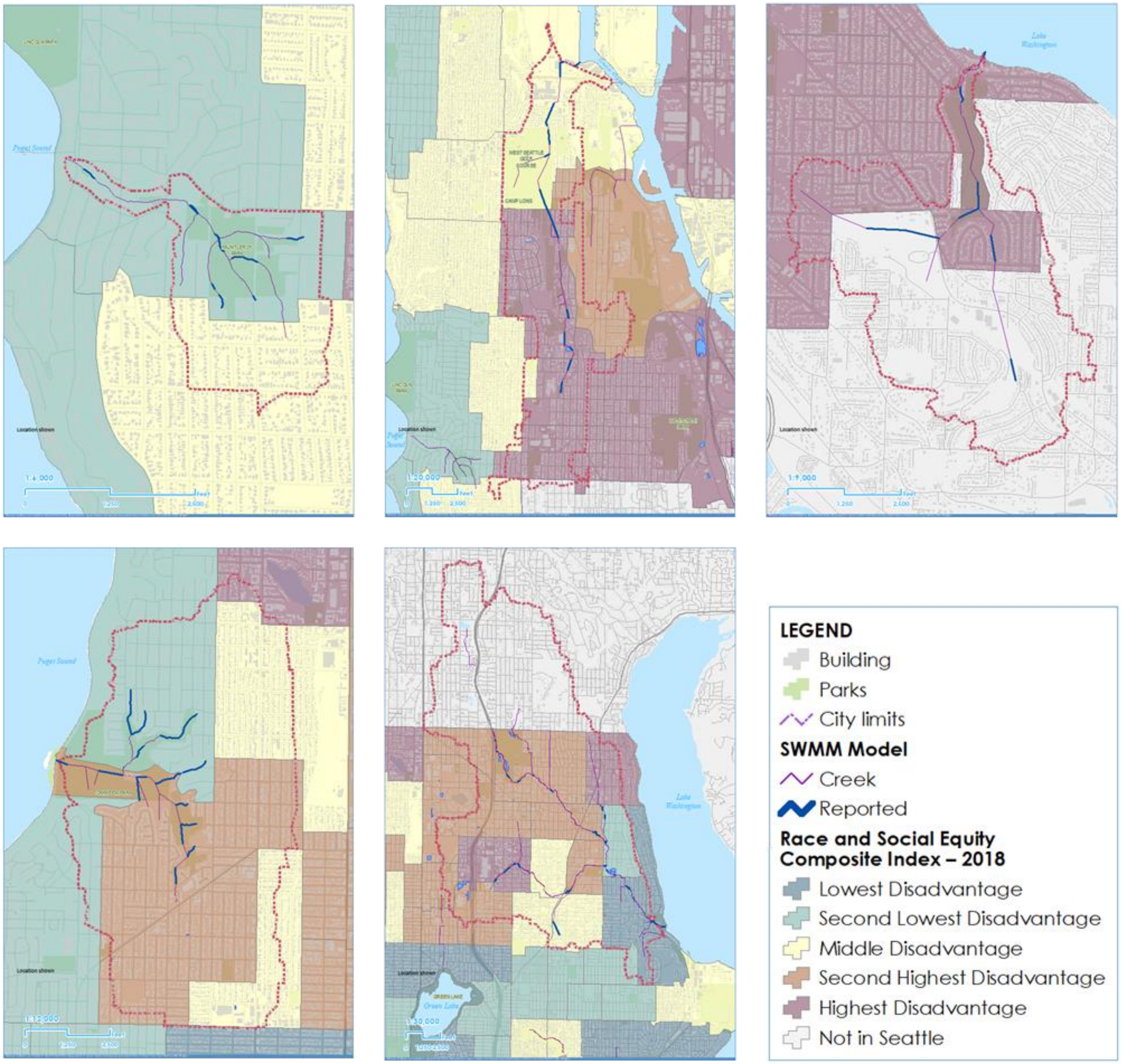


Figure 4-6. Race and Social Equity Composite Index Overlay

4.2.3 Recommendations for Future Use

The creek flow metric is a powerful tool for assessing the degree to which urbanization has affected the flow regimes in the city's five largest creek watersheds. In *Shape Our Water*, SPU should integrate the creek flow metric with other available information (e.g., stream bed stability, fish potential) to develop and prioritize flood reduction, water quality improvement, fish habitat projects, and other creek restoration projects.

Instead of uniform goals for reducing creek flow metric values (e.g., flow metric <2 in potential spawning areas and flow metric <3 in other areas), SPU should consider creek flow metric values within the context of existing problems and restoration objectives by watershed. Perhaps, the clearest way to describe how flow metric values can support project identification and prioritization is through a series of examples based on common issues within the city.

- **Issue: Creek flooding.** In areas with existing flooding, the flow metric values can help determine the underlying causes and potential solutions. Flooding in areas with high creek flow metric levels are an indication the upland areas produce too much flow. Flow control projects, such as distributed GSI, would be an appropriate part of the solution. However, flooding in areas with low to moderate creek flow metric values may indicate other factors may be contributing to flooding, such as floodplain development or in-channel sediment accumulation. In these circumstances, reducing storm hydrographs may be ineffective, which suggests that in-channel projects that reduce the risk/consequence of flooding may be more effective.
- **Issue: Degraded fish habitat.** Flashy flows can reduce fish habitat potential by washing out gravels, incising channels, and leaving behind armored or unstable conditions. High velocities during storm conditions can also wash out redds and create hazardous conditions for fry. The magnitude of creek flow metric values can be one factor to consider when assessing habitat improvements. Geomorphologists and biologists should consider site conditions (e.g., sediment supply, channel structure) along with the likely range of velocities (indicated by the creek flow metric) when assessing the suitability of a stream channel for restoration. For example, channels with suitable wood, refuge areas, and floodplain connectivity may function well with moderate creek flow metric values so long as the underlying channel structure is suitable for high flow pulses.
- **Issue: Low benthic invertebrate counts.** Similar to the fish habitat discussion above, SPU staff should use to creek flow metric results as an indication of the range of flows and velocities within the channel. The flow rates (and likelihood that higher flows increase pollutant loading) could be compared to B-IBI counts to indicate where stormwater is contributing to B-IBI declines. Improvements could include in-channel structural changes to support macroinvertebrates, such as adding wood, and upstream drainage system retrofits to reduce flows and high flow pulses. Improvements that increase macroinvertebrate populations and diversity would improve fish habitat as well as rearing and foraging viability by increasing food availability for salmon.
- **Issue: Viability of floodplain reconnection.** The creek flow metric can provide an early indication of the flood reduction potential of floodplain reconnection projects. In areas with low to moderate creek flow metric values, reconnection projects can be designed to engage the floodplain with a frequency and depth that supports habitat enhancement. In higher creek flow metric areas, reconnection projects are likely to produce less frequent but deeper inundation of the floodplain in a manner that is less supportive of habitat enhancement.
- **Issue: Channel incision.** Creek flow metric values should closely correlate with the risk of channel incision. For example, Fauntleroy Creek runs through a steeply sloped, densely wooded ravine with park trails that provide access to the community. Large sections of the channel are incised, which is consistent with the high creek flow metric values computed for the watershed. In addition to reducing functional habitat, incised channels can be hazardous to adults and children who cross the creek while hiking in the park. Channel incision can also be harmful to culverts by eroding material at the pipe outlet, which can lead to pipe damage (e.g., unsupported and failing pipe suspended above creek channel) and potentially undermine the adjacent roadway prism. Culverts with incised channels at their

outlet can also present barriers to fish migration. The creek flow metric mapping results can function as a high-level screening tool to identify areas with significant channel incision.

- **Issue: Prioritizing areas for storm drainage retrofits.** Instead of targeting the highest creek flow metric locations for upstream retrofits, SPU staff should consider the creek location, habitat potential, and flood consequences when planning retrofit projects. The highest creek flow metric values generally occur in the upper watershed areas. These flow pulses can generate incision and contribute excess sediment to downstream areas. However, in some cases the high creek flow metric values may reflect the very low flows from a small area for pasture conditions (i.e., small denominator creating large creek flow metric value) and not necessarily predict instability in the current stream channel. High values in Appendix D should be evaluated on-site, and if problematic, addressed through upstream flow control measures, such as distributed GSI. Otherwise, areas with lower creek flow metric values in areas with greater sensitivity or potential benefits should be prioritized.

As SPU develops *Shape Our Water* , the creek flow metric results should be combined with other geomorphic and ecological tools to understand the causes of existing problems and to develop strategies to meet SPU's goals for creek function and community benefits. Each of the five watersheds has its own combination of factors that lead to flooding, degraded habitat, water quality concerns, and other issues. SPU should consider the role that flashy flows play in contributing to these issues and their solutions.

5. Limitations

The results presented in this TM should help SPU identify areas that experience flashy flows. When applying these results, SPU staff should consider the following limitations:

- The pasture conditions models were developed to approximate the hydrographs produced by MGS Flood and WWHM models, which use HSPF to compute watershed hydrology. Because the pasture parameters were not developed by calibration to actual flow monitoring data, SPU should focus on the relative creek flow metric values across and within watersheds and not the absolute values. If possible, SPU could compare the pasture modeling results to a reference watershed in Western Washington that has little development and pasture land cover. However, a gauged watershed with these characteristics may not exist in the area.
- The models are limited by the quality of the calibration. The models will be less representative of the basin's impervious rainfall-runoff response and peak flow rates for reporting locations that are far upstream of monitoring locations or not tributary to monitoring locations. The Shoreline portion of the Thornton Creek watershed is an example of a model area that could be limited by distance to calibration data. Additionally, available calibration storms may have been smaller than the 2-year flow, which could limit the models' ability to estimate flows during larger storms.
- The existing and pasture conditions models use the existing channel cross-sections. Many of these channels have been straightened, armored, and otherwise constrained in a manner that reduces the creek-floodplain connection. The pasture conditions models may be overestimating the 2-year flow rate, because with natural, unaltered channel cross-sections this flow rate would be more likely to produce overbank flow and associated floodplain storage and attenuation. The creek flow metrics could therefore be underestimated. However, the effect of this limitation should be minor because SPU staff should consider the relative creek flow metric values (e.g., low, medium, high, very high) more than the absolute values.
- The SWMM model stream network does not precisely line up with the urban watercourses GIS dataset. This could be an issue if SPU staff wanted to represent the modeling results by rendering the urban watercourses data. In most cases, this should be a minor limitation because the model conduits are generally close enough that creek flow metric results could be visually assigned to a specific creek reach. Additionally, the limited comparison of the urban watercourses data and LiDAR topography data in this analysis indicated the watercourses themselves do not always line up with the LiDAR data.

6. References

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Appendix A: Estimating Wintertime Base Flows

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Appendix A

Estimating Wintertime Base Flows

This modeling analysis initially focused on the 2-year peak flow to winter base flow ratio to evaluate flashiness, but early modeling results showed problems that affected the viability of this approach:

1. Without predevelopment monitoring data, there was no definitive method for estimating winter base flows for undeveloped, pasture conditions models. (Note: for this analysis, the winter or wet season was defined as the period from the beginning of October to the end of April.)
2. Uncertainty in wet season base flow estimates created an exaggerated effect on the flashiness flow metric calculation, which is particularly problematic in upper watershed locations where small base flows and the correspondingly small denominator in the flashiness metric calculation overwhelms the influence of higher peak flows.

Base flows for Existing Conditions

Winter base flows for *existing conditions* were computed from monitoring data by visually inspecting October through April hydrographs (across multiple wet seasons) and estimating average inter-storm low flows for periods with five days or more between storm events. The results are provided in Table A.1. A discrepancy was observed. The Fauntleroy Creek and Taylor Creek watersheds have similar total winter base flow values even though the Taylor Creek watershed is more than four times larger. The difference in impervious areas and fraction of till and outwash soil could explain some of the discrepancy, but there could also be subsurface complexities that cause more of the Fauntleroy Creek watershed recharge to reach the creek than in the Taylor Creek watershed. Both watersheds have relatively flat upland areas with creeks that run through steep ravines, so topography is not the underlying cause.

Table A-1. Monitored Winter Base Flows[a, b]

Watershed	Monitor Name	Model Conduit	Tributary Area (ac)	Directly Connected Impervious	Till Fraction	Outwash Fraction	Base Flow	
							(cfs)	(cfs/ac)
Fauntleroy	FCB_008_X1	FCMain013	**137.3**	9.2%	91 ac (66%)	46 ac (34%)	**0.80**	**0.0058**
Longfellow	STA098A	LF-029_LF-030	1,389	20.2%	984 ac (71%)	405 ac (29%)	1.20	0.0009
Taylor	STA401	CJ386.66	**638**	19.9%	482 ac (75%)	156 ac (25%)	**0.80**	**0.0013**
Piper's	STA508	PC-005_PC-004	1,276	16.0%	1,179 ac (92%)	97 ac (8%)	1.40	0.0011
Thornton	TC_MBN031_X1	CJ5789	6,201	14.4%	4,776 ac (77%)	1,426 ac (23%)	21.50	0.0035

a. Winter base flows were computed by examining dry periods between storm events between October and April (5-day minimum between storms) and estimating average base flow values. Multiple wet seasons were examined for each monitoring location.

b. The tributary areas and soil fractions refer to the portion of each watershed that contribute flow to the monitoring location.

Base flows for Pasture Conditions

Even though the variation of existing conditions base flows suggests the pasture conditions models would need watershed-specific approaches to modeling groundwater inflow to the creeks, base flows for pasture conditions were estimated from long term simulations. Monthly minimum flows were computed for the wet season (October through April) for the entire simulation period, and then these monthly minimums were averaged. Computing monthly minimums allowed for automatic identification of dry periods and averaging of inter-storm periods throughout the wet season. Table A-2 show shows the results with the existing conditions.

Table A-2. Summary of Estimated Winter Base Flows

Watershed	Tributary Area (ac)	Directly Connected Impervious	Till Fraction	Outwash Fraction	Existing Conditions Monitored Base Flow		Existing Conditions Modeled Base Flow		Pasture Conditions Base Flow	
					(cfs)	(cfs/ac)	(cfs)	(cfs/ac)	(cfs)	(cfs/ac)
Fauntleroy	**137.3**	9.2%	66%	34%	**0.80**	**0.0058**	**0.80**	**0.0058**	**0.12**	**0.0009**
Longfellow	1,389	20.2%	71%	29%	1.20	0.0009	1.20	0.0009	1.13	0.0008
Taylor	**638**	19.9%	75%	25%	**0.80**	**0.0013**	**0.50**	**0.0008**	**0.5**	**0.0008**
Piper's	1,276	16.0%	92%	8%	1.40	0.0011	0.71	0.0006	1.16	0.0009
Thornton	6,201	14.4%	77%	23%	21.50	0.0035	17.50	0.0028	13.5	0.0022

Impact of Base Flow Uncertainty on Creek Flow Metric Calculation

Base flow uncertainty is problematic when computing a metric that is a ratio, where one part of the ratio is base flow. Base flows are small compared to 2-year flows, and uncertainty in the small denominator term magnifies the uncertainty in the computed flashiness flow metric.

The initial modeling analysis produced the following observations when flow flashiness was computed as (Q2 existing/Q base existing) / (Q2 pasture/Q base pasture):

1. The flashiness values varied widely within each watershed and the averages varied substantially between the watersheds. For example, the Fauntleroy values varied from 0.2 in the lower watershed to infinitely large in the upper watershed areas without continuous wet season flow; Taylor varied from 5.5 to 126; and Thornton varied from 0.2 to 8.0.
2. There was no clear relationship between watershed position or development level and the magnitude of the flashiness flow metric when base flows were included in the calculation. The magnitude of the variation in flashiness was so large that it obscured any trends that would allow SPU staff plan drainage retrofits or creek restoration projects.

In summary, after reviewing the initial modeling results, the DSA Team decided the existing conditions and pasture conditions models were suitable for estimating 2-year flow rates throughout each watershed but not base flows. Therefore, the team decided to compute a flow metric as the ratio of existing to pasture 2-year flows (Q2 existing / Q2 pasture).

Appendix B: Pasture Model Soil Maps

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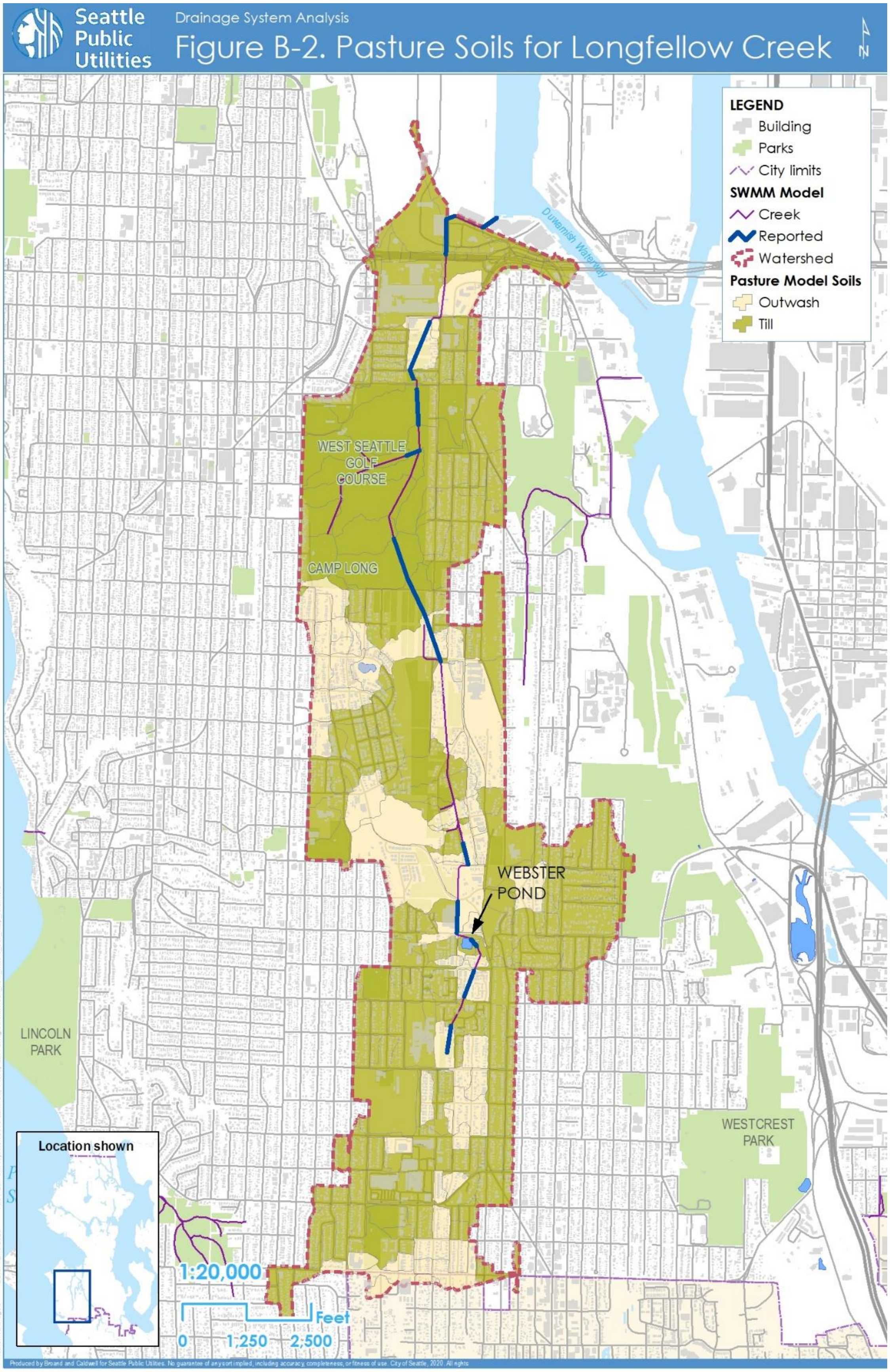
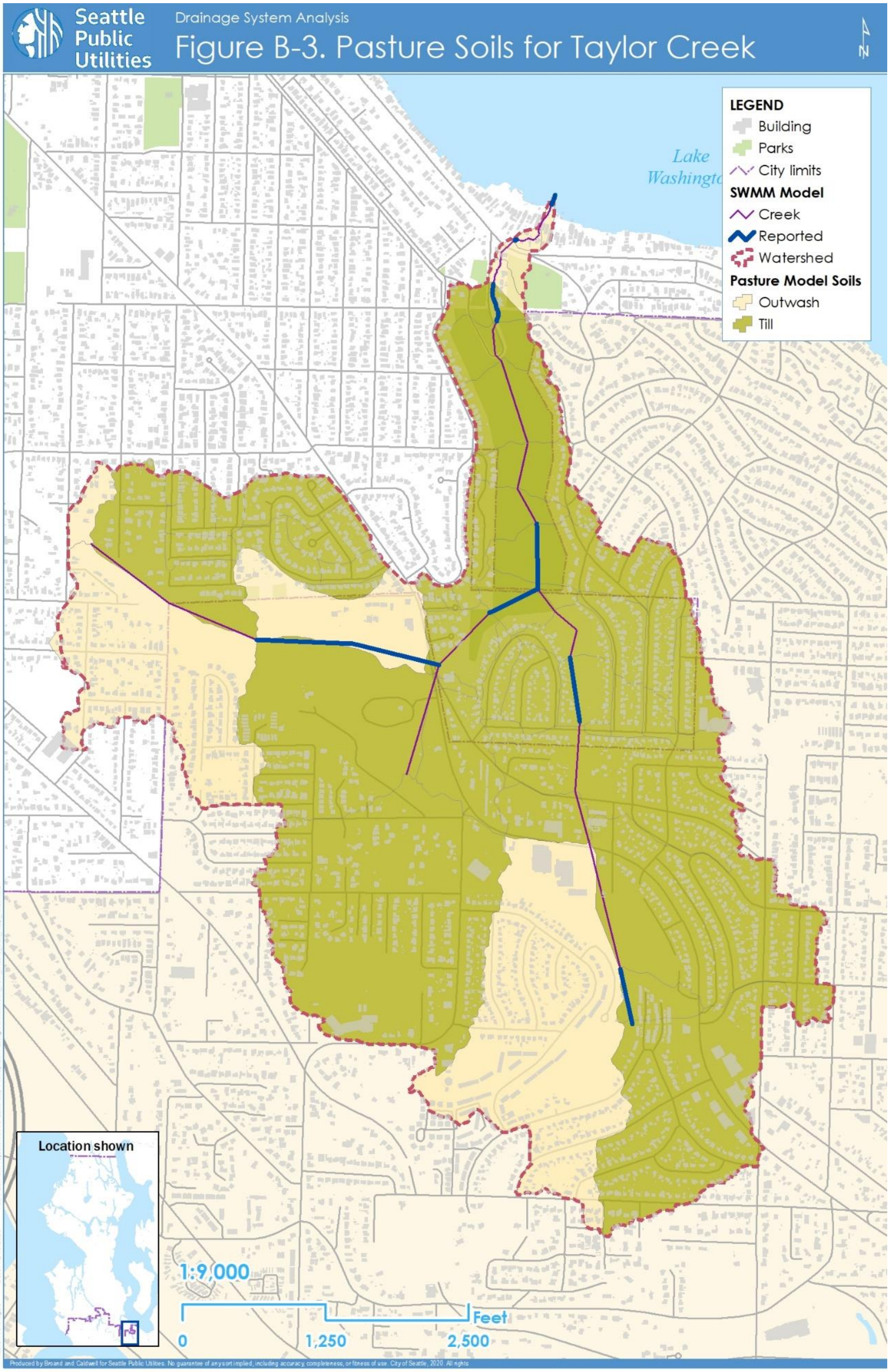
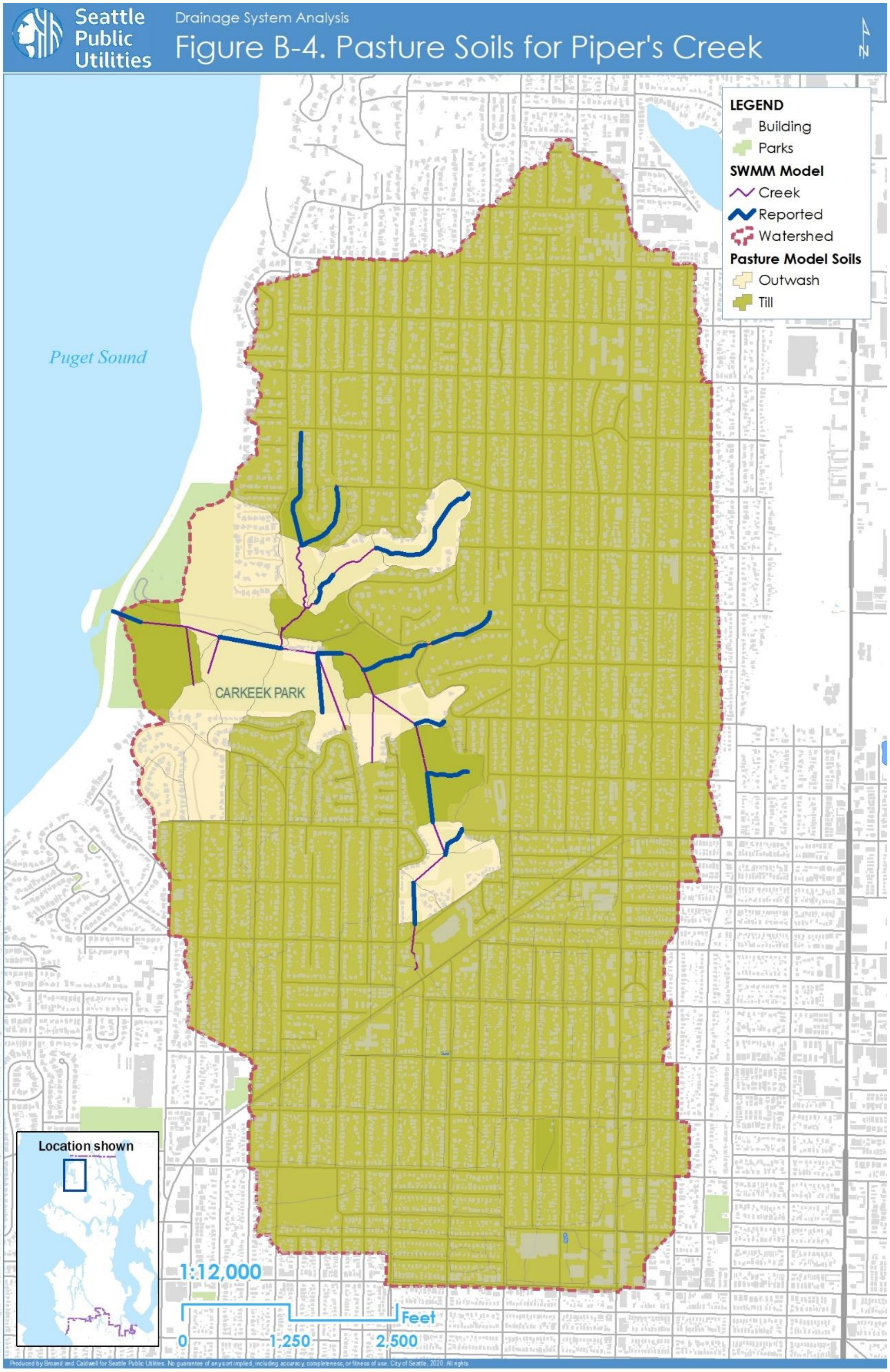
Appendix B
Pasture Model Soil Maps

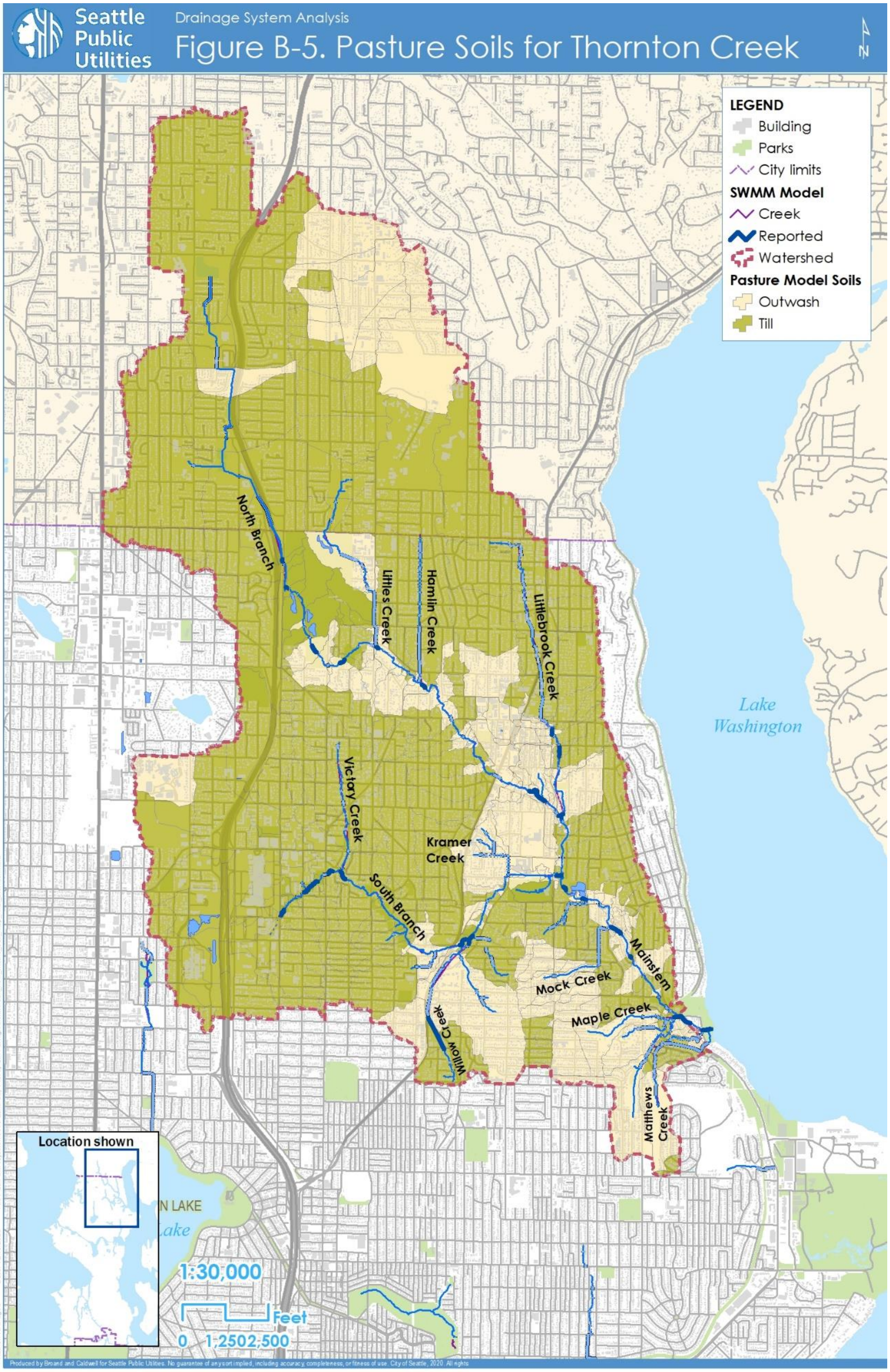
This section contains soil distribution used to assign till or outwash characteristics to the pasture models (see discussion in Section 3.2.2).


Seattle Public Utilities
Drainage System Analysis
Figure B-1. Pasture Soils for Fauntleroy Creek
N
LEGEND
Building
Parks
SWMM Model
Creek
Reported
Watershed
Pasture Model Soils
Outwash
Till
LINCOLN PARK
Puget Sound
FAUNTLEROY PARK
Location shown
1:6,000
0
1,250
2,500
Feet


Seattle Public Utilities
Drainage System Analysis
Figure B-2. Pasture Soils for Longfellow Creek
N
LEGEND
Building
Parks
City limits
SWMM Model
Creek
Reported
Watershed
Pasture Model Soils
Outwash
Till
Duwamish Waterway
WEST SEATTLE GOLF COURSE
CAMP LONG
WEBSTER POND
LINCOLN PARK
WESTCREST PARK
Location shown
1:20,000
Feet
0
1,250
2,500


Seattle Public Utilities
Drainage System Analysis
Figure B-3. Pasture Soils for Taylor Creek
N
Lake Washington
LEGEND
Building
Parks
City limits
SWMM Model
Creek
Reported
Watershed
Pasture Model Soils
Outwash
Till
Location shown
1:9,000
0
1,250
2,500
Feet


Seattle Public Utilities
Drainage System Analysis
Figure B-4. Pasture Soils for Piper's Creek
N
LEGEND
Building
Parks
SWMM Model
Creek
Reported
Watershed
Pasture Model Soils
Outwash
Till
Puget Sound
CARKEEK PARK
Location shown
1:12,000
0
1,250
2,500
Feet


Seattle Public Utilities
Drainage System Analysis
Figure B-5. Pasture Soils for Thornton Creek
LEGEND
Building
Parks
City limits
SWMM Model
Creek
Reported
Watershed
Pasture Model Soils
Outwash
Till
North Branch
Littles Creek
Hamlin Creek
Littlebrook Creek
Lake Washington
Victory Creek
Kramer Creek
South Branch
Mainstem
Mock Creek
Maple Creek
Willow Creek
Matthews Creek
Location shown
1:30,000
Feet
0 1,250 2,500

Appendix C: Flow Metric Calculation Locations

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Appendix C
Flow Metric Calculation Locations

This appendix contains screen captures from the SWMM existing conditions models that show locations (model conduits) where existing conditions and pasture conditions modeled flows were exported to produce the creek flow metric calculations. The locations were selected collaboratively with SPU staff to examine effects of urbanization on different parts of each watershed, such as headwaters, downstream of stormwater outfalls, at tributary confluences, and in lower basin locations. The labels in each figure correspond to the model conduit names reported in each simulation.

Figure C-1. Flow reporting and creek flow metric calculation locations for Fauntleroy Creek watershed

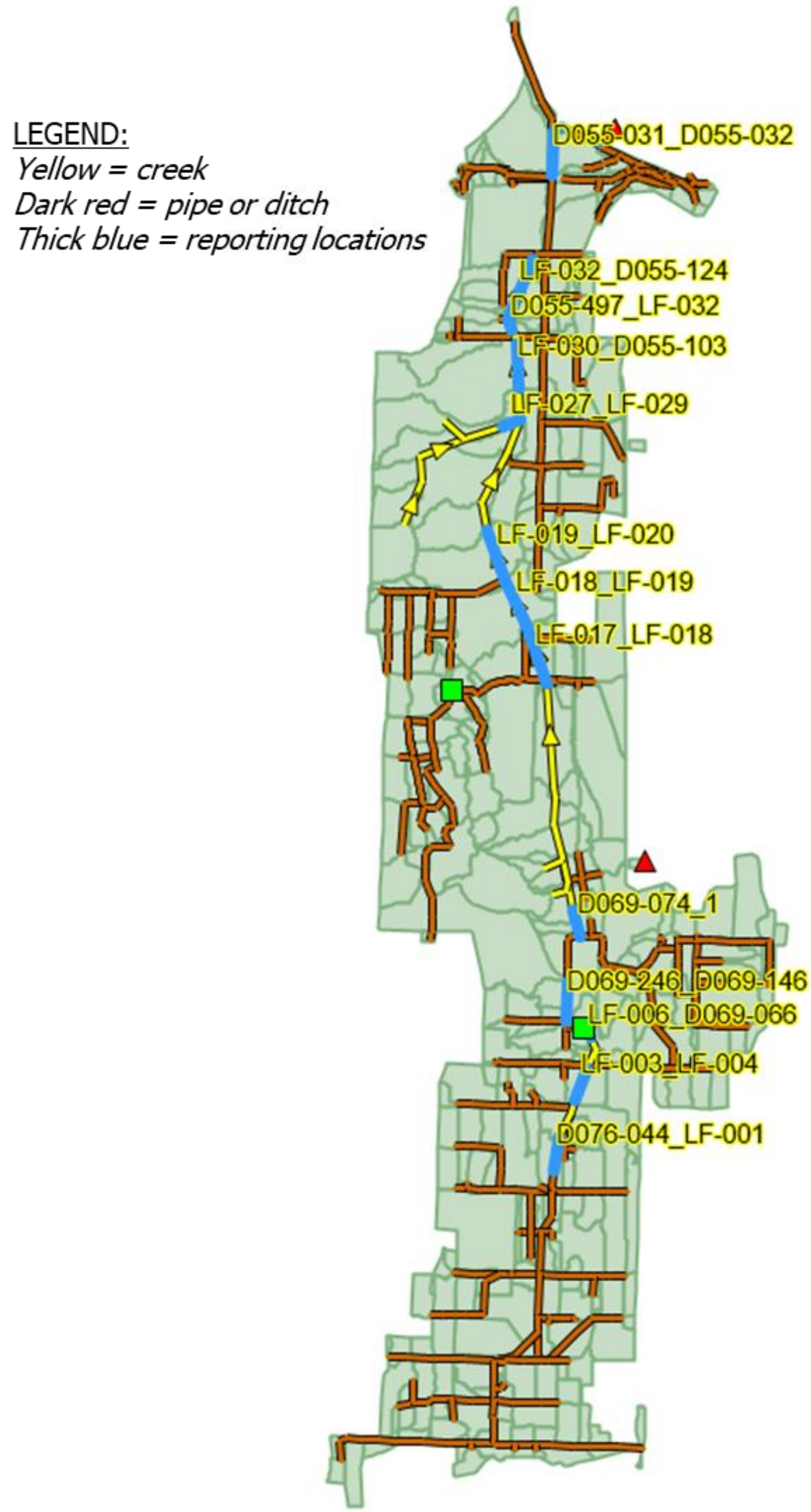

Figure C-2. Flow reporting and creek flow metric calculation locations for Longfellow Creek watershed

Figure C-3. Flow reporting and creek flow metric calculation locations for Taylor Creek watershed

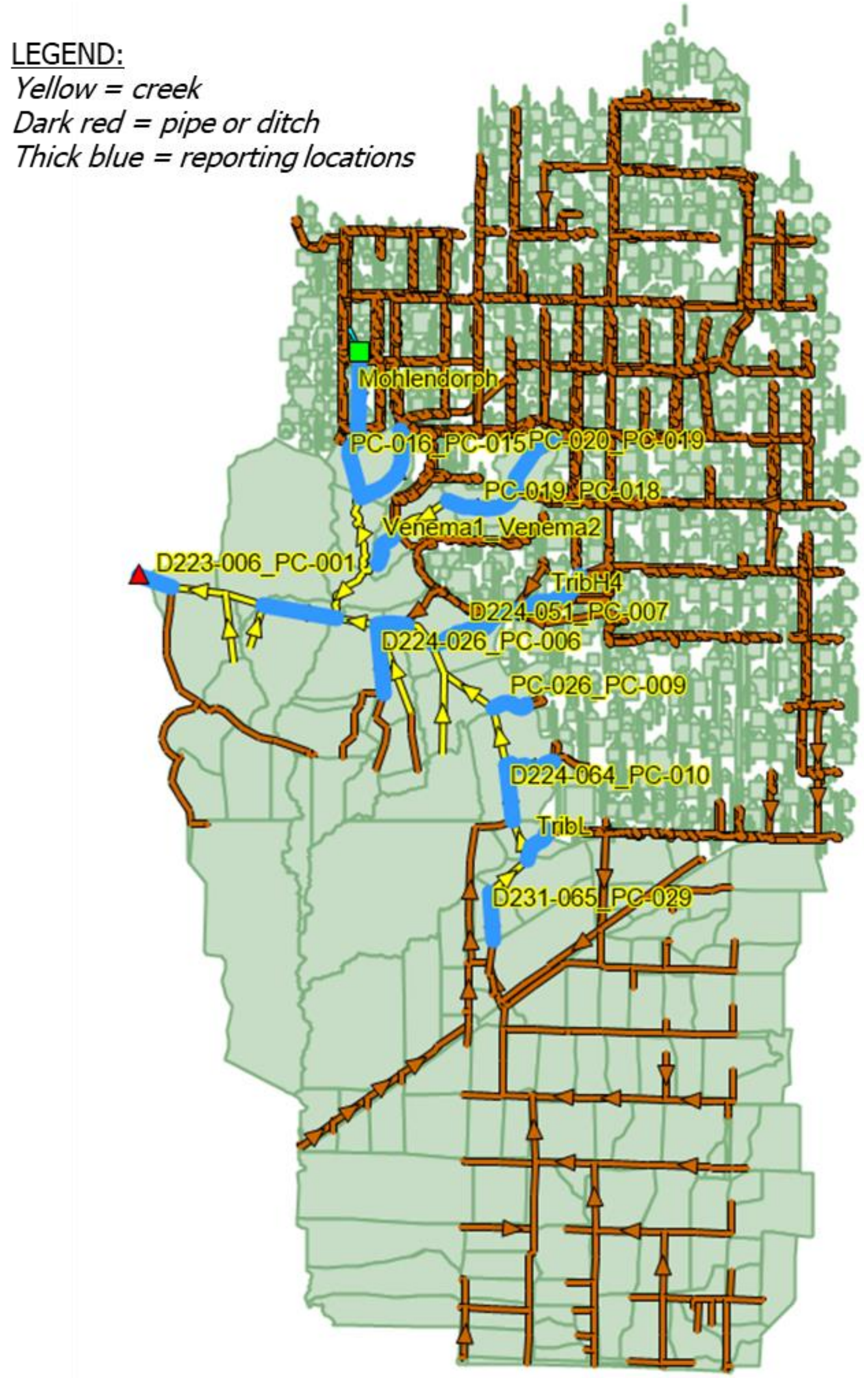

Figure C-4. Flow reporting and creek flow metric calculation locations for Piper's Creek watershed

Figure C-5. Flow reporting and creek flow metric calculation locations for Thornton Creek watershed

Appendix D: Creek Flow Metric Results for All Reported Creek Locations

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Appendix D

Creek Flow Metric Results for All Reported Creek Locations

This appendix contains the computed creek flow metric values for the 84 locations across the five watersheds. Please see the table footnotes for important details.

Table D-1. Creek Flow Metric Results for Fauntleroy Creek Watershed

Model Location	Tributary Area (ac)	Impervious Area (ac)	Connected Imp. Area (ac)[a]	Pasture Q2 (cfs)	Existing Q2 (cfs)	Creek Flow Metric
FC_Main002	144.32	38.81	13.21	2.03	8.73	4.29
FC_TribA002	11.33	4.34	1.31	0.34	1.09	3.21
FC_TribB008	21.47	7.98	2.44	0.33	2.23	6.75
FC_TribB010	1.39	0.51	0.16	0.14	0.19	1.35
FC_TribC002	46.20	13.54	4.37	0.78	4.49	5.79
FC_TribC008	0.24	0.08	0.02	0.005	0.12	23.41
FC_TribD003	36.64	11.87	3.84	0.58	4.25	7.32
FC_TribG100	10.57	3.98	1.28	0.24	1.21	5.06
FC_TribG102	1.45	0.16	0.06	0.04	0.06	1.53
FCMain005	134.42	36.79	11.70	1.99	8.34	4.19
FCMain016	104.80	28.72	9.18	1.54	7.31	4.74
FCMain020	77.78	19.98	6.54	1.10	5.58	5.08

a. The directly connected impervious area was inferred from the "% Routed" field in the SWMM model subcatchment table.

Table D-2. Creek Flow Metric Results for Longfellow Creek Watershed

Model Location[a]	Tributary Area (ac)[b]	Impervious Area (ac)	Connected Imp. Area (ac)[c]	Pasture Q2 (cfs)	Existing Q2 (cfs)	Creek Flow Metric
D055-031_D055-032	2381.4	383.9	307.34	45.41	144.75	3.19
D055-033_D055-036	2387.0	388.4	311.80	163.50	318.9	1.95
D055-458_D055-531	2429.9	422.6	346.02	222.75	199.75	0.90
D055-497_LF-032	2169.85	316.83	240.75	26.31	79.675	3.03
D069-074_1	760.84	223.12	154.14	14.91	46.445	3.12
D069-246_D069-146	521.70	174.49	128.08	10.45	36.24	3.47
D076-044_LF-001	375.02	142.41	104.53	7.32	38.195	5.22
LF-003_LF-004	439.35	154.97	113.74	8.73	40.965	4.69
LF-006_D069-066	490.77	168.48	123.66	9.82	44.45	4.52
LF-017_LF-018	1505.88	232.24	162.00	16.15	51.94	3.22
LF-018_LF-019	1760.55	267.74	194.55	19.89	60.86	3.06
LF-019_LF-020	1837.85	277.90	203.86	20.59	65.525	3.18
LF-027_LF-029	58.80	0.90	0.82	1.31	3.0785	2.36
LF-030_D055-103	2046.78	287.86	212.99	24.98	76.405	3.06
LF-032_D055-124	2179.02	318.37	242.28	26.50	79.735	3.01

a. *Conveyance locations D055-031_D055-032, D055-033_D055-036, and D055-458_D055-531 are tidally influenced. The model results showed reverse flows when tide levels are increasing and large downstream flows when the tides recede. These results were excluded from the summary basin calculations, because the flows are not reflective of watershed hydrology.*

b. *The model contains two large subcatchments totaling 712 acres that were added (previous to this work) to help represent groundwater responses. The tributary area in this table includes these groundwater subcatchments, and therefore the total tributary area above can exceed the Longfellow Creek watershed area.*

c. *The directly connected impervious area was inferred from the "% Routed" field in the SWMM model subcatchment table.*

Table D-3. Creek Flow Metric Results for Taylor Creek Watershed

Model Location	Tributary Area (ac)	Impervious Area (ac)	Connected Imp. Area (ac)[a]	Pasture Q2 (cfs)	Existing Q2 (cfs)	Creek Flow Metric
CJ1317.1_2	640.27	131.37	127.18	11.60	48.30	4.17
CJ334.02	631.10	129.97	125.83	11.48	48.85	4.26
CJ807.08	638.63	131.10	126.92	11.59	49.54	4.28
D316-011_D316-013	175.45	30.61	29.54	2.74	20.22	7.38
D317-011_TC-005	235.74	59.00	57.27	3.92	39.01	9.95
TC-001_TC-002	49.49	14.90	14.52	1.12	8.92	7.98
TC-007_TC-013	576.89	123.62	119.73	10.32	53.31	5.17
TC-009_D316-011	85.32	18.72	18.10	1.02	12.34	12.12
TC-011_TC-007	294.03	53.27	51.45	5.40	29.54	5.47

a. *The directly connected impervious area was inferred from the "% Routed" field in the SWMM model subcatchment table.*

Table D-4. Creek Flow Metric Results for Piper's Creek Watershed

Model Location	Tributary Area (ac)	Impervious Area (ac)	Connected Imp. Area (ac)[a]	Pasture Q2 (cfs)	Existing Q2 (cfs)	Creek Flow Metric
D223-006_PC-001	1450.38	345.30	232.35	28.63	87.645	3.06
D224-026_PC-006	12.93	3.23	3.23	0.30	2.6135	8.69
D224-051_PC-007	112.91	38.64	16.58	1.15	9.538	8.32
D224-064_PC-010	644.48	134.75	121.23	14.32	75.775	5.29
D231-065_PC-029	19.88	6.98	6.98	0.69	4.3645	6.29
Mohlendorph	35.79	13.62	6.87	0.76	5.2865	6.97
PC-005_PC-004	1276.06	322.95	210.00	26.22	82.615	3.15
PC-016_PC-015	172.76	61.29	27.99	3.73	15.03	4.03
PC-017_PC-015	51.22	17.46	7.37	0.61	5.045	8.27
PC-019_PC-018	73.58	27.31	12.38	1.24	7.577	6.11
PC-020_PC-019	65.87	25.03	11.32	1.09	7.539	6.95
PC-026_PC-009	24.16	9.21	0.40	0.50	3.262	6.54
PC-027_PC-010	30.47	9.99	0.92	0.64	1.794	2.81
Pipers1_PC-006	889.12	207.22	151.82	18.93	69.685	3.68
TribH4	65.32	24.46	10.50	1.35	6.793	5.04
TribL	60.75	22.24	8.72	1.25	9.905	7.90
Venema1_Venema2	110.34	36.71	17.23	2.06	8.138	3.96

a. The directly connected impervious area was inferred from the outlet routing in SWMM model subcatchment table. Subcatchments that discharge to model conduits are considered directly connected; subcatchments that discharge to other subcatchments are not. Please note, the Piper's model was constructed with a different methodology than the other SWMM models.

Table D-5. Creek Flow Metric Results for Thornton Creek Watershed						
Model Location	**Tributary Area (ac)[a]**	**Impervious Area (ac)**	**Connected Impervious Area (ac)[b]**	**Pasture Q2 (cfs)**	**Existing Q2 (cfs)**	**Creek Flow Metric**
CJ10671_1	3143.85	1094.33	336.72	53.8	100.2	1.86
CJ10671_2	3356.21	1200.94	352.14	56.7	109.8	1.93
CJ1090	7754.96	2576.90	954.41	161.8	245.7	1.52
CJ10999	886.81	478.86	228.13	18.0	105.4	5.86
CJ116	1782.94	830.36	333.67	35.9	122.6	3.42
CJ12074	680.88	359.45	166.15	13.6	75.8	5.58
CJ16354_2	2846.48	952.89	275.33	48.8	82.8	1.69
CJ18131	2305.60	775.79	208.55	40.9	47.6	1.16
CJ19574	1613.10	547.69	85.79	31.7	20.6	0.65
CJ20784	1502.66	497.69	76.60	30.2	17.9	0.59
CJ22902	1416.03	489.23	75.88	28.5	28.0	0.98
CJ23821	1225.38	409.85	66.16	24.9	22.6	0.91
CJ297	7904.98	2629.19	977.05	108.7	253.1	2.33
CJ3561	7668.93	2541.07	935.51	106.8	221.7	2.08
CJ3992_1	1409.13	699.43	290.38	29.7	98.0	3.30
CJ3992_2	1659.06	784.94	316.03	33.0	111.6	3.39
CJ4297	1409.13	699.43	290.38	29.7	98.0	3.30
CJ4525	7606.45	2514.01	920.60	105.9	205.8	1.94
CJ6208	7473.99	2457.73	890.92	104.3	178.5	1.71
CJ7011	6025.97	2438.91	886.59	104.2	271.6	2.61
CJ7381	3982.88	1494.20	509.04	68.5	335.0	4.89
CJ9360	3913.84	1466.50	497.06	67.2	153.7	2.29
CJ951	7897.93	2625.77	974.49	108.7	252.8	2.33
CJ9563	1143.05	616.83	281.70	23.4	129.3	5.54
CJ9921	970.79	528.27	245.46	19.7	112.2	5.68
LB-P050_LB-P051	315.81	164.97	103.86	6.3	31.9	5.03
LB-P052_LB-P053	446.03	224.47	130.48	9.0	40.3	4.45
NB-N106_NB-N105	497.56	245.22	139.29	9.8	45.1	4.59
SB-P062_SB-P063	29.49	12.18	3.65	0.9	3.6	4.17

a. The model contains one 1,400-acre subcatchment that was added (previous to this work) to help represent groundwater responses in the lower watershed. The tributary area in this table includes this groundwater subcatchment, and therefore the total tributary area above can exceed the Thornton Creek watershed area.

b. The directly connected impervious area was inferred from the "% Routed" field in the SWMM model subcatchment table.

Appendix E: DSA and *State of the Waters* Flow Metric Comparison

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Appendix E
DSA and *State of the Waters* Flow Metric Comparison

Figure 35 of the *State of the Waters* report showed creek flow metric values for the five largest watersheds. The 2007 report indicates existing stream flow data, as well as hydrologic modeling, was used to estimate the flow differences between forested condition and current conditions. While the exact methodology from State of the Waters is not known (preventing a more detailed comparison of results), Figure E-1 shows that the results of this analysis and State of the Waters are generally consistent.

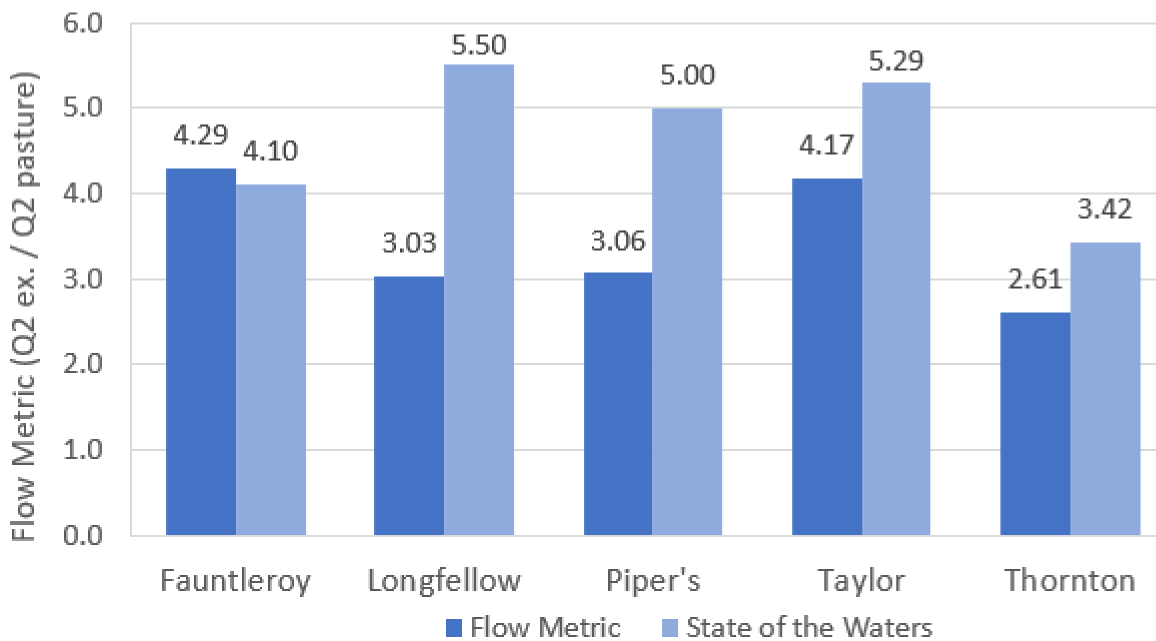

Figure E-1. Comparison with *State of the Waters* creek flow metric values

On average, the flow metric values produced in this analysis are 26 percent lower than those produced for State of the Waters. One key difference is that the State of the Waters report used forest land cover as the undeveloped condition whereas this analysis uses pasture land cover. In MGS Flood and WWHM, the 2-year flow is about 25 percent larger for pasture land cover over till soils than for forested conditions. The difference in the "denominator" portion of the creek flow metric calculation suggests the results produced by this study would be 20 percent lower than the State of the Waters results based on the land cover difference alone.

Looking at specific watersheds, the Longfellow and Piper's Creek flow metrics produced by this analysis are lower than the State of the Waters report. The difference could be attributable to the inclusion of detailed flow hydraulics in this analysis (e.g., this analysis incorporates the Webster Pond in Longfellow Creek and potential for flooding and floodplain attenuation in Piper's Creek). The Fauntleroy Creek flow metric produced by this analysis is larger than the value included in State of the Waters. Reasons for this difference are more difficult to ascertain. However, one possibility stands out. More flow monitoring data is available now than during the preparation of the State of the Waters report and could reflect a different level of understanding of the watershed's hydrology. Fauntleroy Creek's base flow is large enough that its influence is apparent even during a two-year flow event. If Fauntleroy Creek had a wet season base flow more in line with the other creek watersheds, the existing conditions Q2 value would be lower and the corresponding creek flow metric value would also be lower.

Appendix F: Creek Flow Metric Maps

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Appendix F

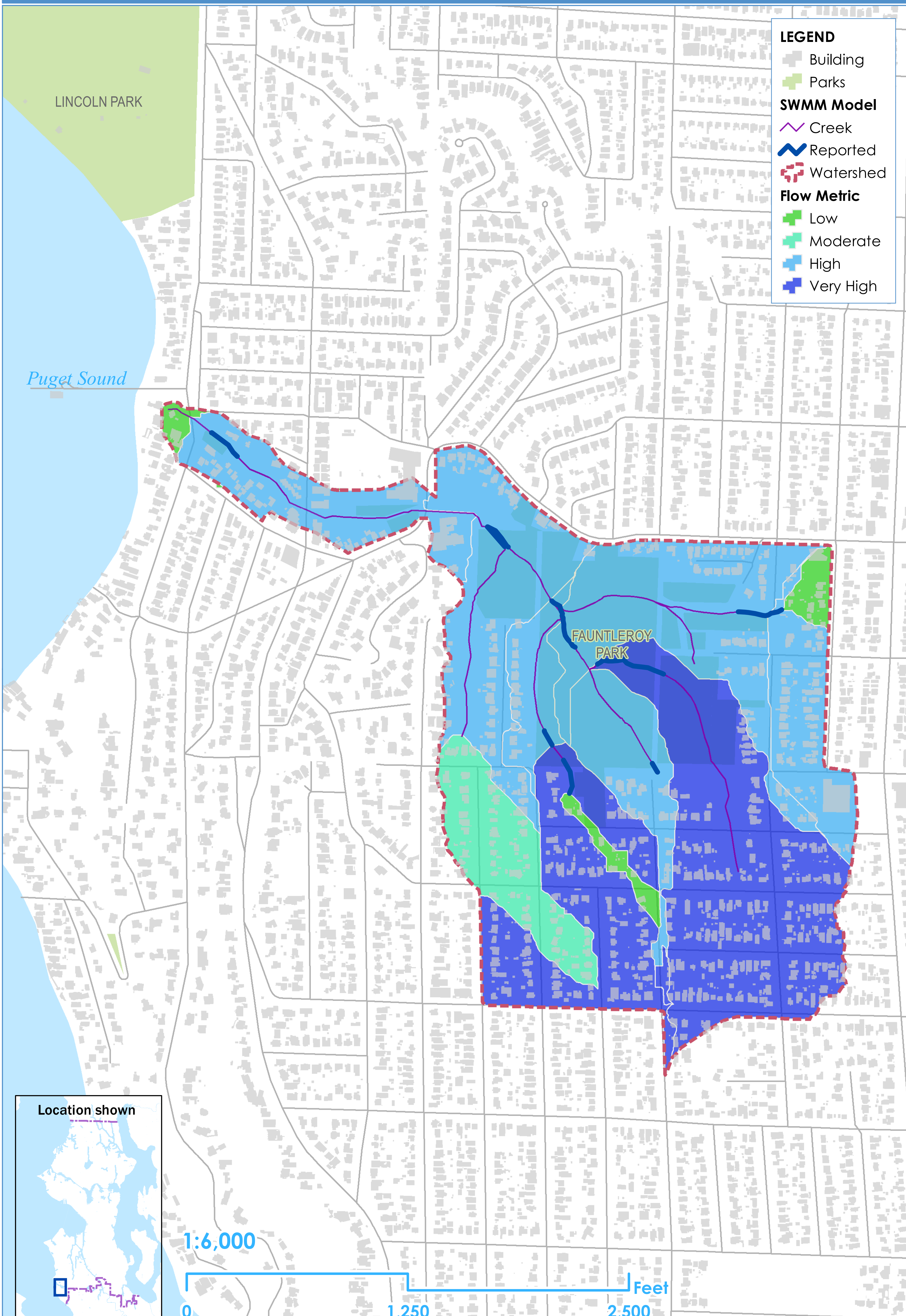
Creek Flow Metric Maps

This section contains creek flow metric maps for each watershed (see discussion in Section 4.1).

Seattle Public Utilities

Drainage System Analysis

Figure F-1. Flow Metrics for Fauntleroy Creek

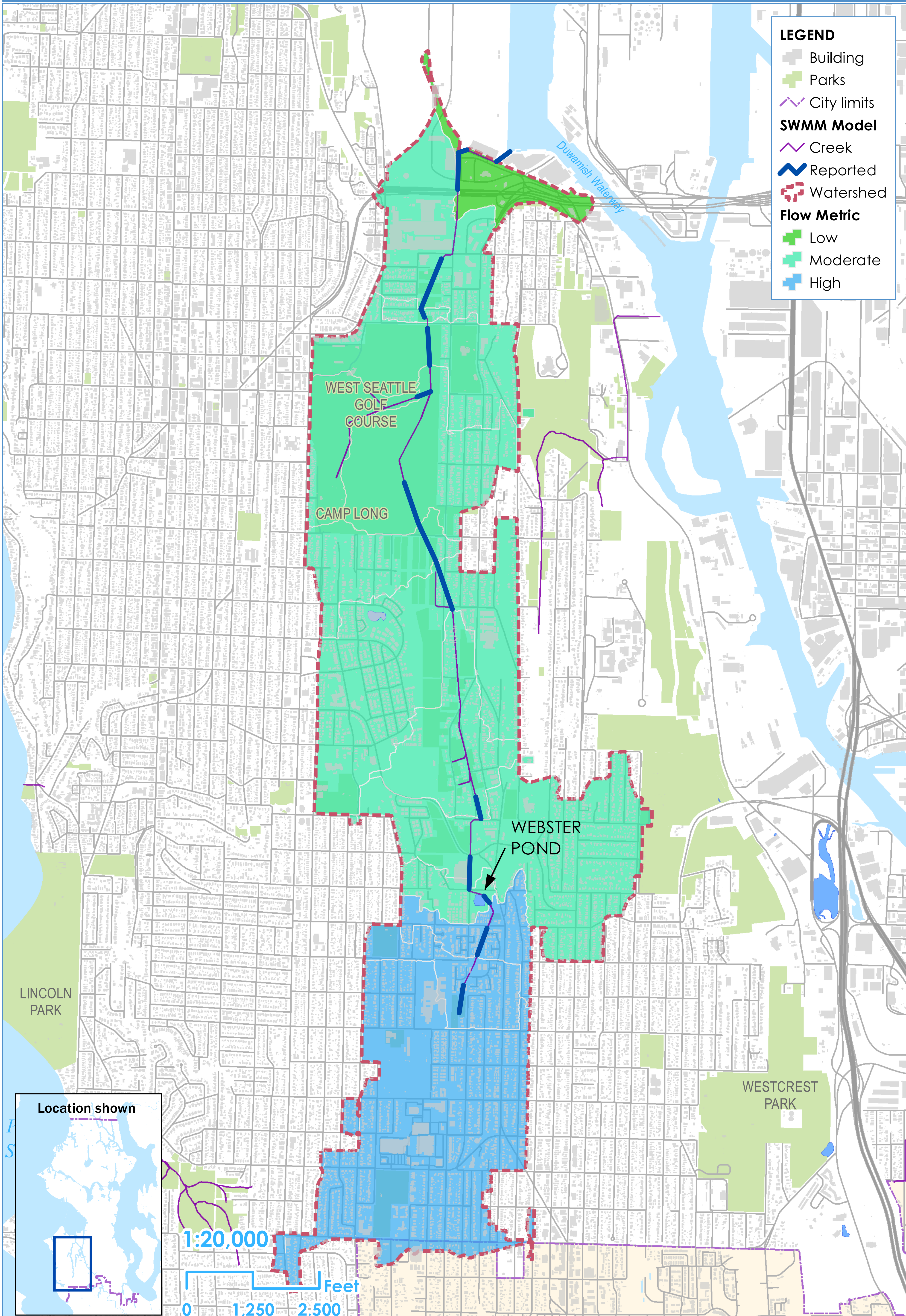


Author: NHFoged Date: 12/18/2020 File Path: C:\Projects\10056 Lake City Floodplain Park\gis\mxd\creek_flow_metric_results_final.mxd

Seattle Public Utilities

Drainage System Analysis

Figure F-2. Flow Metrics for Longfellow Creek



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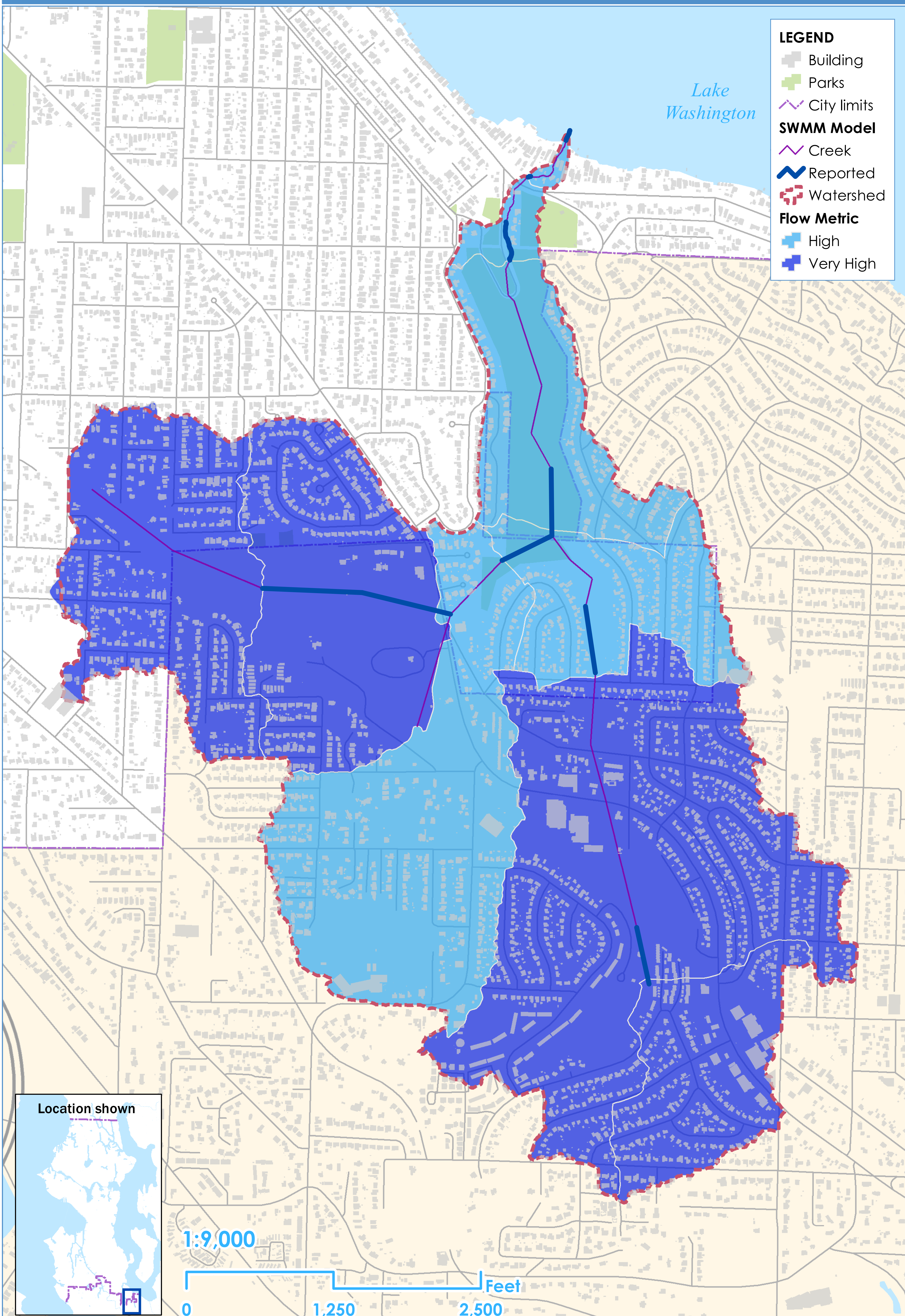
Seattle Public Utilities

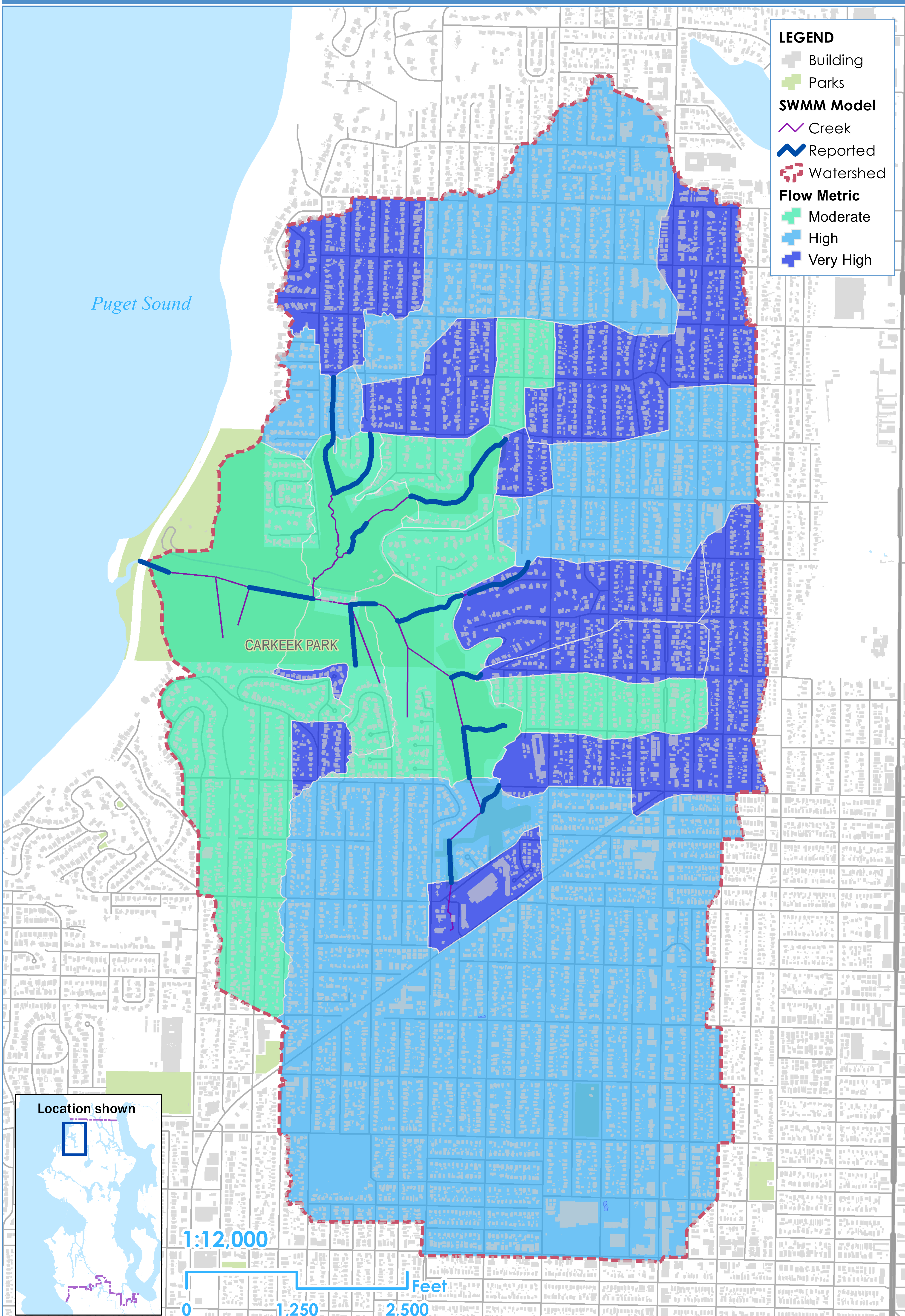
Drainage System Analysis

Figure F-3. Flow Metrics for Taylor Creek



Drainage System Analysis

Figure F-4. Flow Metrics for Piper's Creek



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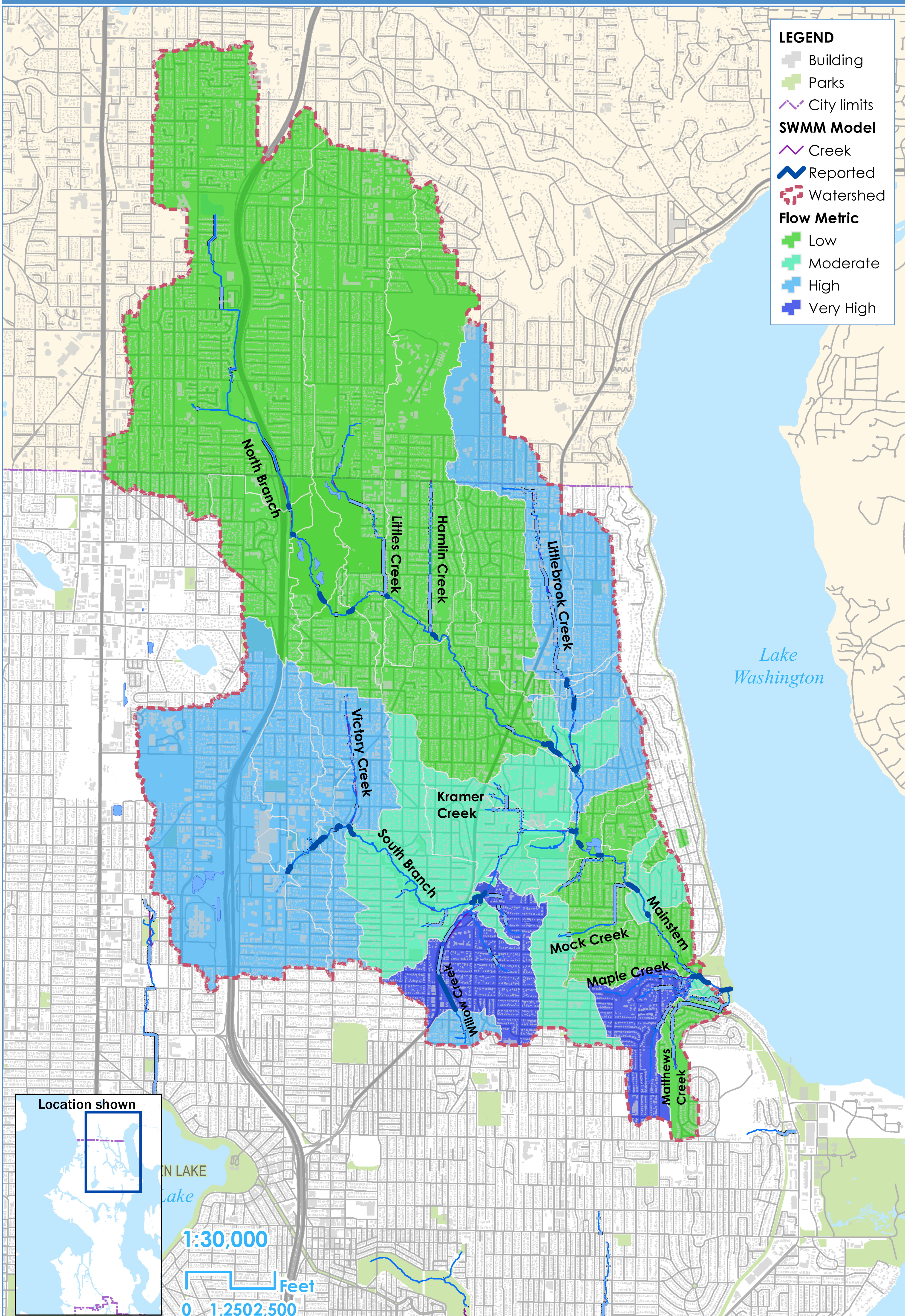
Drainage System Analysis

Figure F-5. Flow Metrics for Thornton Creek



Author: NHFoged Date: 12/18/2020 File Path: C:\Projects\10056 Lake City Floodplain Park\gis\mxd\creek_flow_metric_results_final_thornton.mxd