Downtown Basin Stormwater Plan
For
City of Port Orchard

Owner:
Port Orchard
Public Works Department
216 Prospect Street
Port Orchard, Washington 98366

December 16, 2022

Reid Middleton

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The engineering material and data contained in this report were prepared under the supervision and direction of the undersigned, whose seal as a registered professional engineer is affixed below.

12/16/2022

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EXECUTIVE SUMMARY

Introduction

The City of Port Orchard received a water quality grant from the Department of Ecology to develop a stormwater plan for their downtown drainage basin. This plan will provide a roadmap for implementing water quality treatment for total suspended solids (TSS), modernizing stormwater infrastructure, and reducing flooding within the downtown basin. The study basin area has untreated stormwater discharging to the adjacent Sinclair Inlet through several outfall pipes. The existing conveyance system is showing signs of deterioration, and the commercial district is subject to flooding during high tidal events that coincide with significant storm events.

This stormwater basin study is an evaluation of the stormwater management system, including conveyance and stormwater quantity and quality assessments. The study included hydrologic and hydraulic modeling, evaluation of the existing storm system, and water quality analysis. The study also included conceptual mitigation improvements to address vulnerabilities identified during the study analysis.

Site/Field Investigation and Data Collection

Field investigations consisted of site observations to verify existing geographic information system (GIS) information, clarify unknowns and inconsistencies, and perform dye and water tests to identify conveyance routing.

Stormwater monitoring data was collected during the wet season at selected locations within the study area. Continuous flow data was collected at one-minute intervals at the monitoring locations. Grab samples to measure TSS at the monitoring locations during rain events were collected and sent to a laboratory for analysis. Rainfall data was collected from a rain gage installed near the Port Orchard City Hall building.

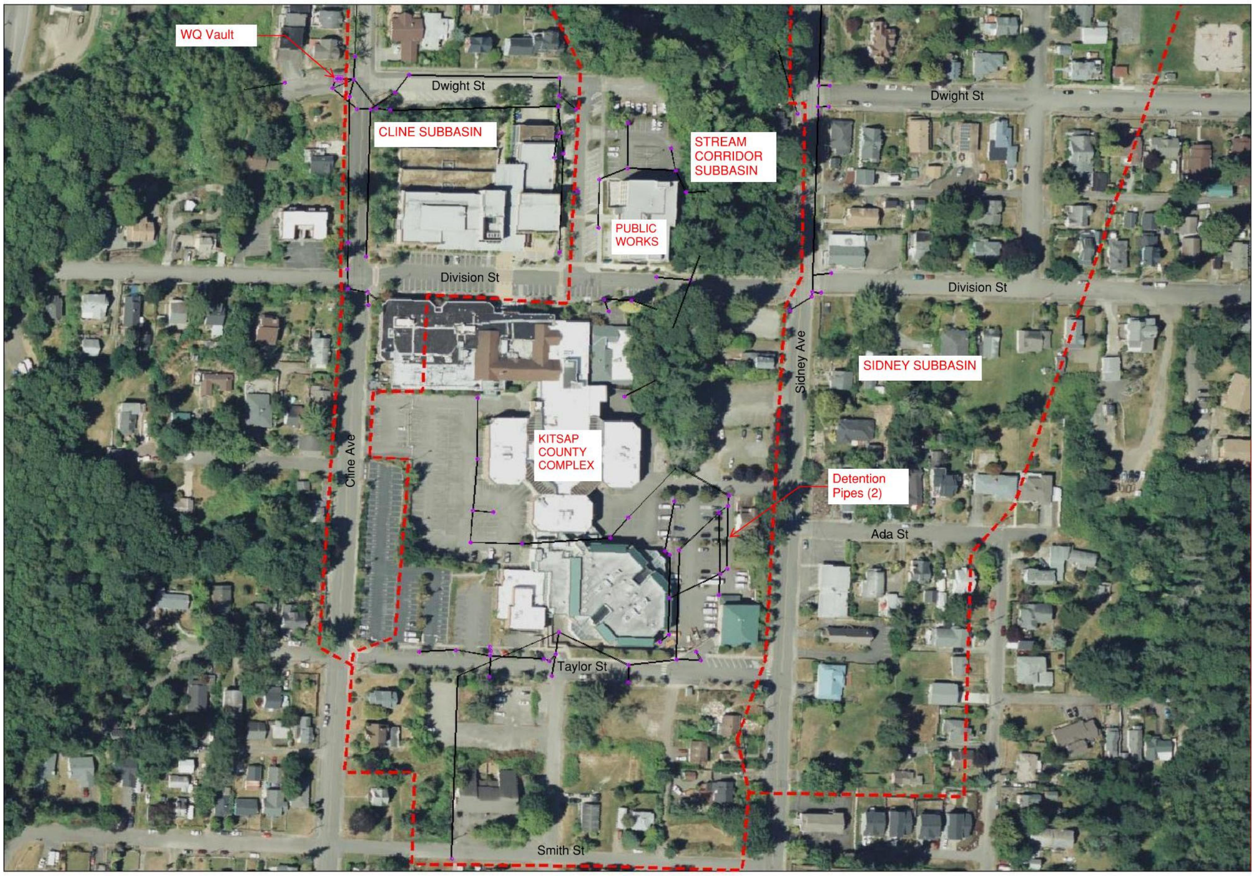
The stormwater inventory included collecting and reviewing record drawings and accessing the GIS database to identify pipe and structure information for the drainage system. The analysis, evaluation, and modeling of the system included the construction of three separate hydrologic/hydraulic models to predict stormwater quantity and quality, conveyance capacity, and potential flooding.

Existing Conditions Description

Port Orchard is located on the south shoreline of Sinclair Inlet, an arm of the Port Orchard Strait, which connects to Puget Sound. The basin is highly developed, with residential and commercial properties and paved roadways. The basin slopes steeply to the northwest, with an elevation drop of approximately 750 feet from Taylor Street in the south to Bay Street in the north. The basin becomes relatively flat from Bay Street north to the waterfront. The basin has eight existing outfalls of various sizes that discharge to Sinclair Inlet. The southern two-thirds of the basin is mostly residential properties and the Kitsap County Civic complex. The northern third of the basin is composed mostly of commercial buildings and paved parking for the Port Orchard Waterfront.

There are three major collection and conveyance routes within the drainage basin (see Subbasin Maps below for reference): Cline and Stream Corridor Subbasin, Sidney Subbasin, and Lower Subbasin.

Stormwater Subbasin Map – North



Stormwater Subbasin Map - South

There is one existing water quality facility, near the Kitsap County Development Building. There are no other water quality treatment devices within the remaining downtown basin. Likewise, there are only a couple detention pipe systems in the same area, plus another near City Hall. There are no other detention facilities within the downtown basin.

Results and Key Findings

The key findings of the stormwater system assessment are summarized in the following sections. These sections break the system down into the water quality assessment and the stormwater system capacity.

Water Quality Analysis

1. A modified version of the QUAL2K spreadsheet model was created to simulate stormwater flows to determine TSS loading. Stormwater flows were derived from the output information of the WWHM/SWMM stormwater flow model.
2. Grab-sample information at select monitoring locations was used to calibrate the model. The monitoring locations were selected based on various land cover and development areas within the downtown basin.

3. TSS models were completed at selected locations within each of the three separate subbasins.
    a. The Cline subbasin had two locations that represented public sector, existing stream channel, high density housing.
    b. The Sidney subbasin had three locations that represented roadway areas and medium to high density residential housing.
    c. The Lower subbasin (Harrison Avenue) had one location that represented the commercial district area.
4. Cline subbasin: Areas at the north end of the basin near Bay Street had nearly six times the TSS loading compared to the upstream southern location.
5. Sidney subbasin: Areas at the north end of the basin near Bay Street had nearly two to three times the TSS loading compared to the other two uphill southern locations. This area has TSS loading that is twice the amount compared to the northern location of the Cline subbasin.
6. Lower subbasin (Harrison Avenue): The TSS loading at this location had the lowest value of all the subbasin locations by a considerable amount.

System Capacity

1. A stormwater model was created using PCSWMM software. This model was used to run scenarios to identify pipe capacity deficiencies and potential flooding locations. Two storm conditions – the 25-year storm and 100-year storm – were run at three tidal conditions: the Mean Higher High Water (MHHW), the 10-year return period tide, and the 100-year return period tide.
2. Most of the storm pipes north and west of Bay Street, including the two main 36-inch outfalls, are at or exceeding 100% capacity for the 25-year storm event. All pipes in the area are at or above capacity for the 100-year storm and tidal events above the MHHW.
3. Upper Basin: There are limited areas of flooding, which is expected given the steep slopes. Pronounced flooding occurs during large storm events at the intersections along Sidney Avenue due to a series of custom catch basin structures that have limited capacity.
4. Lower Basin: The major factor contributing to flooding in this area is tidal impacts during storm events. Flooding occurs at any structure immediately upstream of any existing outfall during tidal events larger than the MHHW during storm events. Two locations most prone to flooding are at the intersection of Bay Street and Sidney Avenue and at Bay Street adjacent to the boat launch area.

Recommendations – Improvement Options

Stormwater Management Option (SMO) 1 focuses on structure and storm pipe upgrades to increase stormwater collection and improve conveyance flow routing. Stormwater modeling identified potential flooding at some of the intersections along Cline Avenue and Sidney Avenue due to small pipe diameters and structures. Site observations indicate that flows bypassing drainage structures at those intersections and large area drains will improve collection.

Evaluation of the conveyance system near the Boat Launch parking, which includes the main 36-inch outfall, shows a patchwork of storm pipe connections and convoluted routing. Access to critical portions of the storm pipe system is difficult or nonexistent.

Improvement designs related to storm pipe and drainage structure upgrades include the following:

1. Cline and Sidney Roadways: Most of the stormwater improvements involve replacing the existing small, custom-made non-standard structures with standard Type-1 catch basins and reconfiguring the storm system pipes at some of the intersections.
2. Bay Street and Boat Launch Parking Area: Replace and reconfigure the existing storm system piping and structures that connect to the main outfall pipe. New manhole structures are needed to better access the storm system and main outfall pipe.

SMO 2 focuses on water quality improvements to address areas of concern identified in the water quality modeling analysis. Topography and limited space constraints dictate the use of centralized and larger water quality treatment facilities.

Water quality improvement projects using improved conveyance routing include the following:

1. Kitsap County Complex Vicinity: Improvements involve installing water quality vaults and smaller catch basin units in parking lots and roadways surrounding the Kitsap County Complex buildings that discharge to the existing stream channel. The water quality facilities will have media filtration technologies such as StormFilter cartridges.
2. Cline and Sidney Upper Roadways: Install a centralized water quality vault or catch basin unit at a select intersection along Sidney and Cline Avenue roadways. The selected intersection will have favorable topography to install the facilities.
3. Lower Basin: Install large, centralized water quality vaults in the Boat Launch and Marina parking lots to provide treatment for surrounding roadways and parking lots. An oil/water separator will be installed in the Marina parking lot due to the high vehicle traffic. These new water quality facilities will be incorporated into the stormwater improvements described in SMO 1 above.

SMO 3 focuses on flood reduction improvements to address areas of concern identified in the stormwater modeling analysis. Most flooding occurs during high tidal events coupled with storm events.

Improvement projects combined with conveyance routing improvements to reduce potential flooding include the following:

1. Block and abandon the small outfall pipes that discharge under buildings and to Sinclair Inlet. The storm pipe system will be combined and rerouted to the existing 36-inch pipe outfalls.
2. Install manholes with backflow devices in the 36-inch pipe outfalls to reduce tidal backwater into the upstream storm system.
3. Optional detention vaults can be installed in the Marina and Boat Launch parking lots to provide temporary stormwater storage during high tide and storm events. The proposed detention system will provide a supplementary means to reduce potential flooding, mostly for significant storm events.

Conclusion and Lessons Learned

This stormwater plan provides analysis on the water quality, storm quantity, pipe capacity, and flood potential of the stormwater system within the Port Orchard Downtown Basin. This study developed three separate SMOs for the City of Port Orchard to consider. The key points from the study are summarized below.

Storm system capacity, maintenance, and water quality treatment are essential considerations for any future development or expansion of the downtown area and the health of Sinclair Inlet. Stormwater modeling was conducted to evaluate basin stormwater quantity, water quality, and conveyance capacity, and to identify locations and impacts of potential flooding. The storm conveyance system in the lower basin receives stormwater from the upper steep reaches of the basin and contains several outfalls that are tidally influenced. The existing conveyance system is a patchwork of aging and custom-made non-standard infrastructure with minimal water quality and detention facilities. Most of the stormwater generated within the basin discharges untreated into Sinclair Inlet, with the dense residential areas generating large amounts of pollutants. Flooding in the lower basin is a combination of high tide elevations and upstream stormwater flow during rain events.

An extensive CCTV inspection of the storm system is recommended to determine the condition of the storm pipes and verify conveyance routing. Additional studies that focus on the impacts of sea level rise on the stormwater system are also recommended.

TABLE OF CONTENTS

Tables

Figures

Appendices

1. INTRODUCTION

1.1 Purpose of Study

This study is based on requirements from a Washington State Department of Ecology (ECY) grant to develop a Stormwater Plan for the City of Port Orchard Downtown Basin. The subject basin of this study is approximately 74 acres of mixed development that drains to Sinclair Inlet.

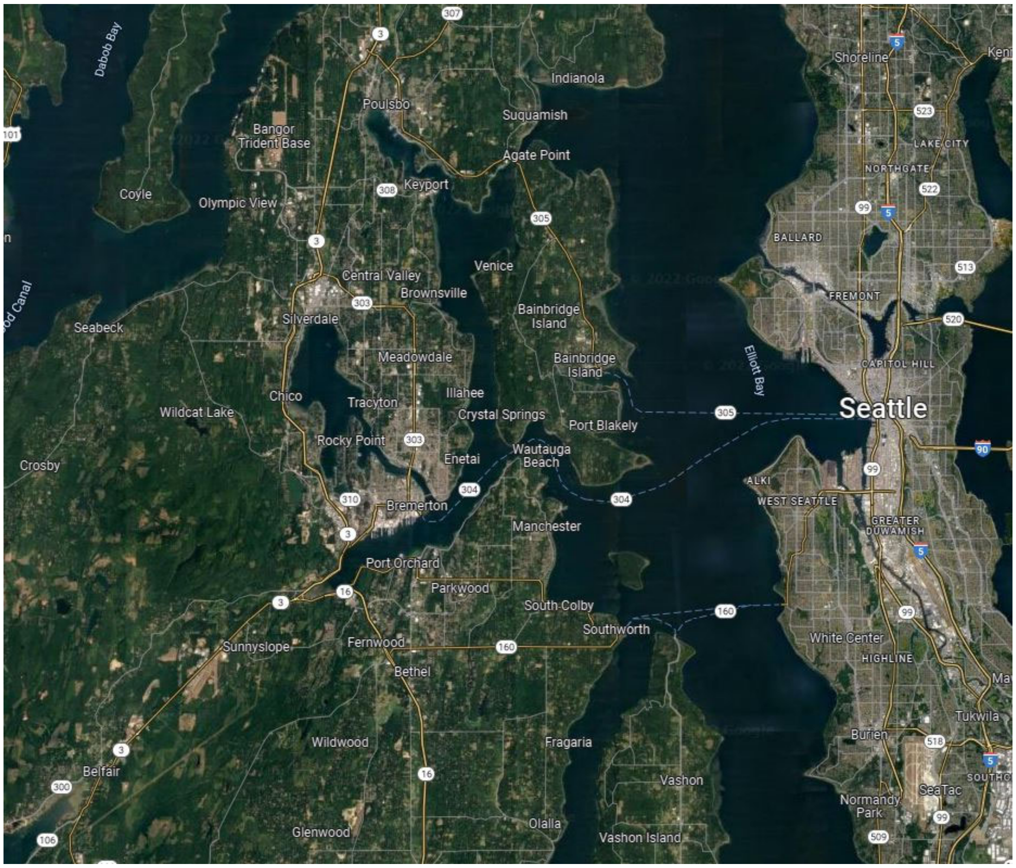
The Stormwater Plan will provide guidance for infrastructure improvements for both structural and nonstructural best management practices (BMPs) to improve water quality and conveyance within the existing commercial and residential areas of the downtown basin. The Stormwater Plan will identify and prioritize capital projects to provide long-term water quality for Sinclair Inlet, increase stormwater conveyance, and reduce tidal-influenced flooding. The Stormwater Plan report will include an existing conditions assessment, basin constraints, stormwater modeling, and stormwater improvement recommendations and implementation.

To complete this scope of work, the study team conducted on-site reconnaissance, analyzed and evaluated water quality, and generated hydraulic data using modeling tools. Identified data gaps were addressed with coordinated assistance from the City of Port Orchard staff. This effort is to identify existing conditions, vulnerabilities, and potential mitigation efforts to improve the stormwater system's condition, capacity, and water quality. This project will help protect and restore water quality in Sinclair Inlet by reducing stormwater impacts from existing infrastructure and development.

1.2 Existing Condition Assessment

1.2.1 Downtown Basin Description

Port Orchard is located on the south shoreline of Sinclair Inlet, an arm of the Port Orchard Strait, which connects to Puget Sound. The basin is in Water Resource Inventory Area (WRIA) 15, in Kitsap County. The geology in the Port Orchard area is characterized by alluvium, artificial fill, glacial outwash, and glacial till. Steelhead, coho, cutthroat, chum, and Chinook habitat areas, shown on maps created by the Washington Department of Fish and Wildlife (WDFW), are within several streams and marine waters adjacent to Port Orchard.



Vicinity Map

The downtown basin is highly developed, with residential and commercial properties and paved roadways. The basin is bounded to the south by Taylor Street, to the west by Cline Avenue, to the north by Port Orchard Marina and Sinclair Inlet, and to the east by Harrison Avenue and tributary areas uphill of Bay Street. The basin slopes steeply to the northwest, with an elevation drop of approximately 750 feet from Taylor Street to Bay Street. The basin becomes relatively flat from Bay Street north to the waterfront. The basin has eight existing outfalls of various sizes that discharge to Sinclair Inlet. An existing stream channel within a deep ravine, located in the western middle of the basin, collects and conveys stormwater to an outfall in the northwest corner of the basin. The southern two-thirds of the basin is mostly residential properties, with approximately 14 acres for the Kitsap County Civic Complex. The northern third of the basin is composed mostly of commercial buildings and approximately 4.5 acres of paved parking for visitors to the Port Orchard Waterfront.

1.2.2 Stormwater Basin Description

Stormwater from the basin is collected and conveyed by a series of catch basins and storm pipe to the various outfalls into Sinclair Inlet. There are three major collection and conveyance routes within the drainage basin (Figures 1 and 2, Subbasin Maps).

Figure 1. Stormwater Subbasin Map – North.

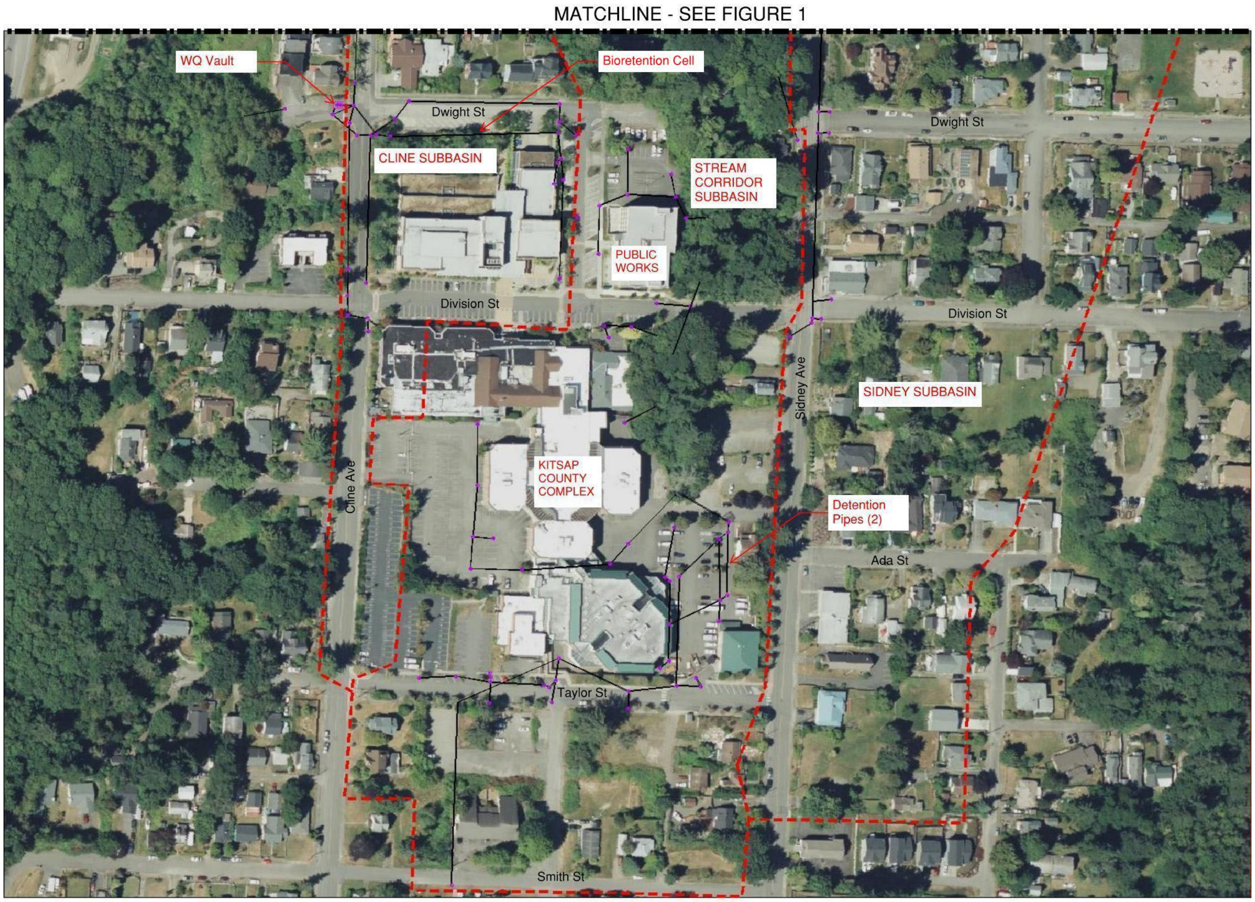


Figure 2. Stormwater Subbasin Map – South.

The first main conveyance route (Sidney Subbasin) is along Sidney Avenue, from Taylor Street to the marina. The conveyance system collects stormwater from Sidney Avenue and tributary roadway surfaces east of Sidney. Stormwater from the residential properties drains onto the adjacent roadways by sheet flow or through weep holes in the sidewalks. Many of the catch basin structures in the upper reaches of the basin are non-standard customized curb inlet structures that are essentially half-round pipes with a grate to collect stormwater from the road gutter. As the conveyance system nears the marina, stormwater from portions of the marina parking lot is collected and conveyed to this system before discharging to Sinclair Inlet.

The second main conveyance route (Stream Corridor Subbasin) is along the existing stream channel corridor that stretches from Division Street to Kitsap Street. The developments surrounding the stream corridor include residential properties, most of the Kitsap County courthouse complex, and the Kitsap County Public Works building. Stormwater from the municipal building and roadways is tightlined to the stream by storm drainpipe. Stormwater from the residential properties discharges to the stream through sheet flow or splash blocks. The stream channel eventually discharges to a 36-inch pipe system near Prospect Street, heading northwest to the outfall at the Port Orchard Boat Launch Ramp.

Another main conveyance route (Cline Subbasin), along Cline Avenue from Taylor Street to Bay Street, combines with the stream corridor basin. Most of this conveyance system is not located within the Downtown Stormwater Basin, but stormwater from this system eventually discharges to the existing 36-inch storm pipe system described above. This system receives runoff from adjacent residential properties, a portion of the Kitsap County courthouse complex, and the Kitsap County Administrative Services building.

The third major subbasin area (Lower Subbasin) is situated between Bay Street and the waterfront, with some tributary areas along Prospect Street. This area collects stormwater from Bay Street, Prospect Street, and the adjacent commercial properties. Stormwater along Bay Street is collected and routed to various discharge locations that include the storm system along Sidney Avenue (described above), the 36-inch storm system (described above), and outfalls under the existing building structures north of Bay Street. Stormwater from the waterfront parking lot area is collected and conveyed to the other outfalls along the waterfront through a series of catch basins and storm pipe.

1.2.3 Water Quality and Detention Description

Site reconnaissance performed during this study confirmed an existing water quality system downstream of the Kitsap County Administration Building, which includes a bioretention cell and a media filtration vault. There are no additional water quality systems identified in the Downtown Basin study area.

Site reconnaissance performed during this study also confirmed existing detention pipe systems within the Kitsap County Courthouse's east parking lot and a parking lot northeast of the Bay Street and Robert Geiger Street intersection. There are no additional detention systems within the Downtown Basin study area.

1.2.4 Data Gap Description

The City of Port Orchard has existing storm infrastructure information that was gathered and inserted into their Geographic Information System (GIS) network. The City's GIS included the following data points for the stormwater infrastructure system:

1. Catch basin identification and location
2. Catch basin dimension and type
3. Measurements within the catch basins to the pipe inverts
4. Storm pipe material and diameters

During the initial review of GIS data, it was discovered that many of the catch basin structures did not have pipe invert information or rim elevations. After the initial site visit by our team, missing storm pipe connections, catch basin structure information, and discrepancies in pipe diameters were identified. Through the combined field work by Port Orchard personnel and the study team, which included surveying, dye testing, flow testing, and further field investigation, most of the missing pipe and structure information was obtained and used in the modeling analysis. We recommend using utility location services and camera inspections in the future to verify and clarify some of the conveyance routing that was not confirmed or resolved.

2. TECHNICAL ANALYSIS/EVALUATION/MODELING

2.1 Technical Analysis/Evaluation/Modeling Overview

The technical analysis, evaluation, and modeling consisted of inventory mapping and three modeling tools.

1. **Infrastructure Inventory and Mapping**: Completed a stormwater infrastructure inventory and formulated data sources, including physical basin data, stormwater monitoring data, and meteorological data.
2. **Stormwater Quantity Model**: Developed a WWHM-SWMM model to predict stormwater quantity at three identified monitoring locations of interest.
3. **Water Quality Model**: Developed three water quality spreadsheet models to quantify the runoff and magnitude of total suspended solids (TSS) based on the locations of interest from the Stormwater Quantity model.
4. **Hydraulic Model:** Developed a PCSWMM model to evaluate the existing storm system for conveyance capacity and potential flooding locations. This model was used to evaluate proposed infrastructure improvements to address flooding and capacity concerns.

2.2 Stormwater Infrastructure Inventory and Mapping

2.2.1 Methodology

The City of Port Orchard's ArcGIS geodatabase of their stormwater system was used as the framework for the stormwater infrastructure inventory. As discussed in Section 1.2.4, Data Gap Description, additional site investigation and research was completed to clarify unknown conveyance routings. The following process was used to address conveyance uncertainties:

1. Performed site reconnaissance to verify GIS information and identify data gaps.
2. Generated exhibits identifying missing information for Port Orchard staff to gather.
3. Port Orchard staff performed limited survey using GPS and measurements of catch basins to obtain invert and rim elevation information. The vertical accuracy is approximately 3 inches, according to City of Port Orchard Staff.
4. Used this updated surveyed data and storm routing adjustments from the site visit to update the Port Orchard GIS system.
5. Completed a coordinated site investigation with Port Orchard Staff and the Design team using dye and water trucks to identify and clarify the remaining routing uncertainties to assist with modeling efforts.

2.3 Stormwater Quantity Model

2.3.1 Methodology

Development of the three WWHM-SWMM stormwater models associated with each monitoring location required several data sources. Those sources include physical basin data (topographic, stormwater network, land use, and soil type), stormwater monitoring data (runoff quantity), and meteorological data (rainfall and evaporation). Physical basin data and meteorological data were required for basic model development. The existing stormwater infrastructure inventory was generated by City of Port Orchard in ArcGIS. Basin delineation and land use mapping was created in AutoCAD 2019.

2.3.1.1 Physical Basin Data: Input to Model

Modeling inputs included:

- Topographic data obtained from Kitsap County 2018 LiDAR.
- Soil information obtained by USDA Web Soil Survey.
- Stormwater network data obtained from GIS data and record drawings from Port Orchard.
- Catch basin contributing areas delineated in AutoCAD.
    - Catch basin contributing area boundaries were revised based on dye and flow testing conducted in areas of uncertainty to improve model results following the initial model runs.
- Land use delineated using aerial google maps, Kitsap County GIS elevation data, and storm system data in AutoCAD.
    - Land cover data analysis was performed and further categorized land cover by slope and hydrologic soil groups using topographic and soils data.

2.3.1.2 Meteorological Data: Input to Model

- Evaporation data is built into the WWHM-SWMM model based on project location.
    - Evaporation data from the WWHM-SWMM software was extended to include the modeled time period.
- Rainfall data for the model is a combination of data collected by the City of Port Orchard and Bremerton Airport precipitation gauge information.
    - A regression was made between the City of Port Orchard gage and the Bremerton Airport gage to convert Bremerton Airport data to City of Port Orchard data (multiplication factor of ~0.8). The converted data was used to fill in data gaps in the City of Port Orchard data.

2.3.1.3 Stormwater Modeling Data: Used for Calibration

- Flow data was collected by the City of Port Orchard using weirs and pressure transducers installed in catch basins in select locations.
- The study team determined that higher flows were not being accurately captured by the installed weirs during the WWHM-SWMM model calibration process.

2.3.1.4 Results

A detailed analysis of the model results is described in the March 18, 2022, technical memorandum for Tasks 3.3 and 3.4 to the Washington State Department of Ecology (see Appendix A). This section summarizes the technical memorandum and steps moving forward to address an uncalibrated model.

The observation data collected at all three monitoring locations contains data points that are invalid because the observed stage was outside of the recommended range for developed regressions from stage to discharge for the installed weirs. Calibration of stormwater models relies heavily on peak storm flows and total runoff volumes. The observed data is not accurate for the larger observed storm events due to the installed weirs being undersized. The data collected from the undersized weirs for peak flows and total runoff volumes was inaccurate.

To move forward with the Water Quality modeling and Stormwater Plan report, the design team, with ECY agreement, used the uncalibrated WWHM-SWMM models to support development of the stormwater plan. The existing uncalibrated WWHM-SWMM models incorporate much site-specific data and use default values for other inputs that are estimated to be generally representative of actual conditions. Results from the existing models could be used for water quality modeling and to assess the most cost-effective alternative(s) to address deficiencies through structural and nonstructural BMPs. Without monitoring data, model calibration cannot be completed, and calibration results cannot be compared to Quality Assurance Project Plan (QAPP) Model quality objectives.

2.4 Water Quality Model

2.4.1 Methodology

Spreadsheet-based water quality models for TSS have been developed for each of the three designated downtown stormwater basins. The QUAL2K model described in the QAPP was replaced with a project-specific spreadsheet that is more directly applicable for simulating stormwater runoff through storm pipe systems. The QUAL2K model simulating natural stream environments is not directly applicable to this urban basin analysis. The May 24, 2022, technical memorandum, Summary of Water Quality Models, in Appendix B explains the project-specific model spreadsheets.

The spreadsheet models use the same land-use inputs as the three WWHM-SWMM hydrologic models and use WWHM/SWMM output results combined with literature-derived event mean TSS concentrations that vary by land use.

Eight grab samples were collected from the manhole monitoring locations in each of the three basins. The TSS samples are used to generate a TSS calibration factor for the spreadsheet model output. TSS load data is a useful metric as compared to TSS concentrations because it can be compared between locations within a basin, and between basins, to aid in understanding where stormwater treatment facilities can provide the most benefit by capturing the most TSS.

2.4.2 Results

Strategic locations were identified within each of the three basins to generate the TSS loading data. Table 1 summarizes the locations and TSS loading results. Refer to Appendix B of the Water Quality technical memorandum for maps showing the manhole monitoring locations.

Table 1. TSS Loading Results by Location.

Basin and Location	TSS Loading in Stormwater Flows less than half of the 2-year Storm Event (lb/yr)	Area Represented
Cline Basin		
324 ("monitoring" manhole near Kitsap County Auditor building)	1,745	Public sector and roadway area
142 (manhole north of Bay Street, between Water Street and Robert Geiger Street)	10,408	Stream channel and high-density housing
Sidney Basin		
4002 (manhole at intersection of Sidney Avenue and Dwight Street)	11,356	Dense residential zone
4016 (manhole near intersection of Sidney Avenue and Division Street)	7,284	Less-dense residential zone
3648 (manhole on Sidney Avenue, south side of Bay Street)	24,867	Roadway area and dense residential zone
Lower Subbasin (Harrison Avenue)		
3632 (monitoring manhole in Parking lot near library)	690	Commercial District

2.5 Hydraulic Modeling of the Storm Drain System

2.5.1 Methodology

A hydrologic and hydraulic stormwater model was developed using the SWMM 5.1.015 version of PCSWMM, a proprietary stormwater modeling software program used to evaluate the capacity of a stormwater conveyance system, such as pipes, structures, and outfalls. The precipitation intensity, duration, and frequency (IDF) curve assigned to each subbasin was used to calculate the quantity of stormwater entering downstream catch basins. The model calculated pipe capacities to identify flooding locations and flood volume for modeled storm events.

2.5.2 Model Inputs Methodology

The physical basin data generated for the Stormwater Quantity Model was imported into the PCSWMM model. Subbasins delineated in AutoCAD to assign a tributary drainage area to each catch basin node with a grate were imported to the model.

2.5.2.1 Precipitation

Precipitation data was gathered from the National Oceanic Atmospheric Administration (NOAA) Atlas 2 Volume 9 maps, which provide rainfall depths for various storm events. This data was used to create the IDF curves for the model.

2.5.2.2 Tidal Influences

Existing and future tide information was obtained from NOAA. The nearest station that can provide adequate information for the modeling simulations is NOAA tidal station 9447130, located in Seattle.

2.5.2.3 Simulation Analysis

Several scenarios (simulations) were conducted with the model to evaluate the conveyance capacity and potential surface flooding of the existing stormwater system. The model was used to evaluate two 24-hour design storms that include the 25- and 100-year events against tidal events that include the Mean Higher Highwater (MHHW), 10-year, and 100-year return period events.

2.5.3 Model Setup

2.5.3.1 Model Components

Delineated subbasins were assigned a basin slope percentage, impervious area percentage, roughness coefficients for overland flow, and depths of storage for pervious and impervious areas. Pipes were given a Manning's 'n' roughness coefficient based on material type. All pipes were given a conservative roughness coefficient value of 0.015 to reflect the age and deterioration of the system.

2.5.3.2 Precipitation Input

Data for the two design storms obtained from NOAA Atlas 2 Volume 9 was entered into PCSWMM's design storm creator. The cumulative rainfall depths were given a Soil Conservation Service (SCS) Type 1A distribution to represent rainfall conditions in western Washington. PCSWMM generated IDF curves for the 25-year and 100-year return periods, shown in Figure 3.

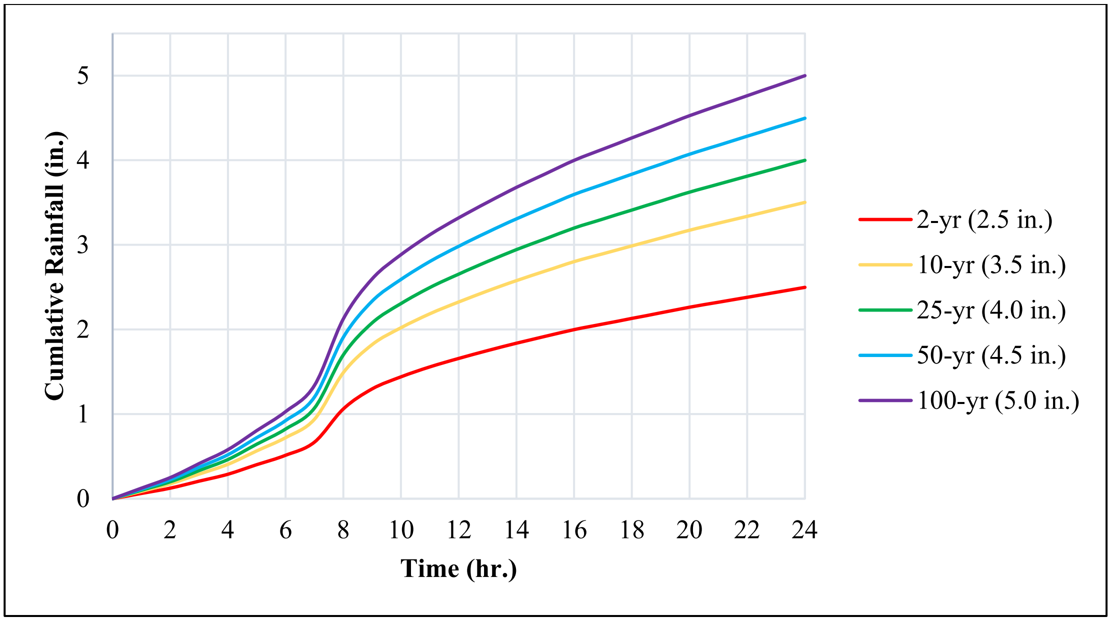


Figure 3. PCSWMM-Generated IDF Curves.

2.5.3.3 Tidal Conditions

Tidal elevations, shown in Table 2, were provided from the NOAA station data. The tidal elevation is set as the initial water depth at each structure and outfall of the model. Manholes and null structures were given additional surcharge depth, allowing initial depths to exceed available depth. Increased surcharge depths at structures incapable of flooding enabled the Energy Grade Line (EGL) and Hydraulic Grade Line (HGL) to reflect the tidal condition. The return periods shown in the table represent estimates of extreme sea level events based on probabilities of their occurrence.

Table 2. Tidal Elevations.

Tidal Scenario	MLLW Datum
Mean Higher-High Water (MHHW)	11.36
10-Year Return Period	14.15
100-Year Return Period	14.54

2.5.3.4 Modeling Assumptions

The Hydrologic & Hydraulic (H&H) modeling included the following assumptions:

1. Missing invert elevations were interpolated from known upstream and downstream elevations.
2. Missing outfall elevations were estimated using a 0.5% slope from a known upstream invert elevation. A slope of 0.5% was assumed because the survey information collected indicates that most of the storm main pipes within the study area are approximately 0.5%.

2.5.4 Results

2.5.4.1 Results Overview

Several model simulations were performed for the 25-year and 100-year storm events and three tidal conditions. The 25-year design storm, a typical storm used to evaluate and size storm conveyance systems based on local jurisdiction code requirements, was chosen to evaluate pipe capacity and potential flooding. The 100-year design storm was chosen to highlight flooding vulnerabilities during worst-case scenarios. Analysis and discussion of the results is separated into two major areas: the flatter area along and north of Bay Street, and the remaining steeper-sloped area south of Bay Street.

2.5.4.2 25-year at MHHW Condition

A model simulation was performed for the 25-year design storm during an MHHW (11.36 feet) tidal condition to identify pipe capacity and surface flooding areas. The 25-year design storm is typically used to determine storm pipe diameters to convey incoming stormwater flows. Figures 4 and 5 show the flooding results for the study area. The colored circles in the figure are nodes that indicate catch basin structures with grates that are flooding. MG in the legend refers to million gallons.

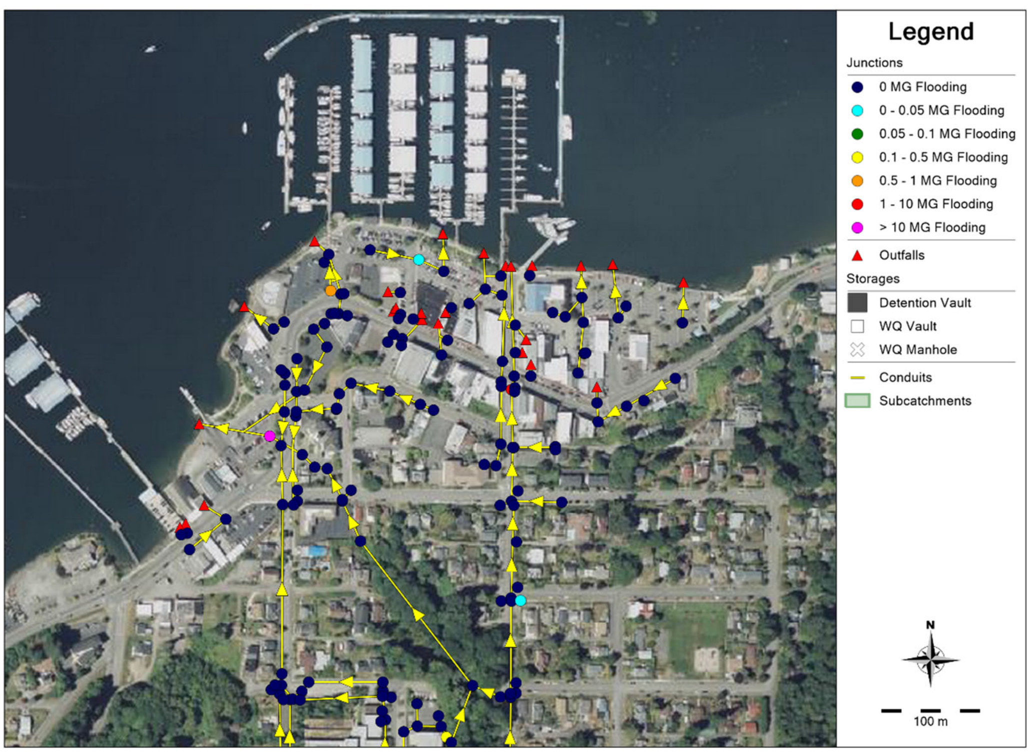


Figure 4. Flood Visual Map (North) – 25-year Storm, MHHW.

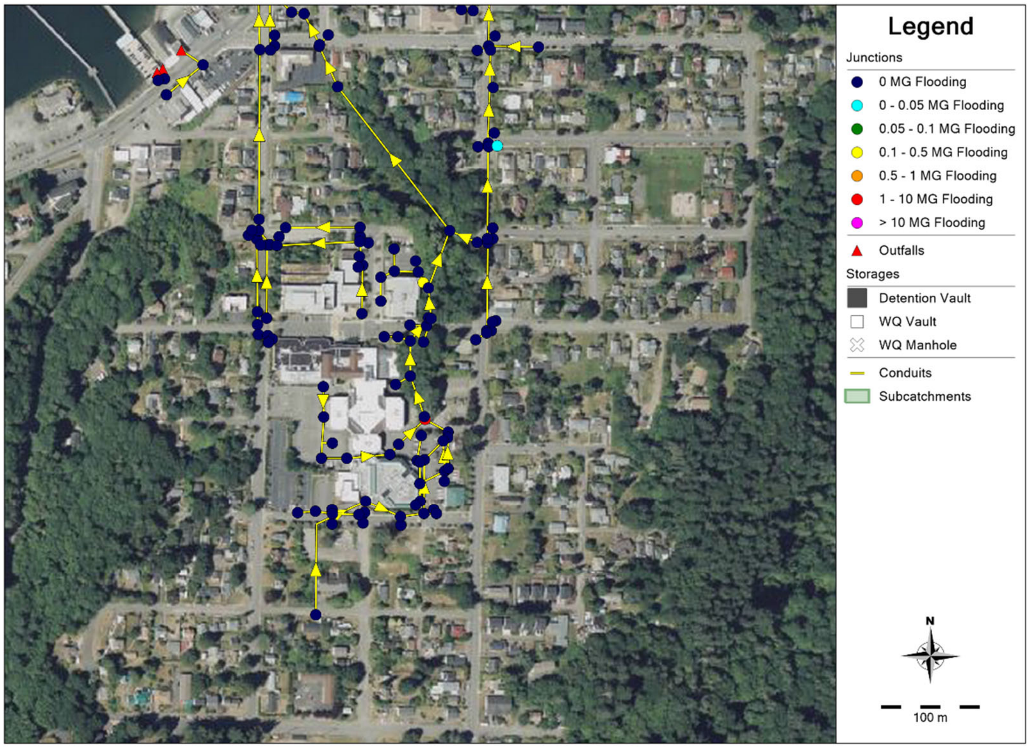


Figure 5. Flood Visual Map (South) – 25-year Storm, MHHW.

2.5.4.2.1 Upper Basin

The start of pronounced flooding, indicated by the cyan circle, occurs at the intersections along Sidney Avenue. This corresponds with the series of custom-made, non-standard catch basin structures described in Section 1.2.2. These structures have limited capacity to collect and convey surface stormwater. A fair amount of stormwater will bypass these structures during storm events and sheet flow down the paved roadways.

2.5.4.2.2 Lower Basin

As indicated by the magenta and red circles, the major areas of flooding occur at the intersection of Bay Street and Sidney Avenue and the boat launch. Flooding at the intersection is likely a result of: 1) transitioning from very steep to flatter-sloped pipes, 2) bypassed surface stormwater along Sidney Avenue, and 3) tidal backwater conditions. The flooding at the boat launch parking lot is due to the convergence of three large tributary basins: the stream channel basin, the Cline Avenue basin, and a portion of the lower Bay Street basin. Tidal backwater conditions also contribute to the flooding occurrence.

2.5.4.3 25-year at Two Tidal Conditions

Model simulations were performed for the 25-year design storm during each of the two tidal conditions. The upper basin locations of flooding described for the 25-year storm at MHHW Condition are still consistent at the 10- and 100-year tidal return period conditions. This result is expected, given the large elevation difference between the upper and lower basins.

2.5.4.3.1 Lower Basin

In addition to the flooding locations described in the MHHW section, flooding occurs at any structure immediately upstream of an existing outfall (see Figures 6 and 7). This is illustrated by the series of red and orange circles north of Bay Street. Other than the outfalls that discharge to Sinclair Inlet, there are smaller outfalls that discharge under several existing buildings. These outfalls are affected by the tidal elevations.

As a result of the tidal conditions, pipes are at full capacity for most of the lower basin during the 10- and 100-year tidal return periods.

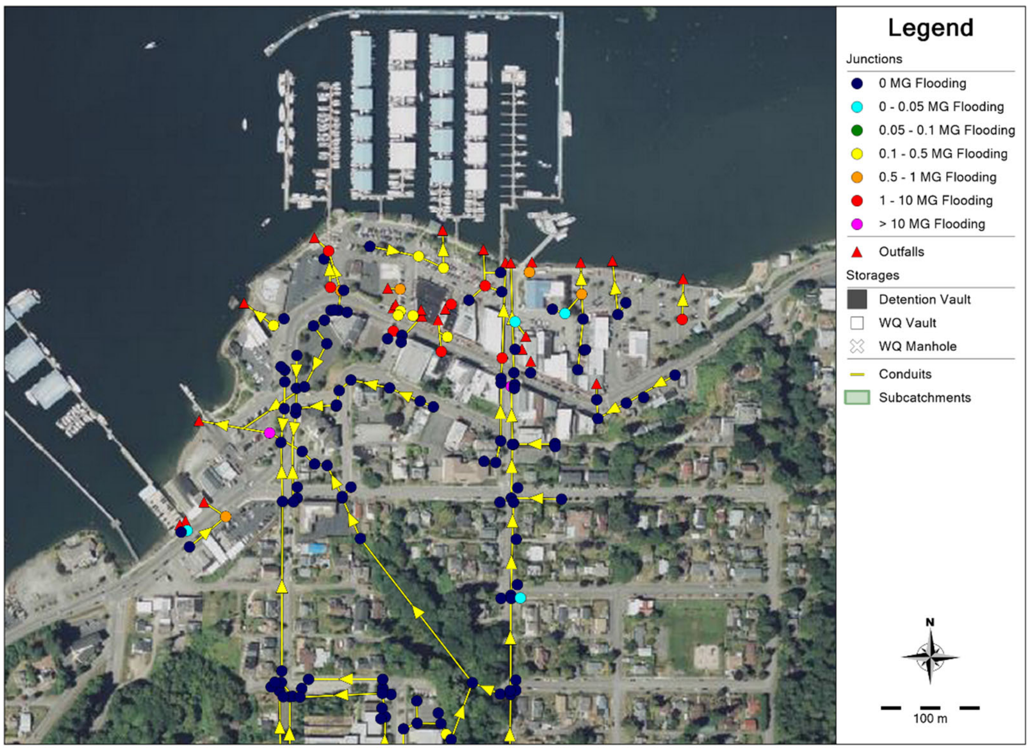


Figure 6. Flood Visual Map (North) – 25-year Storm, 10-year Tide.

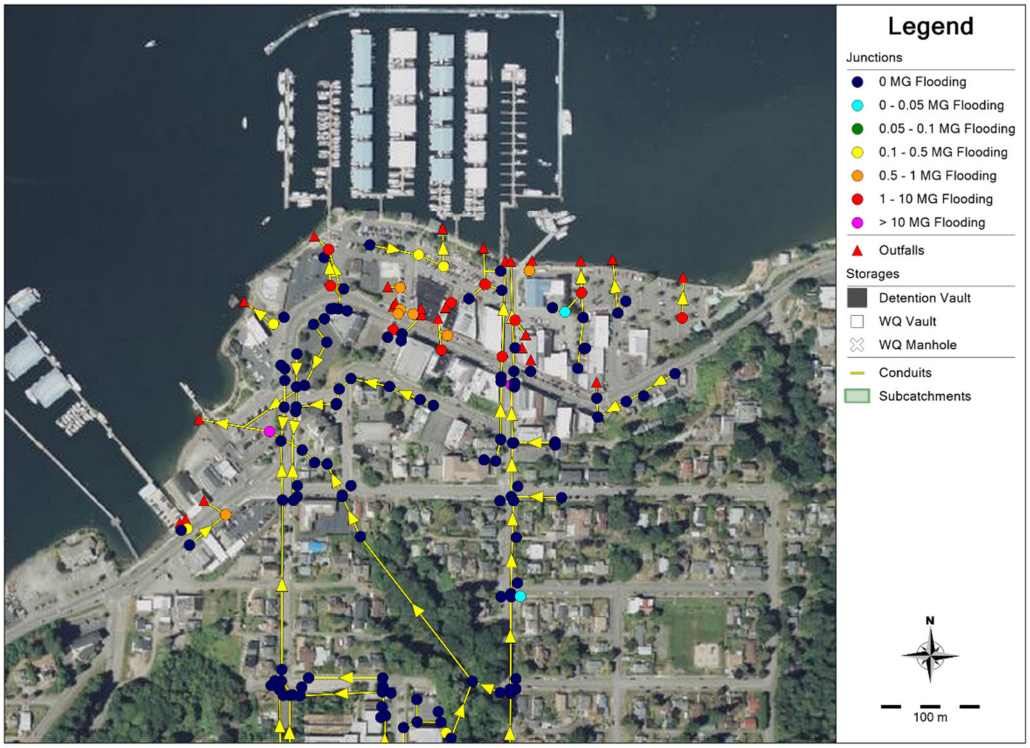


Figure 7. Flood Visual Map (North) – 25-year Storm, 100-year Tide.

3. STORMWATER MANAGEMENT OPTION (SMO) LIST

Based on the analysis discussed in Section 2, a list of stormwater management options (SMOs) was developed. An SMO is an overall strategy using Best Management Practices (BMPs) and engineering designs to address identified vulnerabilities in the drainage system. These SMOs were developed to address the following concerns: storm system structural condition, stormwater system capacity and flooding mitigation, and water quality mitigation. Each SMO presented will contain specific improvement projects at various locations to address the main concerns for the Downtown Basin. Some of the improvement projects will overlap within different SMOs. Figures 8 through 12 show site plan improvements.

3.1 SMO 1

SMO 1 focuses on storm pipe and drainage structure upgrades to increase stormwater collection and improve conveyance flow routing. The following improvement projects address two areas identified in the analysis for stormwater mitigation.

3.1.1 Sidney Avenue and Cline Avenue

As discussed in the Upper Basin Results section, the drainage system along Sidney Avenue is composed of small custom-manufactured, non-standard drains that have limited collection and conveyance capacity. There is also a small number of structures to collect stormwater from a large upstream basin area (roadways and residential development), which contributes to increased sheet flow runoff along roadways. This same pattern occurs along Cline Avenue. The intersections are the convergence points for the upstream stormwater flows and need upgrades to maintain conveyance functionality. SMO 1 includes the following improvements, with site numbers corresponding to the site plan figures shown below:

- Site 1: Install standard Type-1 catch basins and 12-inch storm pipe at the Sidney Avenue and Taylor Street intersection and route to the existing system in Taylor Street to the west.
- Site 2: Install standard Type-1 catch basins and 12-inch storm pipe at the Sidney Avenue and Ada Street intersection and route to the existing system in the Kitsap County Complex Parking lot to the west.
- Site 4: Replace and reconfigure the existing conveyance system at the intersection of Sidney Avenue and Division Street with standard Type-1 catch basins and 12-inch storm pipe. The reconfigured system will connect back into the existing storm pipe system.
- Site 6: Replace and reconfigure the existing conveyance system at the intersection of Sidney Avenue and Dwight Street with standard Type-1 catch basins and 12-inch storm pipe. The reconfigured system will connect back into the existing storm pipe system and eliminate an existing outfall pipe that discharges to the existing stream corridor to the west.
- Site 7: Replace and reconfigure the existing conveyance system at the intersection of Sidney Avenue and Dekalb Street with standard Type-1 catch basins and 12-inch storm pipe. The reconfigured system will connect back into

the existing storm pipe system. Water quality devices, discussed in SMO 2, will be installed within the reconfigured storm system.

- Site 9: Install standard Type-1 catch basins and 12-inch storm pipe near the Cline Avenue and Dwight Street intersection and route to the existing system in Cline Avenue to the west.
- Site 10: Install standard Type-1 catch basins and 12-inch storm pipe at the Cline Avenue and Dekalb Street intersection and route to the existing system in Cline Avenue.
- Site 12: Replace and reconfigure the existing conveyance system at the intersection of Cline Avenue and Kitsap Street with standard Type-1 catch basins and storm pipe. The reconfigured system will connect to a new water quality facility before releasing to a new storm pipe system.
- Site 13: Replace and reconfigure a portion of the existing conveyance system at the south side of the intersection of Sidney Avenue and Bay Street with standard Type-1 catch basins and 12-inch storm pipe. The reconfigured system will connect back into the existing storm pipe system.

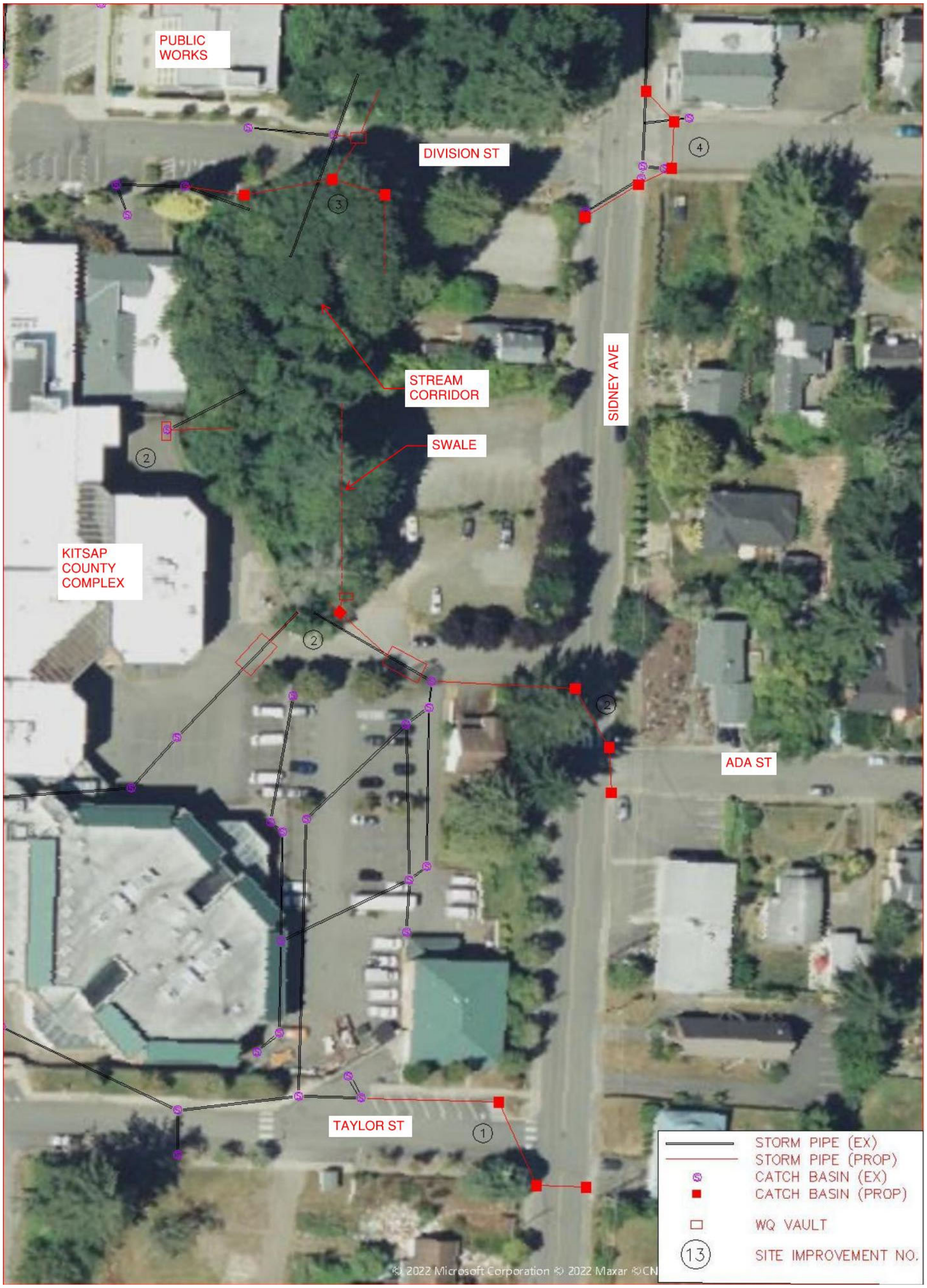


Figure 8. Sites 1 through 4.

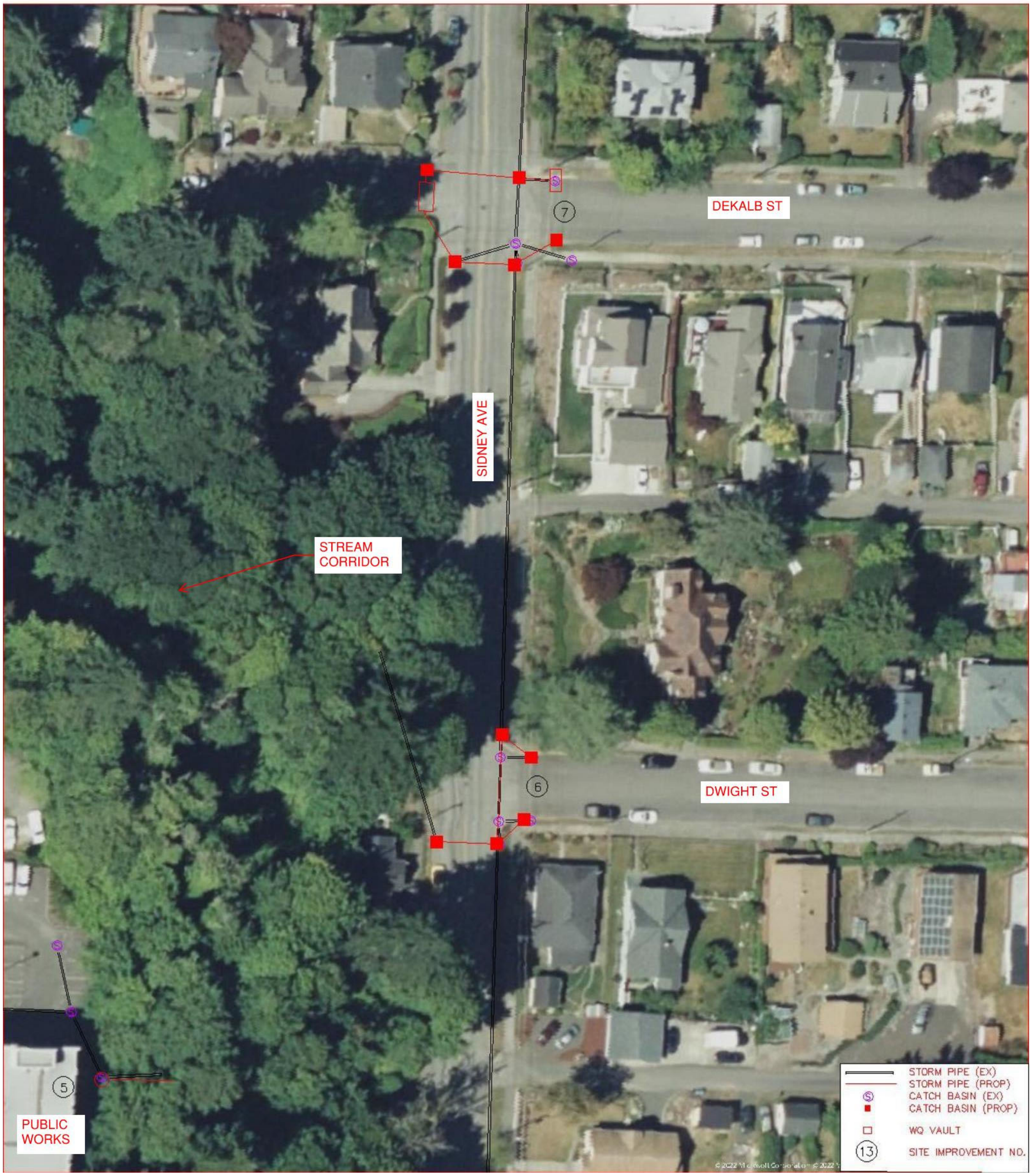


Figure 9. Sites 5 through 7.

Figure 10. Sites 8 and 9.

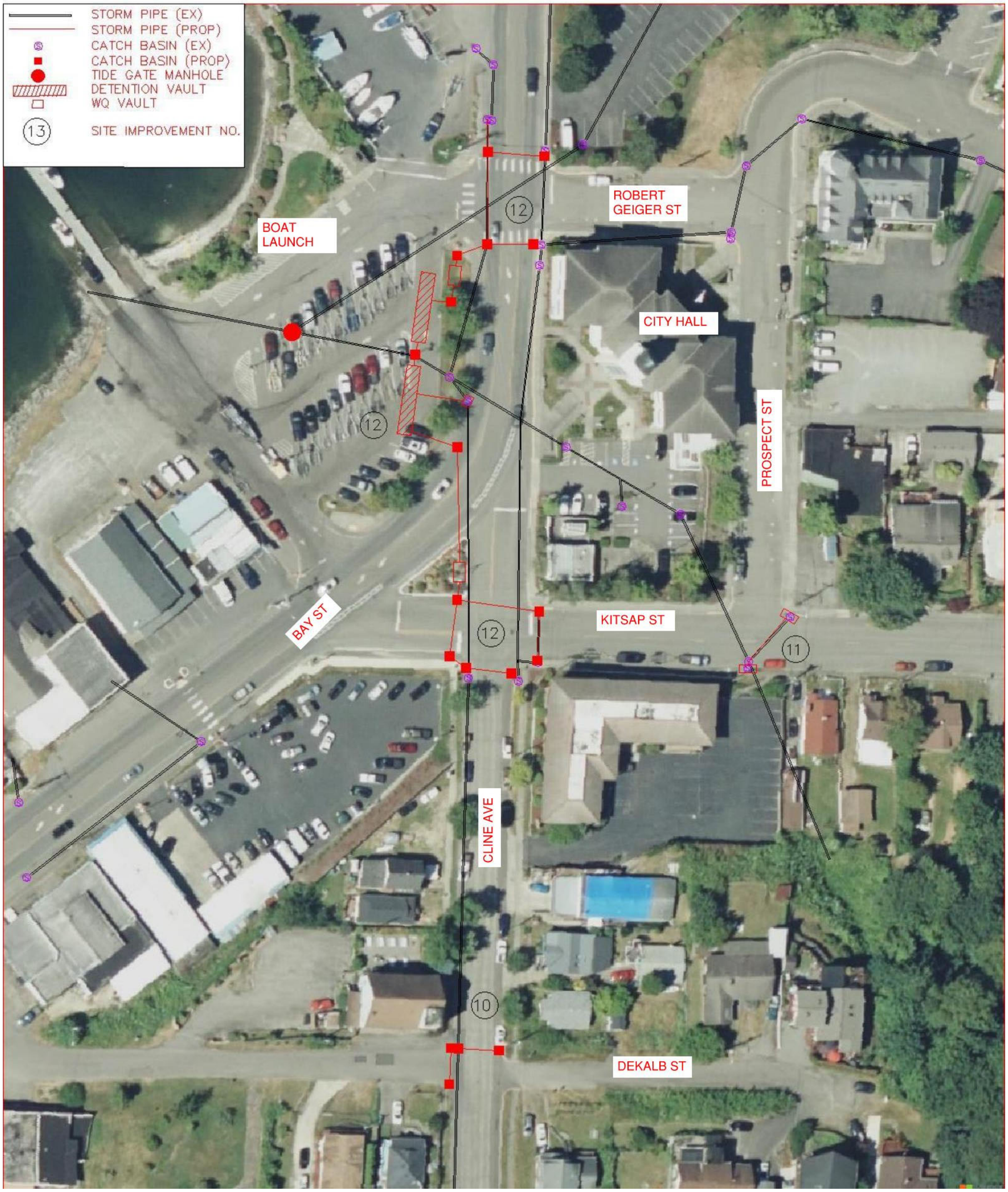


Figure 11. Sites 10 through 12.

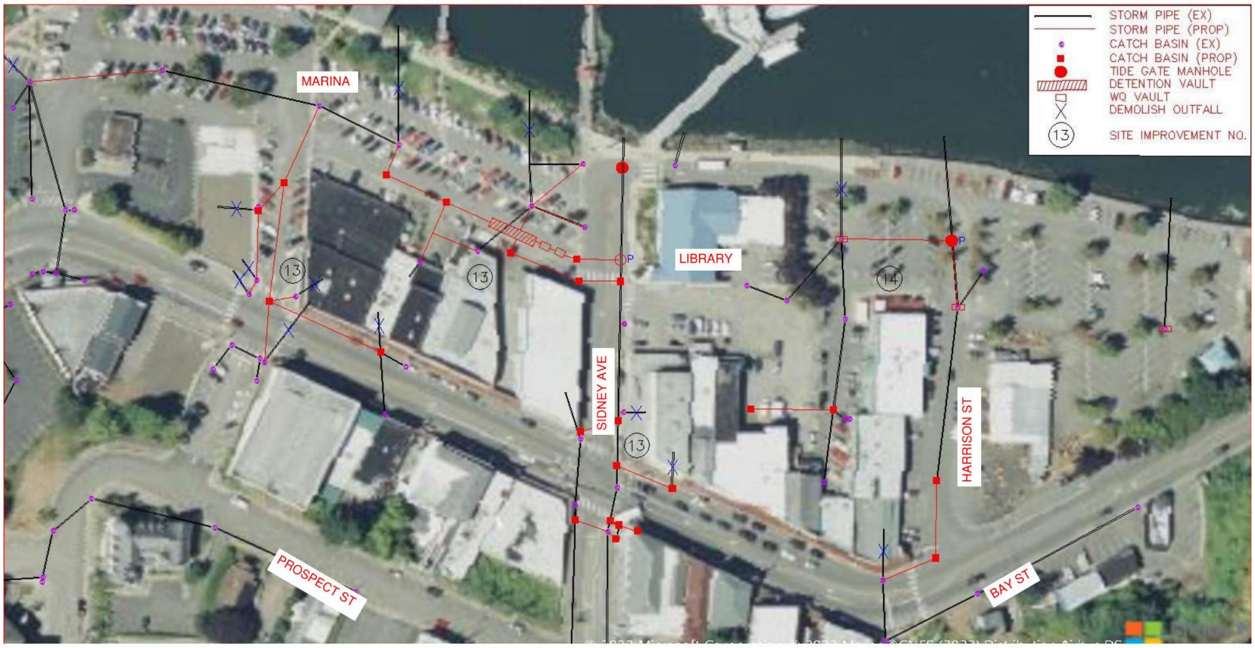


Figure 12. Sites 13 and 14.

3.1.2 Boat Launch Parking Lot and Bay Street

During the site investigations and GIS review, the existing storm system along Bay Street between Robert Geiger Street and Kitsap Street was observed to be convoluted and difficult to evaluate. The system does not have access points for inspection or maintenance at some of the assumed pipe connections to the existing 36-inch storm main. SMO 1 includes the following improvements to reconfigure the system to enhance conveyance flow and provide a means to access and maintain the system.

- Site 12: Replace and reconfigure the existing conveyance system at the intersection of Bay Street and Robert Geiger Street with standard Type-1 catch basins and 12-inch storm pipe. The reconfigured system will extend to a new water quality facility (see SMO 2) before connecting to the existing 36-inch storm pipe system with a new storm manhole structure.
- Site 12: Install new storm pipe from the new Cline Avenue and Kitsap Street intersection storm system and connect to the 36-inch storm pipe with a new storm manhole.
- Site 12: Install a new storm manhole at the assumed connection to the 36-inch storm pipe from the existing detention tank north of City Hall.

3.2 SMO 2

The second SMO focuses on water quality improvements to address treatment deficiencies within the basin. As discussed in the Water Quality Model Results section, the major areas that contribute a large portion of TSS include the Sidney basin, the Stream Corridor basin, and the Lower Subbasin. The Lower Subbasin is an area that generates the most pollution loading due to the high traffic use along Bay Street and access and parking for the commercial district.

Steep topography and limited right-of-way space in the upper basin create difficult conditions to install water quality facilities. The recommended approach is to consolidate water quality treatment into larger vaults located in flatter areas, such as parking lots, throughout the basin. This strategy is cost effective, reduces the number of facilities to maintain, generates less disturbance to the existing storm and pavement systems, and is easier to locate within the site. City of Port Orchard prefers to use and maintain proprietary water quality units rather than low impact development BMPs such as bioretention cells. The water quality units should provide enhanced treatment and have a General Use Level designation (GULD) per the Department of Ecology TAPE (Emerging Stormwater Treatment Technologies) program. These GULD units provide minimum 80 percent removal of total suspended solids, 30 percent removal of dissolved copper, and 60 percent removal of dissolved zinc. The preferred units should have a small elevation drop through the facility and internal bypass capabilities. The following recommended units have a GULD designation and are suited for urban environments:

1. BioPod Biofilter from Old Castle: An underground unit that does not require the use of a tree.
2. Linear Modular Wetland from Contech Engineered Solutions: An underground unit with tree vegetation at the surface.
3. Filterra Systems from Contech, with curb inlets: Can be used for smaller tributary areas along roadways and parking lots.
4. Aquip from StormwateRx: An above-ground unit used mainly for industrial areas or locations where aesthetics is less of a concern.

SMO 2 includes the following water quality improvements for the Stream Corridor Basin, Sidney Avenue Basin, Cline Avenue Basin, and Lower Basin.

3.2.1 Stream Corridor Basin

The existing stream ravine and 36-inch storm pipe that discharges to Sinclair Inlet at the boat launch ramp receives untreated stormwater from the Kitsap County Municipal complex, portions of Division Street, the Kitsap County Public Works development, and portions of Kitsap Street, Prospect Street, and Bay Street that drain to the existing 36-inch outfall pipe. Outfalls and storm connections to this system should be treated to reduce TSS loading. SMO 2 includes the following improvements and areas of treatment, with site numbers corresponding to the site plan figures.

- Site 2: Install water quality vaults at the two outfall pipes that discharge to the stream ravine to treat the Kitsap County Complex parking lot.
- Site 2: Install a drainage swale and water quality catch basin to treat the gravel parking lot near the Kitsap County Complex parking lot.
- Site 3: Install a series of Type-1 catch basins and storm pipe within Division Street to collect and convey surface runoff to a water quality manhole. Stormwater from an adjacent gravel parking lot will be collected and conveyed to the water quality manhole that will discharge to the stream corridor.
- Site 5: Install a water quality manhole at the Kitsap County Public Works development storm outfall.

- Site 11: Install water quality catch basins at the intersection of Kitsap Street and Prospect Street to treat road and residential stormwater before discharging to the 36-inch storm pipe.
- Site 12: Remove and replace an existing structure with a water quality catch basin at the low point in Bay Street across the street from City Hall.
- Site 12: Install a water quality vault (SMO 1, Item 1, of the Boat Launch Parking lot and Bay Street section). This vault will treat portions of Bay Street, Robert Geiger Street, and Prospect Street and can be installed in the parking lot or right-of-way.

3.2.2 Sidney Avenue Basin

SMO 2 includes the following improvements and areas of treatment:

- Site 2: The storm pipe improvements described in SMO 1, Sidney and Cline Avenue, Items 1 and 2, will send stormwater to one of the large water quality vaults at the Kitsap County Complex parking lot. This will treat tributary road and residential stormwater runoff.
- Site 7: Install a water quality vault at the storm pipe improvements at the intersection of Sidney Avenue and Dekalb Street. The vault can be installed in the flat section of the dead-end private road.
- Site 13: A new water quality vault, described in Section 3.2.4, Lower Basin, Item 1 below, will provide treatment for the Sidney roadway and upstream tributary residential developments and roadways.

3.2.3 Cline Avenue Basin

SMO 2 includes the following improvements and areas of treatment:

- Site 8: Install water quality catch basins at the intersection of Cline Avenue and Division Street to treat the Cline Avenue roadway up to Taylor Street. The storm system will be reconfigured and connect back to the existing conveyance system.
- Site 9: Clean the existing water quality vault at the intersection of Cline Avenue and Dwight Street to restore proper functioning.
- Site 12: Install a water quality vault just north of the storm pipe improvements at the intersection of Cline Avenue and Kitsap Street. The vault will be installed in the triangular island and will treat roadway (Cline Avenue) and tributary residential development stormwater.

3.2.4 Lower Basin

The lower basin encompasses the main Port Orchard business district and marina, including the high vehicle traffic of Bay Street. A more centralized approach to collecting and treating stormwater is recommended, with new facilities located within the parking lot areas. SMO 2 includes the following recommended improvements to treat Bay Street and the paved parking lots.

- Site 13: Install a large oil/water separator followed by a large water quality vault in the marina parking lot west of Sidney Avenue. These facilities will provide treatment for the marina parking lot, a portion of Bay Street, and tributary portions of Sidney Avenue and Frederick Avenue. Stormwater will be conveyed to this proposed stormwater treatment facility with a new storm reroute conveyance system. This proposed conveyance system is described as part of SMO 3.
- Site 14: Install water quality manhole and catch basin units in the retail business parking lot east of the library. These facilities will provide treatment for this parking lot, Harrison Avenue, and tributary portions of Bay Street.

3.3 SMO 3

SMO 3 focuses on reducing flooding that occurs during a combination of high tidal conditions and storm events. Most of the documented flooding occurs in the lower basin along Bay Street, the business district, and the marina parking lot. This has been confirmed by the stormwater modeling results described in Section 2.5.4. Tidal conditions are one of the major factors that contribute to basin flooding.

The storm system for the areas mentioned above tends to discharge to smaller pipe outfalls under adjacent buildings. One recommended approach to reduce the tidal influence is to remove these smaller outfalls and reroute the upstream conveyance system to the existing larger pipe outfalls that discharge to Sinclair Inlet. Another approach is to install backflow devices in outfall pipes to reduce tidal backwater impacts.

A model simulation was conducted with a tide gate inserted at each existing outfall and with the proposed conveyance reroute to determine if flooding can be reduced. Results of the model indicate a considerable reduction in potential flooding due to the tide gates (see Figures 13 and 14 for flood maps). Flooding occurs by a combination of tidal backwater moving upstream and upstream stormwater flows exceeding the capacity of the conveyance system. The tide gates eliminate one of those factors from contributing water to the drainage system and creates a temporary detention system within the upstream conveyance network. The model shows that the existing conveyance system has sufficient storage to contain stormwater during storm events until the tide recedes.

A model simulation was also conducted with a proposed detention flow control system inserted along with the tide gates to determine if flooding can be further reduced. The model indicates there is a slight flood reduction as compared to the tide-gate-only scenario discussed above. The optional detention system is only feasible in conjunction with the tide gates to provide temporary storage of the upstream stormwater. A detention system has a greater benefit to flood reduction during large storm events, such as the 100-year storm events.

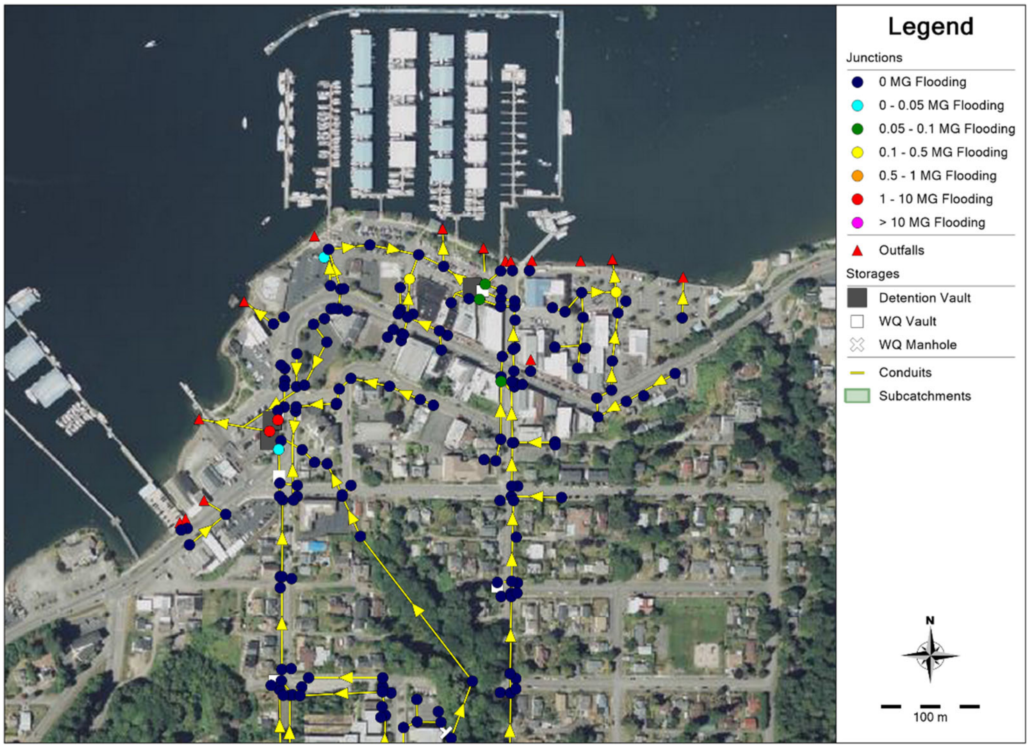


Figure 13. Flood Visual Map (North) – 25-year Storm, MHHW, with Tide Gate.

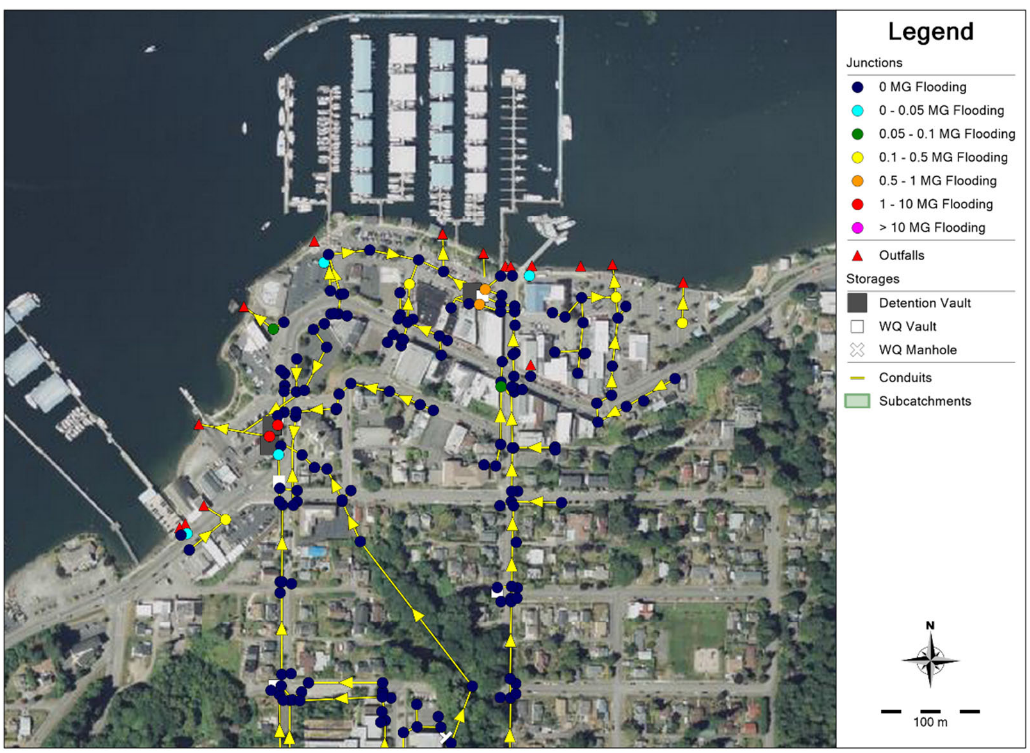


Figure 14. Flood Visual Map (North) – 25-year Storm, 10-year Tide, with Tide Gate.

3.3.1 Bay Street near City Hall (Site 12)

Bay Street near City Hall is a major convergence point for conveyance systems and surface runoff from upstream sources, including the existing stream channel/ravine. The stormwater model and anecdotal evidence indicates tidal conditions during storm events lead to flooding of Bay Street.

As described in the SMO 1 and SMO 2 sections for this area, water quality and storm routing improvements are recommended. A tide gate backflow device is proposed in the new manhole described in SMO 1, Boat Launch area, Item 1. Installation of a backflow device in the manhole structure reduces potential flooding upstream and allows for efficient maintenance and access to the outfall pipe and backflow device.

An optional detention system (e.g., precast concrete vault) can be installed to temporarily detain upstream stormwater during storm events to supplement the tide gate. Detention is typically not required for areas that discharge directly to salt water. This optional detention is intended to temporarily hold upstream stormwater flows during high tide events to reduce backwater influences upstream.

3.3.2 Business District and Marina Parking Lot (Site 13)

This area is described in SMO 2, Lower Basin, and is a continuation of Item 1 of that section. This area contains most of the outfalls into Sinclair Inlet, plus several outfalls that discharge under the surrounding buildings. With numerous outfalls, high-elevation tide events will generate negative backwater impacts at more locations within the area.

A new conveyance system of catch basins and storm pipe is proposed to eliminate the under-the-building outfalls and route stormwater to the centralized water quality and oil/water separator vaults discussed in SMO 2, Lower Basin. The new system will combine with portions of the existing storm conveyance to eliminate some of the existing outfalls that discharge directly to Sinclair Inlet. This system will connect to the existing 36-inch outfall (largest of the outfalls in this area) with a new storm manhole equipped with a pump station. The combination of new storm routing, elevation drop within the water quality vault, and flat topography will require the proposed system outfall elevation to be lower than the existing outfall pipe. To maintain the existing outfall elevation within the proposed conveyance system, a pump station may be necessary.

Another manhole structure equipped with a backflow device is proposed in the 36-inch pipe downstream of the proposed pump station. Installation of a backflow device in the manhole structure reduces potential flooding upstream and allows for efficient maintenance and access to the outfall pipe and backflow device.

An optional detention system, such as an underground precast vault, can be installed upstream of the water quality facilities to temporarily detain upstream stormwater during storm events to supplement the backflow device.

3.4 Prioritization Description

The improvement projects described above are grouped into 14 separate project areas. Projects will be evaluated on the criteria listed below. Each item will be assigned a value (from 0 to 2) that will be used to create a project ranking to assist with prioritization of the project list. The projects with the highest score are ranked highest priority.

1. Flood Reduction: Reduction in potential flooding. ‘0’ represents no flood reduction.
2. Water Quality Improvement Outcomes: Size of water quality treatment area. ‘2’ corresponds to treatment for a large tributary area.
3. Operation and Maintenance Factor: Level of efficiency to operate and maintain the system or facility. ‘2’ represents improved access to, maintenance of, and operation of stormwater system.
4. Conveyance Outcomes: Level of improvement to the storm conveyance system compared to the existing condition.
5. Site Impacts: Level of disturbance to existing pavements, landscaping, utilities, vehicular and pedestrian traffic. A value of 2 represents minimal or no impacts.
6. Costs: Level of construction costs. ‘2’ represents less than $50K; ‘1’ represents $51K to $500K; ‘0’ represents over $500K.
7. Benefit Factor: Level of benefit from improvement project. ‘0’ represents improvement to small area; ‘2’ represents improvement to a large area.

4. STAKEHOLDER ENGAGEMENT

The project team coordinated with City of Port Orchard staff during site investigations, brainstorming sessions, and design option meetings to solicit information and feedback. City staff that provided assistance included the Stormwater program manager, GIS personnel, facilities and maintenance personnel, and stormwater engineers. The city staff provided background information on the existing drainage system, status of water quality improvements, location of flood-prone areas, upcoming redevelopment, parallel City projects, and partnering opportunities.

The 14 improvement project areas were discussed with the stormwater manager to get feedback on the proposed projects and scoring criteria. Input from City staff helped with adjustments to the project scoring matrix to generate a final priority list of projects. The improvement projects generated from this report have not been discussed with the Downtown Basin landowners. The City of Port Orchard staff plan to communicate with community leaders once the plan is finalized.

5. FINAL PRIORITY (SMO) LIST

The proposed improvement projects address three major categories described in each of the SMOs. Each project site was scored based on a set of criteria to assist Port Orchard with prioritization of the projects. Table 3 shows the scored project list in order of rank from highest to lowest score. Figures 8 through 12 show locations of Site IDs.

Table 3. Project Scores from Highest to Lowest.

Site ID	Flood Reduction (0-2)	Water Quality Outcomes (0-2)	Operation & Maintenance Factor (0-2)	Conveyance Outcomes (0-2)	Site Impacts (0-2)	Costs (0-2)	Benefit Factor (0-2)	Total Score
12	2	2	2	2	0	0	2	**10**
13	2	2	2	2	0	0	2	**10**
2	1	2	1	1	1	1	1	**8**
7	0	2	1	2	1	1	1	**8**
14	1	2	1	1	1	1	1	**8**
3	1	1	1	1	1	1	0	**6**
8	0	1	0	1	1	1	1	**5**
11	0	1	0	0	1	2	1	**5**
1	0	0	0	1	1	2	0	**4**
4	0	0	1	2	0	1	0	**4**
5	0	1	0	0	1	2	0	**4**
6	0	0	1	2	0	1	0	**4**
9	0	1	0	0	1	2	0	**4**
10	0	0	0	0	1	2	0	**3**

6. SCHEDULE FOR IMPLEMENTATION

Port Orchard is currently updating their Stormwater and Watersheds Comprehensive Plan. Several of the higher-scoring improvement projects discussed in this report have been added to the Capital Improvement Prioritization (CIP) project list for the Comprehensive Plan update.

7. BUDGETING AND FUNDING SOURCES

As part of Comprehensive Plan update, a Stormwater Management Action Plan will be developed to align with local long-range plans. The City of Port Orchard has a surface water management utility rate structure that generates annual revenue for projects on the CIP list. The annual revenue from the utility rate is approximately $2 million. Another potential source of revenue is imposing local sales taxes as add-ons to the state general sales and use taxes. Special taxing districts or service drainage districts are recurring surcharges levied by the local jurisdiction on the population to cover entire communities. Port Orchard could levy these in the form of taxes dedicated to stormwater management or as fees. Grant funding is available for supporting specific initiatives of capital projects from government and private foundation sources. Debt financing, such as municipal bonds and loans, is another potential funding source.

Non-traditional funding sources include Public-Private partnerships and volunteer programs for small residential LID projects.

8. ADAPTIVE MANAGEMENT AND UPDATE PROCESS

An Adaptive Management process initially includes the formulation of improvement projects generated in this report to address Port Orchard's goals and needs in the downtown basin. The following list summarizes the steps of the adaptive management process.

1. Identify projects to address City concerns and needs. This stormwater plan report completes this step.
2. Once funding is secured to construct any of the identified improvement projects, monitoring of selected parameters to measure performance will be implemented. For example, monitoring locations at storm structures downstream of water quality facilities will be identified to analyze effectiveness of the facilities. Areas prone to flooding should be observed during rain and tidal events.
3. Results of the monitoring should be assessed to determine if adjustments or modifications are needed. The results should meet the desired goals to be considered a successful project.
4. Design modifications or structure upgrades, if needed, can be implemented for future improvement projects or the current deficient project.

Appendix A

Technical Memorandum, City of Port Orchard, Task 3.3 And 3.4

GeoEngineers

Memorandum

To: Heather Bearnes-Loza – Washington State Department of Ecology

Zack Holt – City of Port Orchard

Julian Doge and Mark Davis – Reid Middleton

From: Devan Fitzpatrick, Ken Fellows, and Joe Callaghan - GeoEngineers, Inc.

Date: March 18, 2022

File: 12309-017-00

Subject: Technical Memorandum City of Port Orchard Task 3.3 and 3.4

GeoEngineers, Inc. (GeoEngineers) prepared this technical memorandum to support the development of the City of Port Orchard Downtown Basin Stormwater Plan, grant number WQC-2018-PoOrPW-00206. GeoEngineers was tasked with developing three WWHM-SWMM models to predict stormwater quantity at three monitoring locations of interest (Task 3.3 and 3.4), and to develop a water quality model to quantify the runoff and magnitude of total suspended solids (TSS) in the downtown City of Port Orchard basin (Task 3.5). This document serves as a summary of the WWHM-SWMM models that were developed by GeoEngineers to complete Tasks 3.3 and 3.4. as outlined in the Quality Assurance Project Plan (QAPP) (Quality Assurance Project Plan Port Orchard Downtown Basin Plan, 2020). GeoEngineers met with Reid Middleton, the Washington State Department of Ecology, and the City of Port Orchard on March 8, 2022, to select the preferred option to move forward with the project following the discovery of observation data errors (Section 4.0). Option 2 was selected as the preferred option and was approved by the Washington State Department of Ecology.

WWHM-SWMM models have been fully developed for each of the three designated stormwater basins as described in Task 3.3 and 3.4 as outlined in the QAPP (Quality Assurance Project Plan Port Orchard Downtown Basin Plan, 2020); however, the models have not been successfully calibrated with measured stormwater flow data as described in Section 6.4 of the QAPP. Stormwater flow data was collected by the City of Port Orchard staff at the three designated monitoring locations. Initial calibration efforts did not meet performance targets and the project team investigated potential sources of error. The team looked for topology errors in GIS data, potential groundwater inputs, conducted dye testing and CCTV of existing infrastructure and reviewed the weir stage discharge relationships. The team concluded that the collected observation data is mostly unsuitable for use in calibrating the high end of the models because the weirs are overwhelmed during larger storm events. Based on observed data, the monitoring weirs were not able to capture high intensity or long duration storm events. These larger events provide the key metrics (peak storm event flows and total run-off volumes, see QAPP Table 5) used to calibrate the models. Without this data, model calibration cannot be completed. The developed models incorporate site specific data, including location adjusted precipitation data as described in QAPP Section 7.2, and may still be suitable for use as tools to aid in developing the stormwater plan and comparing water quality improvement options and strategies.

This memorandum summarizes our stormwater model development work, describes the problem with the stormwater monitoring data, and identifies the selected preferred option to move forward with the project to achieve project goals and objectives. The water quality models will be started following submittal of this memorandum.

1.0 PROJECT OVERVIEW

The existing Port Orchard (City) stormwater infrastructure is outdated and does not provide adequate hydraulic or water quality control. With little to no flow control, the current system is unable to handle high water flows and often backwaters during large storm events. Flooding is not uncommon in downtown Port Orchard. The existing stormwater infrastructure also does not have any mechanisms to improve water quality. The City of Port Orchard Downtown Basin Stormwater project will develop a Downtown Basin Stormwater Plan to identify stormwater quality and quantity improvement opportunities for Port Orchard's downtown and shoreline areas. Quantifying the magnitude of pollutant loading and flows within the downtown basin is essential to address these issues within the Port Orchard stormwater system. The purpose of this project is to conduct stormwater quality and quantity analysis to aide in development of a Downtown Basin Stormwater Plan to identify stormwater quality and quantity improvement opportunities for Port Orchard's downtown and shoreline areas.

Specific goals of this project were as follows:

- Analyze water quality and quantity data collected at three monitoring locations in the project area.
- Use modeling tools to assess current water quality and quantity at the downtown outfalls.
- Inventory stormwater management constraints and opportunities in the downtown basin.
- Assess the most cost-effective alternative(s) to address deficiencies through structural and non-structural best management practices (BMPs).
- Inventory stormwater management constraints and opportunities in the downtown basin
- Address essential data gaps in terms of stormwater infrastructure or water quality.

GeoEngineers Inc. has been conducting hydrologic and hydraulic modeling to complete Tasks 3.3 and 3.4 outlined in the QAPP to move towards meeting project deliverables and goals. An overview of the WWHM-SWMM models is provided in Section 2.0 below.

2.0 WWHM-SWMM MODELS OVERVIEW FOR TASK 3.3 AND 3.4

Hydrologic and hydraulic modeling for this project was conducted using a recently developed model called WWHM-SWMM (Clear Creek Solutions, 2022). WWHM-SWMM combines the hydrologic modeling capabilities of WWHM with the hydraulic modeling capabilities of SWMM. The purpose of selecting this model was to use the Washington-specific information contained within the WWHM software to save time, reduce uncertainty, and increase accuracy compared to only building a SWMM runoff model requiring manual input and calibration of model parameters such as soil hydrologic characteristics, depression storage rates, and evaporation data.

2.1 General Model Inputs

Development of the three WWHM-SWMM stormwater models associated with each monitoring location requires several data sources. Those sources include: physical basin data (i.e. topographic, stormwater network, land use and soil type), stormwater monitoring data (i.e. runoff quantity), and meteorological data (i.e. rainfall and evaporation). Physical basin data and meteorological data were required for basic model development.

Physical Basin Data: Input to model

- Topographic data was obtained from Kitsap County 2018 LiDAR (Washington State LiDAR Portal, n.d.).
- Soil information was obtained by USDA Web Soil Survey (United States Department of Agriculture, 2021).
- Stormwater network data was obtained from Reid Middleton.
- Catch basin contributing areas were delineated by Reid Middleton.
    - Catch basin contributing area boundaries were revised based on dye testing that was conducted in areas of uncertainty to improve WWHM-SWMM model results following the initial model runs.
- Land use was delineated by Reid Middelton.
    - GeoEngineers checked the land cover data for topology errors and further broke down landcover by slope and hydrologic soil groups using topographic and soils data to input into the model.

Meteorological Data: Input to model

- Evaporation data is built into the WWHM-SWMM model based on project location.
    - Evaporation data from the WWHM-SWMM software was extended to include the time period when observation data was collected.
- Rainfall data for the model is a combination of data collected by the City of Port Orchard and Bremerton Airport precipitation gauge data information.
    - A regression was made between City of Port Orchard gage and the Bremerton Airport gage to convert Bremerton Airport data to City of Port Orchard data (multiplication factor of ~0.8). The converted data was used to fill in data gaps in the City of Port Orchard data and extend the precipitation record.

Stormwater modeling data: Used for calibration

- Flow data was collected by the City of Port Orchard using weirs and pressure transducers installed in the monitoring location catch basins.
- GeoEngineers identified that higher flows were not being accurately captured by the installed weirs during the WWH-SWMM model calibration process (see Section 2.3).

2.2 Basin-Specific Model Inputs

Three separate WWHM-SWMM models were developed for the downtown City of Port Orchard project area corresponding with three stormwater basins of interest. In each basin, one specific location was selected as described in QAPP in Section 7.2 where stormwater flows would be measured and used to calibrate the models. Each monitoring location was selected to monitor stormwater from a different land use within the basin. The three monitoring locations include a manhole on Sidney, a manhole on Harrison and a manhole on

Cline. The monitoring location in the Sidney basin represents runoff from residential areas, the monitoring location in the Harrison basin represents runoff from commercial areas, and the monitoring location in the Cline basin represents runoff from areas currently receiving run-off treatment. In each basin, the selected monitoring point was a manhole having in-line flow.

2.3 WWHM-SWMM Model Status

Three WWHM-SWMM models have been developed, one for each of the basins of interest. The models were initially ran with the WWHM-SWMM model default parameters and basin areas delineated prior to field dye testing. Following the field dye testing contributing basin areas were updated and the models were re-ran. Following evaluation of initial model results compared to observed data collected at the monitoring locations, default parameters in WWHM-SWMM were modified to attempt to calibrate the models to obtain performance evaluation targets of good or very good as described in the QAPP. Performance targets for the models can be found in Table 5 of the QAPP and are shown in Table 1 below for reference. The following sections describe calibration efforts and the current status of the three modeled basins.

TABLE 1. QAPP PERFORMANCE TARGETS[1]

Model Component	Very Good	Good	Fair	Poor
Relative Mean Error in total volume	≤ 5%	5% - 10%	10% - 15%	>15%
Error in 50% lowest flow volumes	≤ 10%	10% - 15%	15% - 25%	>25%
Error in 10% highest flow volumes	≤ 10%	10% - 15%	15% - 25%	>25%
Error in storm volume	≤ 10%	10% - 15%	15% - 25%	>25%
R^2 daily values	> 0.80	> 0.70	> 0.60	≤ 0.60
R^2 monthly values	> 0.85	> 0.75	> 0.65	≤ 0.65

Notes: [1]Performance targets for WWHM-SWMM hydrologic/ hydraulic simulation from Table 5 in QAPP.

During the calibration process GeoEngineers identified that the stormwater flow monitoring data did not accurately capture higher flow events because stage measurements exceed the weir depth. Measured water depths at the weirs exceed the valid range of the weirs' stage/discharge curve, so that the stage data could not be used to determine the discharge rates. The issue affects the data from all three basins. Calibration of stormwater models relies heavily on peak storm flows and total runoff volumes. The observed data is not accurate for larger storm events due to the installed weirs being undersized and calibrating the model to inaccurate peak flows and total runoff volumes would not be useful. The below sections describe the calibration efforts up to the point where it was identified that the installed weirs were undersized and there was an error in observed data.

2.3.1 Sidney: Residential Basin

The Sidney monitoring location is at the intersection of Sidney and Dekalb Street. The basin location was selected to characterize runoff from residential areas. The basin consists of a mixture of pervious and impervious surfaces. The weir at the Sidney monitoring location has been reported by the City of Port orchard to have occasional debris issues.

Model key points:

- Basin and landcover updates based on dye testing: No major changes were made to the basin boundaries and landcover following dye testing.

- Relative mean error in total volume before calibration: 15 percent - over predicting.
- Relative mean error in total volume after calibration: 5 percent - over predicting.
- Calibration efforts: Ran a total of 7 different calibration attempts.
  - Increased LZSN (lower zone storage nominal) to decrease total volume. LZSN effects the amount of water stored in the lower zone and increases the opportunity for evapotranspiration.
  - Decreased NSUR (Manning's n for overland flow). Decreasing NSUR increases peak flows while maintaining total volume. Changed to improve comparison of modeled peaks to observed peak values.
  - Other parameters that were tested but ultimately left at default values were: INFLW (interflow inflow parameter), IRC (interflow recession), and INFILT (index to infiltration capacity).

Sidney summary: Total volume relative mean error, R squared daily values, and R squared monthly value targets outlined in QAPP Table 5 can most likely be achieved, but it would be calibrated to the observed data with known errors.

2.3.2 Harrison: Commercial Basin

The Harrison monitoring location is in a parking lot behind the Kitsap Regional Library. The catch basin monitoring location was selected to characterize runoff from commercial areas. The basin consists of largely impervious surfaces. The City of Port Orchard has noted that the catch basin used as the Harrison monitoring location may be tidally influenced and may have groundwater inputs that make model calibration difficult.

Model key points:

- Additional contributing area was added to the basin based on dye testing results compared to initial model runs. The increase in the contributing area improved model results compared to existing model runs but model results were still outside of performance targets.
- Relative mean error in total volume before calibration: 54 percent - under predicting.
- Relative mean error in total volume after calibration: 53 percent - under predicting.
- Calibration efforts: There are limited options for calibration for impervious surfaces.
  - Decreased NSUR to same value used for Sidney (Manning's n for overland flow). Decreasing NSUR increases peak flows while maintaining total volume. Changed to improve comparison of modeled peaks to observed peak values.
  - Decreased RETSC (retentions storage capacity) of roofs to increase total flow volume. Changing this value didn't make a large difference in total volume.

Harrison summary: Calibration of the Harrison model to meet QAPP performance targets appears unlikely due to limited parameters that can be adjusted for impervious surface coverage. The error in model results may be due to additional inputs into the system that were not identified during dye testing, or there may be tidal influence or groundwater coming into the stormwater pipes/joints that is not accounted for in the model. Initial calibration efforts were made using observed data with known errors.

2.3.3 Cline: Treated Basin

The Cline monitoring location is located at the intersection of Dwight Street and Cline Avenue. The catch basin monitoring location was selected to characterize runoff from areas currently receiving treatment. The basin consists of a mixture of land uses. The City of Port Orchard has noted that the catch basin used as the Cline monitoring location has a constant baseflow that may be due to groundwater contributions to the stormwater system. Through efforts from this project, including a Fluoride/Chloride test of water in the Cline catch basin, a water leak was identified near the Kitsap County building. The water leak appears to have started between June and August of 2021 based on water consumption reports. The leak occurred outside of the modeled dates and is not believed to be contributing to the difference between observed and modeled values. A CCTV test has been conducted by the city for storm waterpipes contributing flow to the Cline monitoring location catch basin. Results have not yet been received by GeoEngineers.

Model key points:

- Additional contributing area was added to the basin based on dye testing results compared to initial model runs. Increase in the contributing area improved model results compared to existing model runs.
- Relative mean error in total volume before calibration: 67 percent - under predicting.
- Relative mean error in total volume after calibration: 16 percent - under predicting.
- Calibration efforts: Focused on accounting for dry weather flows observed in the catch basin at the monitoring location that may be due to groundwater inputs.
  - Observed data indicates there is always flow in the Cline monitoring location. Zack, from the City of Port Orchard, also noted consistently observing flow at this catch basin.
  - An average dry weather discharge was calculated for time periods when precipitation was zero from observed data. The average discharge from observed data was added as a dry weather flow to the model results to increase total volume of model results.
  - This improved total volume relative mean error. However, the observed flow during dry weather in the monitoring location fluctuates over time. Adding a constant discharge does not provide an accurate hydrograph shape.

Cline summary: The Cline model may be able to be calibrated to meet the Fair category in the QAPP threshold table for RMSE in Total Volume, but it would be calibrated to the observed data with known errors. It appears unlikely to be able to calibrate the model outside of the Poor range for errors associated with hydrograph shape including the Error in 50 percent Lowest Flow Volumes and Error in 10 percent Highest Flow Volumes with the information we currently have. Observed data indicates the monitoring location at Cline may be receiving groundwater inputs that the model is not considering.

3.0 SUMMARY

The observation data collected at all three monitoring locations contains data that are invalid because the observed stage was outside of the recommended range for developed regressions from stage to discharge for the installed weirs. Calibration of stormwater models relies heavily on peak storm flows and total runoff volumes. The observed data is not accurate for the larger observed storm events due to the installed weirs being undersized and calibrating for peak flows and total runoff volumes will be inaccurate.

GeoEngineers reviewed the stormwater monitoring data, and key points are summarized below:

- Data validity: For the Harrison, Sidney, and Cline basins, 0.3 percent, 0.7 percent, and 0.5 percent of the overall data points were determined to be invalid.
  - These statistics include data points with stages of zero corresponding to zero stormwater discharge.
- Maximum vs allowable stage: The maximum weir stage observed at the Harrison monitoring location for the installed 8-inch weir was 0.86 feet; however, the maximum valid weir stage was 0.325 feet. The maximum valid weir stage for the installed 12-inch weirs at Sidney and Cline was 0.476 feet. The Sidney and Cline maximum observed weir stage was 1.37 feet and 1.06 feet, respectively.
- Maximum observed stage:
  - Harrison: The maximum stage observed was 0.86 feet vs the maximum valid weir stage was 0.325 feet.
  - Sidney and Cline: The maximum stages observed were 1.37 and 1.06 feet, respectively, vs the maximum valid stage of 0.48 feet.
- Maximum Valid Stage and Flow:
  - Harrison: The 8-inch weir has a predicted discharge of 0.19 cubic feet per second (cfs) at the maximum stage of 0.325 feet.
  - Sidney and Cline: The 12-inch weir has a predicted discharge of 0.57 cfs at the maximum stage of 0.325 feet.

The above metrics for the stormwater monitoring data show that although the vast majority of the data points are valid, the data points are only valid when there is little or no stormwater runoff. The available observed data set initially considered for calibration varied from 6 months to a year depending on the basin of interest being modeled. The three developed models were run for the same amount of time that observed data was available: 6 months to a year. During the time that observed data was collected there were numerous times at all three monitoring locations where the recorded stage exceeded the maximum valid weir stage. While this has not been tied to a specific storm return interval, the exceedances occurred frequently.

4.0 OPTIONS CONSIDERED TO MOVE FORWARD WITH PROJECT

Potential options to move forward with the project that were discussed at the March 8, 2022, meeting. Option 2 was selected as the preferred option to move forward with the project and was approved by the Washington State Department of Ecology.

1. Install larger weirs or other forms of stormwater monitoring equipment at all three monitoring locations and collect new stormwater data. Precipitation data will also need to be collected during this time. This

method would likely require a project extension and additional funding. Groundwater inputs into the system at the Harrison and Cline basins would need to be further considered.

2. Use the uncalibrated WWHM-SWMM models to support development of the stormwater plan. The existing uncalibrated WWHM-SWMM models incorporate much site-specific data and use default values for other inputs that are estimated to be generally representative of actual conditions. Results from the existing models could be used for water quality modeling and to assess the most cost-effective alternative(s) to address deficiencies through structural and non-structural BMPs. Without monitoring data, model calibration cannot be completed, and calibration results cannot be compared to QAPP Model quality objectives.
3. Identify storm events within the observed data set that have peak discharges below the maximum valid weir stage and calibrate the WWHM-SWMM models based on an individual storm event. Calibration to one storm event, with smaller peak flows, may still result in models that do not accurately predict the larger peak flows.
4. Add an adjustment factor to the WWHM—SWMM model results to account for the difference in observed values to predicted values from the WWHM-SWMM model. The factor would be applied to the modeled flows and used moving forward for water quality modeling and to assess the most cost-effective alternative(s) to address deficiencies through structural and non-structural BMPs. This option assumes the observed data, even with known errors, is more accurate than the developed WWHM-SWMM models; However, calibration of stormwater models relies heavily on peak storm flows and total runoff volumes. The observed data is not accurate for larger storm events and calibrating for peak flows and total runoff volumes will be inaccurate.

5.0 CONCLUSION

GeoEngineers, Inc. has developed three WWHM-SWMM models to predict stormwater quantity at three monitoring locations of interest to aide in development of the Downtown City of Port Orchard Stormwater Plan completing Tasks 3.3 and 3.4. The developed WWHM-SWMM models were not calibrated to observed data collected by the City of Port Orchard due to errors in collected data (Section 2.0 and 3.0). QAPP performance targets outlined in Table 5 of the QAPP (Table 1 of this report) are not applicable due to the lack of accurate observation data. GeoEngineers met with Reid Middleton, the Washington State Department of Ecology, and the City of Port Orchard on March 8, 2022, to select a preferred option to move forward with the project following the discovery of observation data errors (Section 4.0). Using the existing uncalibrated models (Option 2) was selected as the preferred option, and this approach was supported by the Washington State Department of Ecology during the March 8, 2022 meeting with Douglas Howie and Heather Beams-Loza. It was agreed that this Stormwater Plan is a feasibility study level document, and the uncalibrated models are generally suitable for evaluating and comparing stormwater management alternatives. The professional engineer in charge of final engineering design of specific stormwater facilities will need to assess validity and suitability of the models for specific use at the time such work is completed. Additionally, during the March 8 meeting, it was also agreed that the water quality modeling will be completed using the uncalibrated stormwater models.

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Appendix B

Technical Memorandum, City of Port Orchard, Summary of Water Quality Models

GeoEngineers

Memorandum

To: Heather Bearnes-Loza – Washington State Department of Ecology
Zack Holt – City of Port Orchard
Julian Doge and Mark Davis – Reid Middleton

From: Ken Fellows, Blake Graffe, and Joe Callaghan - GeoEngineers, Inc.

Date: September 21, 2022

File: 12309-017-00

Subject: Technical Memorandum City of Port Orchard – Summary of Water Quality Models

GeoEngineers, Inc. (GeoEngineers) prepared this technical memorandum to support development of the City of Port Orchard Downtown Basin Stormwater Plan, grant number WQC-2018-PoOrPW-00206. GeoEngineers was tasked with developing three water quality spreadsheet models to quantify the runoff and magnitude of total suspended solids (TSS) in the downtown City of Port Orchard basins (GeoEngineers Scope of Work Task 3.5) in accordance with the Quality Assurance Project Plan (QAPP) (GeoEngineers 2020). This memorandum documents the water quality models that were developed.

Spreadsheet based water quality models for TSS have been developed for each of the three designated downtown stormwater basins; however, the models used a project-specific spreadsheet rather than the QUAL2K model as originally envisioned.

QUAL2K MODEL DESCRIPTION

The QUAL2 model was developed to simulate natural stream environments to support planning and implementation of total maximum daily load (TMDL) regulations. QUAL2 is applicable to dendritic streams that are well mixed and can simulate up to 23 water quality constituents. A stream reach is divided into a number of computational elements, and for each element, core analyses are completed that include a hydrologic balance in terms of stream flow, a heat balance in terms of temperature, and a material balance in terms of concentration. The model assumes all channels are trapezoidal with open tops. The QUAL2K model is run for a single event (i.e., a specific date and time). Flows in and out of each dendritic element are calculated and the model produces a series of steady-state water surface profiles. The calculated stream-flow rate, velocity, cross-sectional area and water depth serve as a basis for determining the heat and mass fluxes into and out of each computational element due to flow. Mass balance determines the concentrations of conservative minerals, coliform bacteria, and non-conservative constituents at each computational element. In addition to material fluxes, major processes included in the mass balance are transformation of nutrients, algal production, benthic and carbonaceous demand, atmospheric re-aeration, and the effect of these processes on the dissolved oxygen balance. The model uses a finite-difference solution of the advective-dispersive mass transport and reaction equations to complete the material balance.

The QUAL2K model was not directly applicable to use for simulating stormwater runoff from downtown Port Orchard, as stormwater flow through downtown Port Orchard is conveyed in buried pipes, not open stream channels. Additionally, the QUAL2K model is complex and requires extensive site-specific data to run. In contrast, the water quality data collection and modeling for the downtown Port Orchard stormwater basins is focused on a single water quality constituent – TSS. TSS is assumed to be inert and not subject to transformative processes. The extensive and complex capabilities of QUAL2K could not readily be turned off to run it for a simple analysis of TSS. Additionally, because QUAL2K simulates a single point in time, it is not able to sum flows over time to generate annual runoff volumes and annual TSS loadings, which are of interest to aid planning activities for potential retrofit of stormwater treatment.

GEOENGINEERS PROJECT-SPECIFIC MODEL DESCRIPTION

The GeoEngineers spreadsheet model contains the same basic arrangement of elements and same hydrologic model, in which flow starts at the upstream most element and is increased moving downstream as stormwater inflows occur from additional contributing subbasins. The GeoEngineers model contains essentially the same material mass balance equations as QUAL2K. A TSS value is identified for each inflow. TSS in treated as a conserved inert substance that undergoes no chemical or physical changes moving downstream and has no secondary sources (such as erosion of previously accumulated sediment) or sinks (deposition of sediment).

Appendix A, Manholes and Catch Basins, lists the manholes and catch basins that make up the system network as evaluated in the Western Washington Hydrology Model/Storm Water Management Model (WWHM/SWMM) models, along with the WWHM/SWMM model graphical layout, and schematic layouts of the three downtown basins with City of Port Orchard infrastructure identification numbers and street names. All three storm drain networks are modeled as linear, with no branching, from upstream to downstream. Inflows of stormwater runoff and TSS occur at the nodes (i.e., manholes and catch basins) between the flow elements.

The model uses the following inputs:

- Subbasins and land use: The subbasins and their associated soil types, land uses types and areas within each subbasin are the same as used as inputs to the WWHM/SWMM stormwater flow model (see Table 1).

TABLE 1: SUMMARY OF BASIN LAND USE CHARACTERISTICS

Parameter	Cline/Dwight Basin (%)	Sydney/Dekalb Basin (%)	Harrison Basin (%)
Forest	12	0	0
Open Space	3	4	0
Transportation	14	14	0
Residential	16	59	0
Commercial	31	0	73
Roof	25	24	27

- Stormwater flows: Stormwater flows are an output from the WWHM/SWMM models previously developed for this project.
- Event mean TSS concentrations in stormwater runoff: We researched sources of data for obtaining and/or predicting TSS concentrations in stormwater runoff. An often cited but now somewhat dated reference is: United States Environmental Protection Agency (EPA). 1999. Preliminary Data Summary of Urban Storm Water Best Management Practices. EPA-821-R-99-012 (EPA 1999). Overall, we identified that the Minnesota Pollution Control Agency (MPCA) had completed the most comprehensive and useful summary of event mean TSS concentration in stormwater runoff (MPCA 2022). The full

webpage is included in Appendix B, Minnesota Stormwater Manual Webpage for reference. The MPCA identified the event mean TSS concentrations for a range of land use types that were comparable to those used as inputs to the WWHM/SWMM model (see Table 2).

TABLE 2. EVENT MEAN TSS CONCENTRATIONS IN STORMWATER RUNOFF (MPCA, 2022)

Land Use	Recommended Event Mean TSS Concentration (mg/L)
Forest	49
Open Space	21
Transportation	87
Residential	73
Commercial	120
Roof	20

Notes:
mg/L = milligrams per liter

MPCA acknowledges these TSS concentrations can vary by rainfall intensity and amount, interval between runoff events, length of runoff event, nature of the watershed, and land use specifics. Total sediment mass generated by each land use over time is typically greater than the event mean concentrations suggest because the mass also depends on the runoff volume, which would typically be greatest for commercial and industrial land use and least for open space. MPCA found that TSS mass loadings did not vary greatly with varying soil types.

The models can be run for either a date/time or for a duration (a year or more). If run for a date/time, the model output is in the form of a concentration (mg/L). If run for a duration, the output is in the form of annual TSS loading (pounds per year [lb/year]).

The WWHM/SWMM model was run using available data for the period of record: 1/2/2000 to 3/4/2021. Results for the period of record are summarized in Table 3. These results are for the "monitoring location" where stormwater flow measurements were made (see Appendix A).

TABLE 3: SUMMARY OF TSS LOADING BY BASIN AT MONITORING LOCATION

Parameter	Cline/Dwight Basin	Sydney/Dekalb Basin	Harrison Basin
100-year storm flow (cfs)	6.0	15.4	1.8
25-year storm flow (cfs)	4.5	11.3	1.3
2-year storm flow (cfs)	2.0	4.5	0.6
Average Annual Runoff Volume (cf)	700,016	1,766,190	206,462
Predicted Average Annual TSS Concentration (mg/L)	84	56	92
Predicted Average Annual TSS Mass Loading (lb/year)	3,475	6,199	1,186

Notes:
cfs = cubic feet per second; cf = cubic feet

TSS SAMPLING

Eight grab samples were collected from the monitoring location in each of the three basins. Samples were collected during the period 4/22/2020 to 1/11/2021. Samples were submitted to a laboratory for testing for TSS (see Table 4). The flow predicted by the WWHM/SWMM models was reviewed to categorize the flow condition when each TSS sample was collected as “base flow”, “minor storm event flow”, or “major storm event flow” (see Table 4 for definitions).

TABLE 4. SUMMARY OF TSS SAMPLING DATA

	Cline/Dwight Basin	Sydney/Dekalb Basin	Harrison
Date	**TSS (mg/L)**	**TSS (mg/L)**	**TSS (mg/L)**
4/22/2020**	9.5	374.0	84.0
5/6/2020**	11.0	28.0	70.0
6/12/2020*	14.0	11.6	42.0
8/21/2020**	175	406	99.0
11/3/2020***	8.5	60.0	55.0
11/10/2020**	36.0	33.2	16.8
11/12/2020*	20.0	19.0	236
1/11/2021**	22.0	40.0	45.6
ALL SAMPLES			
Minimum	8.5	11.6	16.8
Average	37.0	121.5	81.1
Maximum	175	406	236
Upper Bound 95th Percentile Confidence Limit	82	253	135
TSS Loading - Base Flow Over Period of Record (% of total loading)	0.09	0.05	0.12
STORM EVENT SAMPLES			
Minimum	8.5	28.0	16.8
Maximum	175	406	99
Average	43.7	157	61.7
Upper 95th Percentile Confidence Value	103	323	88

Notes:

*Flow (as predicted by WWHM/SWMM model) at time of sampling as less than 0.0003 cfs, 0.0005 cfs, and .0001 cfs for Cline, Sydney, and Harrison basins respectively at their monitoring nodes with similar flows occurring for relatively long periods before and/or after the time of sampling. These times were categorized as “base flow” not associated with any storm event flow.

** Flow (as predicted by WWHM/SWMM model) at time of sampling was greater than the base flow rate cutoff, but still relatively small (typically much less than one-half of the 2-year storm event flow.

*** Flow (as predicted by WWHM/SWMM model) at time of sampling was greater than one-half the 2-year storm event flow.

Although TSS concentrations during base flow events were often higher than during storm events, the extremely low flow rates during the times categorized as base flows resulted in the mass loadings associated with the base flows being less than 0.2 percent of total annual TSS loadings. Therefore, it is recommended that only the

TSS sample results associated with storm events flows be used in evaluations in Stormwater Plan, such as for considering retrofit stormwater facilities.

The sample results in Table 4 can also be considered for the dry and wet seasons. Four of the eight samples were collected in each season. The average dry and wet season TSS concentrations are shown in Table 5. For the Cline/Dwight and Sydney/Dekalb basins, TSS concentrations were greater in the dry season than the wet season. TSS mass loadings were not calculated for the dry and wet seasons, but it is anticipated that the wet season loadings would be much greater than the dry season loadings due to the much greater volumes of flow in the wet season as compared to the dry season.

TABLE 5. AVERAGE DRY AND WET SEASON TSS CONCENTRATIONS

	Cline/Dwight Basin	**Sydney/Dekalb Basin**	**Harrison**
Season	**TSS (mg/L)**	**TSS (mg/L)**	**TSS (mg/L)**
Dry	95	209	71
Wet	18	92	85

TSS CALIBRATION FACTOR

A calibration factor for TSS in stormwater was identified for each basin by comparing the average of the measured TSS concentrations for TSS sampled collected during storm events to the average of the TSS concentrations predicted by the models (see Table 6). The predicted TSS concentrations were obtained by running the TSS model using flows predicted by WWHM/SWMM at the same date and time that the TSS sample was collected. For example, the Sydney basin sample for 4/22/2020 was collected at 9:41 am, and the predicted TSS concentration was obtained by running the TSS model using WWHM/SWMM flow results for the corresponding 15-minute modeling period for all subbasins upstream of the monitoring manhole. Since the measured TSS concentrations in the three basins differ, there is a calibration factor for each basin.

A calibration factor less than 1 indicates that measured TSS concentrations were less than predicted by the uncalibrated model, and a calibration factor greater than 1 indicates that measured TSS concentrations were greater than predicted by the uncalibrated model.

TABLE 6. DETERMINATION OF CALIBRATION FACTORS

Metric	**Cline/Dwight Basin**		**Sydney/Dekalb Basin**		**Harrison Basin**	
TSS Concentration (mg/L)	Measured	Predicted	Measured	Predicted	Measured	Predicted
4/22/2020	10.0	85.0	374.0	56.0	84.0	92.0
5/6/2020	11.0	78.0	28.0	56.0	99.0	92.0
8/21/2020	175.0	80.0	406.0	56.0	99.0	92.0
11/3/2020	9.0	78.0	60.0	56.0	55.0	92.0
11/10/2020	36.0	78.0	33.0	56.0	17.0	92.0
1/11/2021	22.0	78.0	40.0	56.0	46.0	92.0
Average Concentration (mg/L)	**43.7**	**54.8**	**157**	**44.1**	**61.7**	**56.0**
Calibration Factor	**0.80**		**3.56**		**1.10**	

TSS LOADING FOR POTENTIAL RETROFIT STORMWATER FACILITIES

For stormwater planning purposes, annual TSS load is a more useful metric than a TSS concentration that is applicable only to specific date and time. TSS differs from most other water quality parameters in that there is no specific acute or chronic water quality standard for TSS. Stream flows can be naturally turbid and generally not harmful to aquatic life if the material comprising the TSS is of natural origin. In urban settings, however, TSS is often comprised of heavy metals and other deleterious substances that have specific water quality limits. Urban generated TSS discharged to natural water bodies can directly impair water quality and also impair stream beds and nearshore areas in marine water. Turbidity is regulated as a measure of sediment in water, but, unfortunately, no simple relationship exists between turbidity and TSS concentrations. Since TSS values are not directly regulated, there is no specific action level indicating when TSS concentrations are excessive.

It is recognized that stormwater treatment facilities remove substantial TSS. Annual TSS load data is useful because it can be compared between locations within a basin, and between basins, to aid in understanding where retrofit stormwater treatment facilities can provide the most benefit by capturing the most TSS. Stormwater treatment facilities are typically designed to treat stormwater runoff up to a certain flow rate and bypass higher flows. Thus, TSS loads in the treated runoff are captured (with a capture efficiency that varies based on the treatment technology employed, system sizing, maintenance, and other factors), whereas TSS loads in the bypassed runoff are not.

To provide illustrative TSS loading data to aid stormwater planning, the TSS models were run for each basin for the period of record to identify annual average stormwater flow volumes and TSS loadings. Calculating the TSS loading from a subbasin requires first calculating the stormwater flow rates for each hour over the period of record, sorting the flow rate data as either greater than or less than the threshold flow rate, and then summing up the flow volumes. This process is repeated for each subbasin upstream of the location of interest. Finally, the flow volume data is combined with the event mean TSS concentration data for each subbasin to identify the annual TSS loading. In a spreadsheet, this process can be streamlined to some extent using pivot tables, but calculating TSS loadings at many points throughout a basin would require substantial effort beyond the current scope of work. Reid Middleton provided a short list of locations where TSS loading data was of interest:

1. Cline/Dwight Basin
    a. 324 (Represents the Public sector)
    b. 142 (Represents the Stream/High Density housing)
2. Sydney/Dekalb Basin
    a. 4002 (Represents dense Residential zone)
    b. 4016 (Represents less dense Residential zone)
    c. 3648 (Represents Roadway area)
3. Harrison Basin
    a. 3632 (Represents Commercial Area)

The threshold flow rates were taken as one-half the 2-year flow as determined by the WWHM/SWMM model. WWHM/SWMM determined the 2-year flow rates for the Cline, Sydney, and Harrison basins to be 1.99, 4.5 and 0.59 cfs, respectively. Therefore, one-half the 2-year flow for the Cline, Sydney, and Harrison basins are 1.0, 2.25, and 0.30 cfs, respectively.

The TSS calibration factors from Table 6 were applied to the raw TSS model output for each basin.

Annual average unadjusted TSS loadings for the locations of interest are shown in Table 7. Final adjusted results after application of the calibration factors from Table 7 are shown in Table 8.

TABLE 7. UNADJUSTED ANNUAL AVERAGE ADJUSTED TSS LOADINGS

Basin and Location	TSS Loading in Stormwater Flows Less than One-half 2-year Storm Event (lb/year)	TSS Loading in Stormwater Flows Greater than One-half 2-year Storm Event (lb/year)
CLINE/DWIGHT BASIN		
324 ("monitoring" manhole near Kitsap County auditor building and intersection of Cline Avenue and Dwight Street)	3,126	444
142 (manhole North of Bay Street, between Water Street and Robert Geiger Street.)	18,050	2,454
SYDNEY/DEKALB BASIN		
4016 (manhole near intersection of Sydney Avenue and Division Street)	2,698	283
4002 (manhole at intersection of Sydney Avenue and Dwight Street	4,209	470
3648 (manhole on Sidney Avenue, South Side of Bay Street)	8,883	1,057
HARRISON BASIN		
Unnamed Manhole in Parking Lot at upstream end of Storm Drain SD-PL4-M	1,030	156

TABLE 8. ADJUSTED ANNUAL AVERAGE TSS LOADINGS

Basin and Location	TSS Loading in Stormwater Flows Less than One-half 2-year Storm Event (lb/year)	TSS Loading in Stormwater Flows Greater than One-half 2-year Storm Event (lb/year)
CLINE/DWIGHT BASIN		
324 ("monitoring" manhole near Kitsap County auditor building and intersection of Cline Avenue and Dwight Street)	1,717	244
142 (manhole North of Bay Street, between Water Street and Robert Geiger Street.)	9,912	1,347
SYDNEY/DEKALB BASIN		
4016 (manhole near intersection of Sydney Avenue and Division Street)	7,527	790
4002 (manhole at intersection of Sydney Avenue and Dwight Street	11,744	1,311
3648 (manhole on Sidney Avenue, South Side of Bay Street)	24,786	2,950
HARRISON BASIN		
Unnamed Manhole in Parking Lot at upstream end of Storm Drain SD-PL4-M	691	105

CONCLUSION

GeoEngineers developed three spreadsheet water quality models to predict TSS concentrations in stormwater runoff at specific dates and times to compare to TSS concentrations in stormwater samples collected at the same dates and times. The models also calculated annual average TSS loadings at selected locations based on data spanning the period of record. The TSS models use the same land use inputs as the three WWHM-SWMM hydrologic models and use WWHM/SWMM output results combined with literature derived event mean TSS concentrations that vary by land use.

Eight grab samples were collected from the monitoring location in each of the three basins. Samples were analyzed for TSS. The flow at the date and time each sample was collected was assessed and TSS data from samples collected during base flow times were discarded. For the remaining data, measured TSS concentrations were compared to TSS concentrations predicted by the water quality models for the same date and time each sample was collected. For each TSS sample, the ratio of the measured concentration to the predicted concentration was calculated. The average of the ratios for each basin is called the calibration factor.

The calibration factors should be applied to any future TSS modeling completed using the three water quality models. The calibration factors should be applied by multiplying the model output by the applicable calibration factor to obtain the adjusted model prediction. A simplifying assumption is that the calibration factors are applicable and constant throughout each basin, as there is no data available to develop location specific calibration factors. It is also assumed that the concentrated derived calibration factors are equally applicable to annual TSS loading. If in the future land use, runoff characteristics, or fraction of stormwater runoff being treated were to change substantially for any subbasin upstream of the location of interest, the calibration factor would no longer be applicable.

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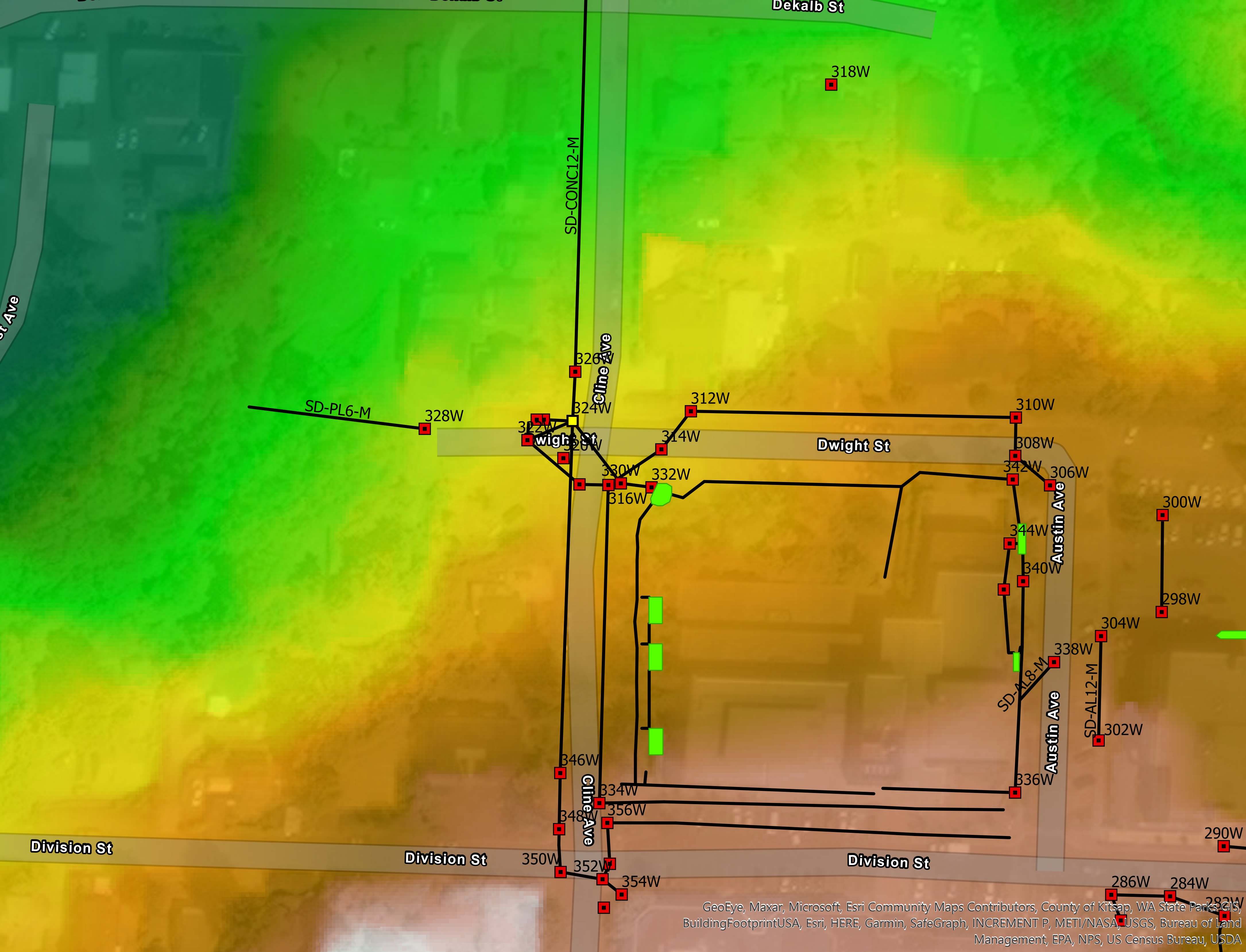
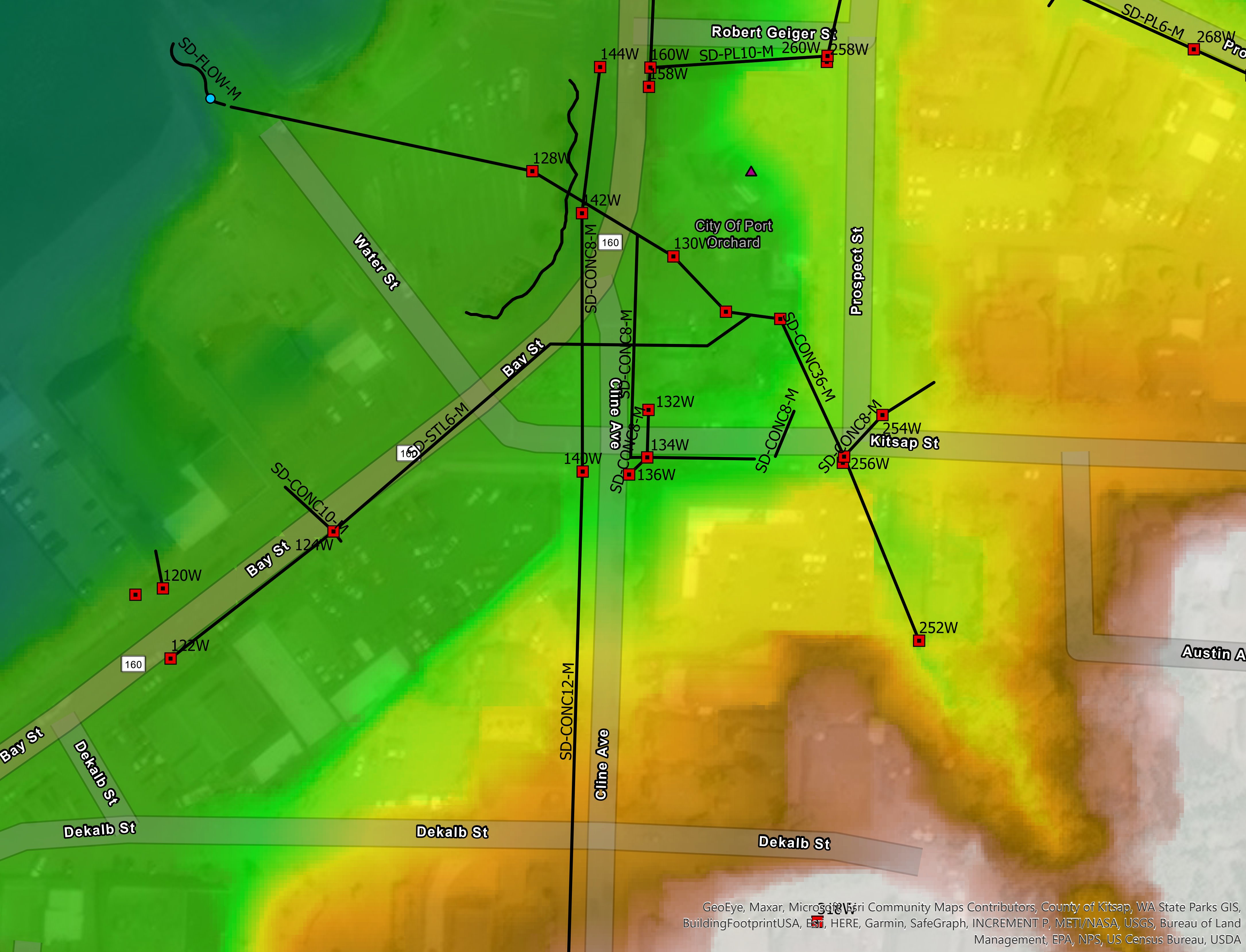
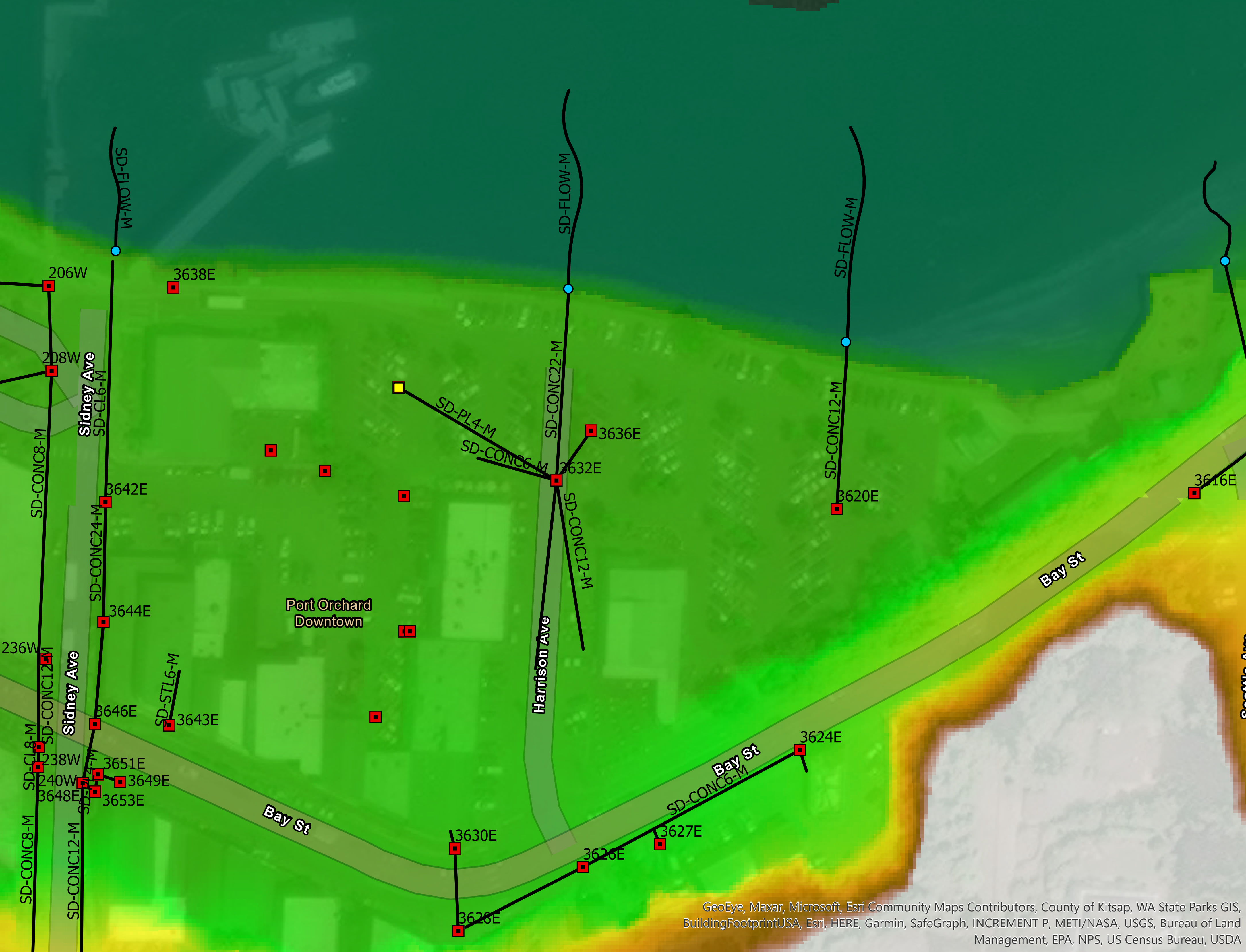
Attachments:
Appendix A. Manholes and Catch Basins
Appendix B. Minnesota Stormwater Manual Webpage

APPENDIX A
Manholes and Catch Basins



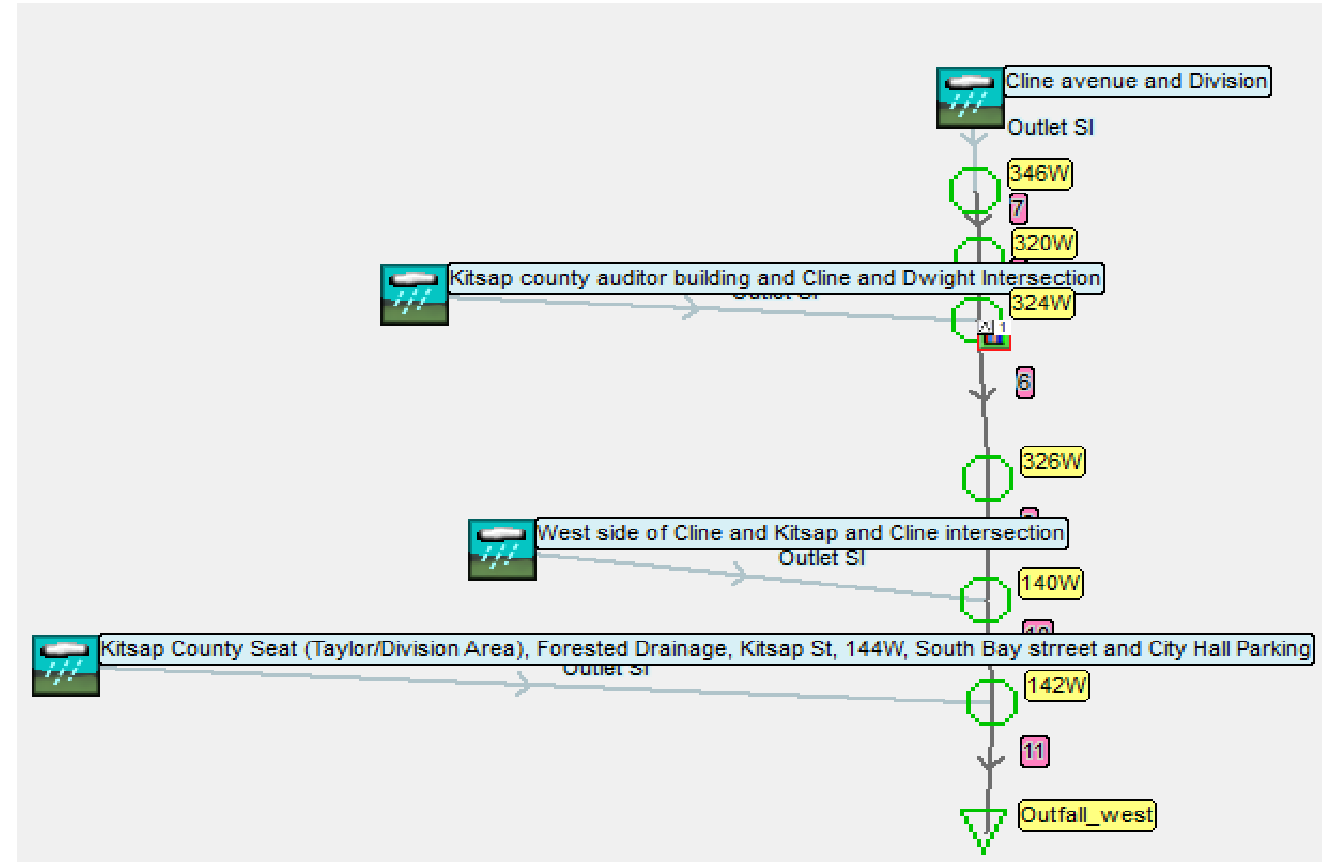
Dekalb St
318W
SD-CONC12-M
Cline Ave
326W
SD-PL6-M
328W
324W
322W
Dwight St
320W
312W
314W
310W
308W
342W
306W
330W
332W
316W
300W
344W
Austin Ave
340W
298W
304W
338W
SD-AL8-M
SD-AL12-M
302W
346W
336W
334W
348W
356W
Division St
350W
352W
354W
290W
286W
284W
282W
GeoEye, Maxar, Microsoft, Esri Community Maps Contributors, County of Kitsap, WA State Parks GIS, BuildingFootprintUSA, Esri, HERE, Garmin, SafeGraph, INCREMENT P, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA


SD-FLOW-M
Robert Geiger St
144W
160W
SD-PL10-M
260W
258W
158W
SD-PL6-M
268W
128W
142W
SD-CONC8-M
160
City Of Port Orchard
130W
Water St
Prospect St
SD-CONC36-M
Bay St
SD-STL6-M
Cline Ave
SD-CONC8-M
132W
134W
136W
140W
SD-CONC8-M
254W
Kitsap St
256W
SD-CONC10-M
124W
120W
122W
252W
SD-CONC12-M
Cline Ave
Dekalb St
Dekalb St
Dekalb St
GeoEye, Maxar, Microsoft, Esri Community Maps Contributors, County of Kitsap, WA State Parks GIS, BuildingFootprintUSA, Esri, HERE, Garmin, SafeGraph, INCREMENT P, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA


SD-FLOW-M
SD-FLOW-M
SD-FLOW-M
206W
3638E
208W
Sidney Ave
SD-CL6-M
SD-CONC8-M
SD-PL4-M
SD-CONC22-M
3636E
SD-CONC6-M
3632E
SD-CONC12-M
3620E
3616E
3642E
SD-CONC24-M
SD-CONC12-M
Bay St
3644E
Port Orchard Downtown
Harrison Ave
236W
SD-CONC12-M
Sidney Ave
SD-STL6-M
3646E
3643E
SD-CL8-M
238W
3651E
240W
3649E
3648E
3653E
3624E
Bay St
SD-CONC6-M
Bay St
3630E
3627E
3626E
SD-CONC8-M
SD-CONC12-M
3628E
GeoEye, Maxar, Microsoft, Esri Community Maps Contributors, County of Kitsap, WA State Parks GIS, BuildingFootprintUSA, Esri, HERE, Garmin, SafeGraph, INCREMENT P, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA

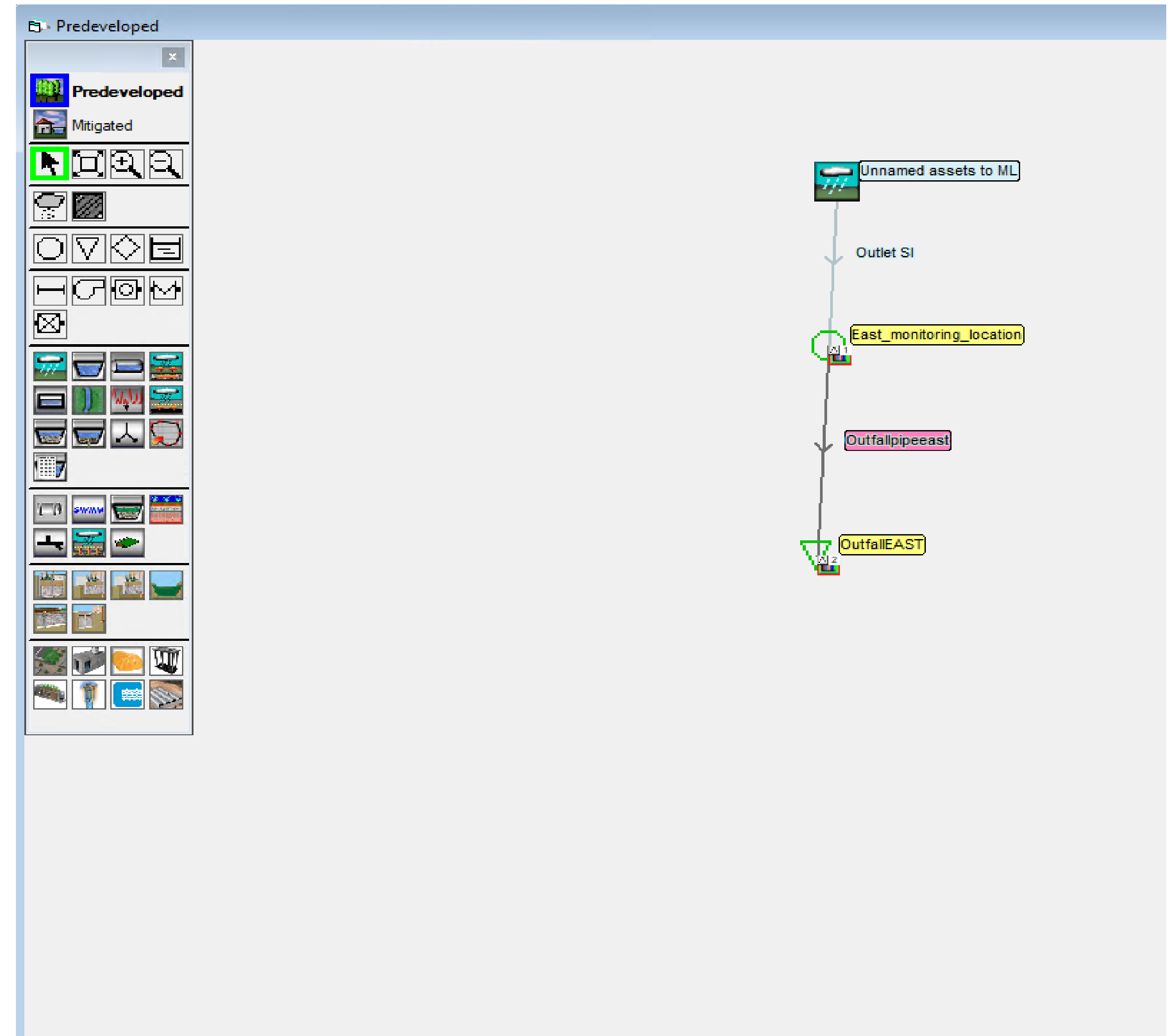
Cline/Dwight Basin

Nodes where TSS can be calculated	Monitoring Location	Approx. Location
346W		Cline avenue and Division
320W		Cline avenue and Division
324W	X	Kitsap county auditor building and Cline and Dwight intersection
326W		Kitsap county auditor building and Cline and Dwight intersection
140W		West side of Cline and Kitsap and Cline intersection
142W		North of Bay St, between Water St and Robert Geiger St.



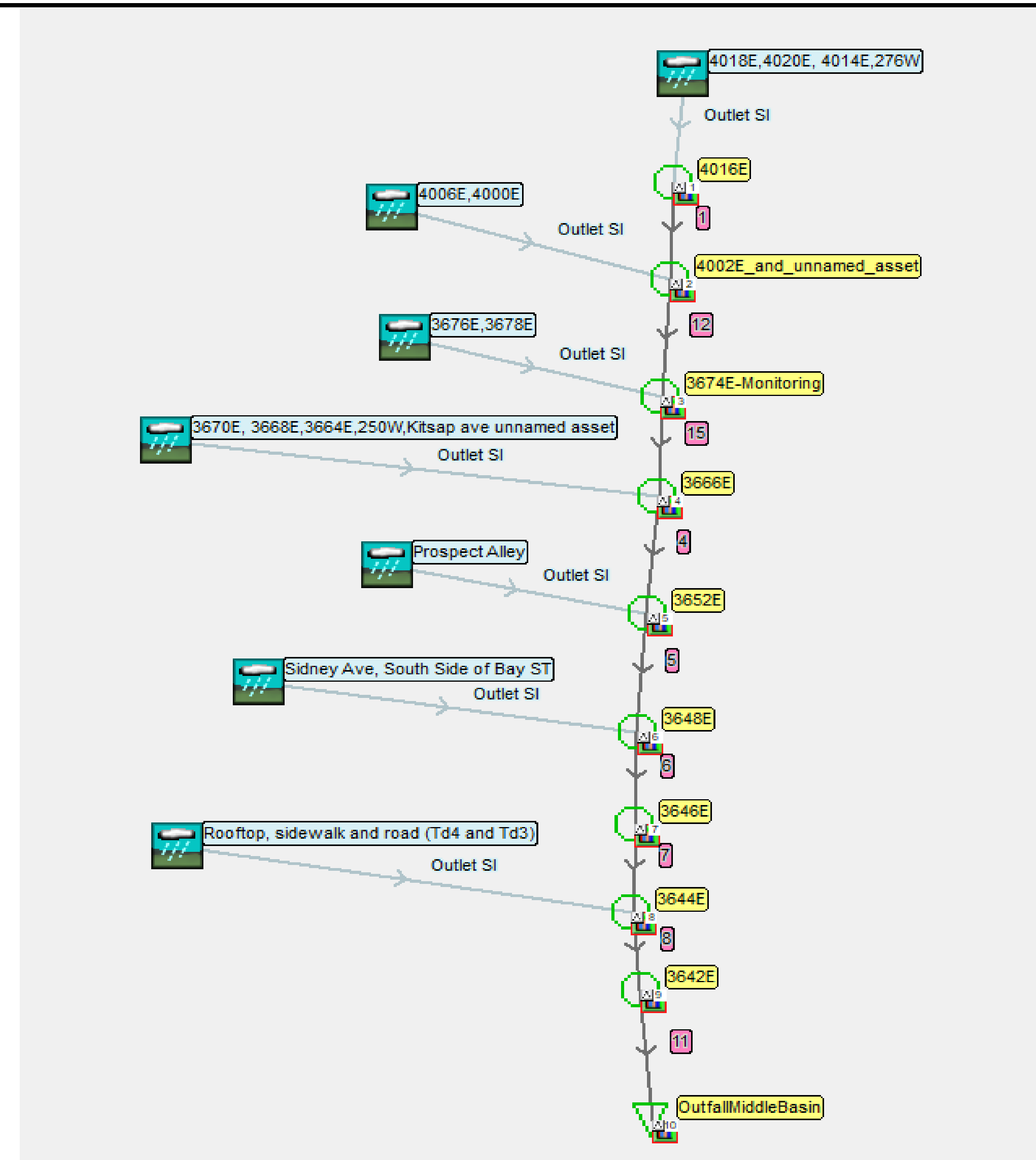
Harrison Basin

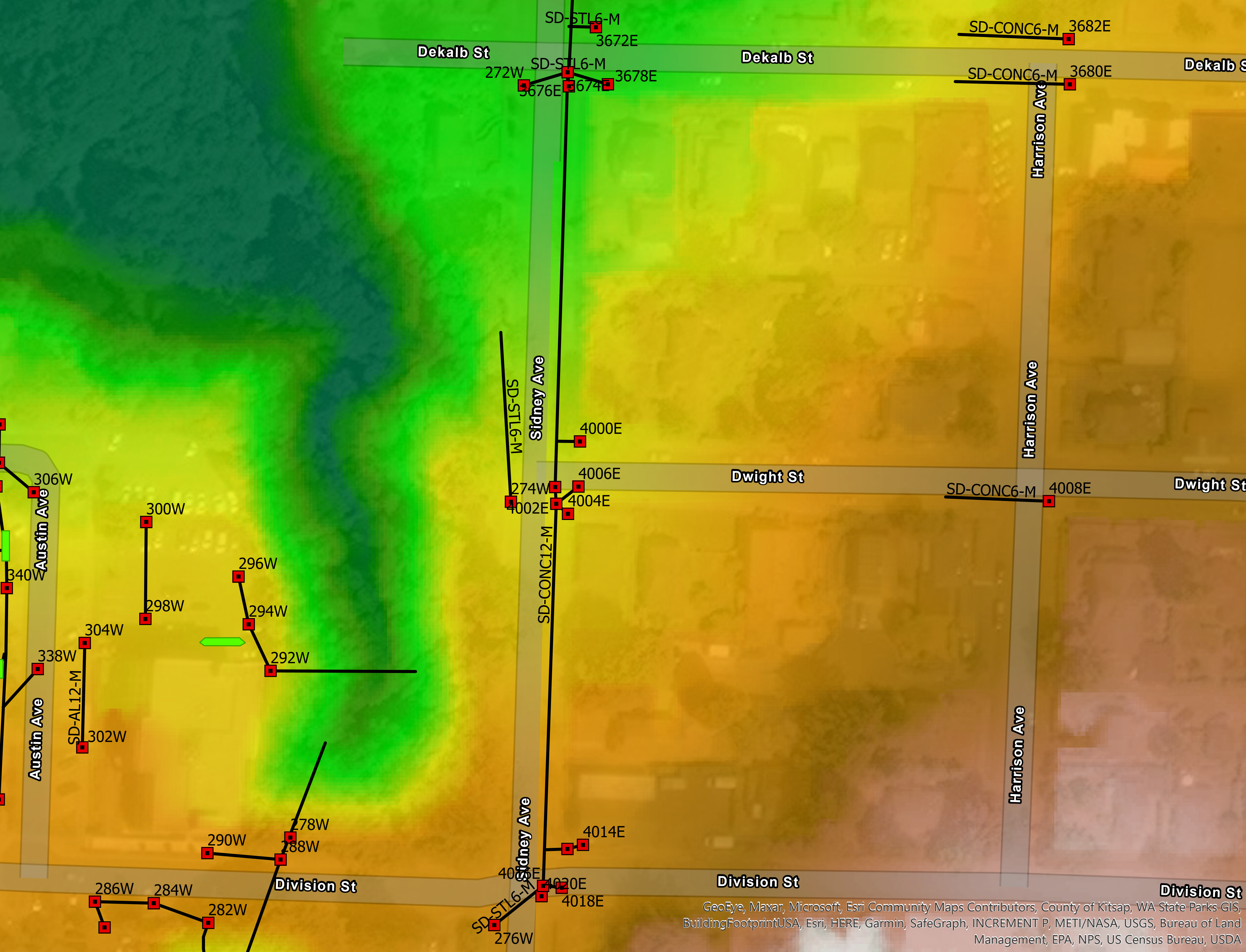
Nodes where TSS can be calculated	Monitoring Location	Approx. Location
Unnamed Asset	X	Upstream end of SD-PL4-M



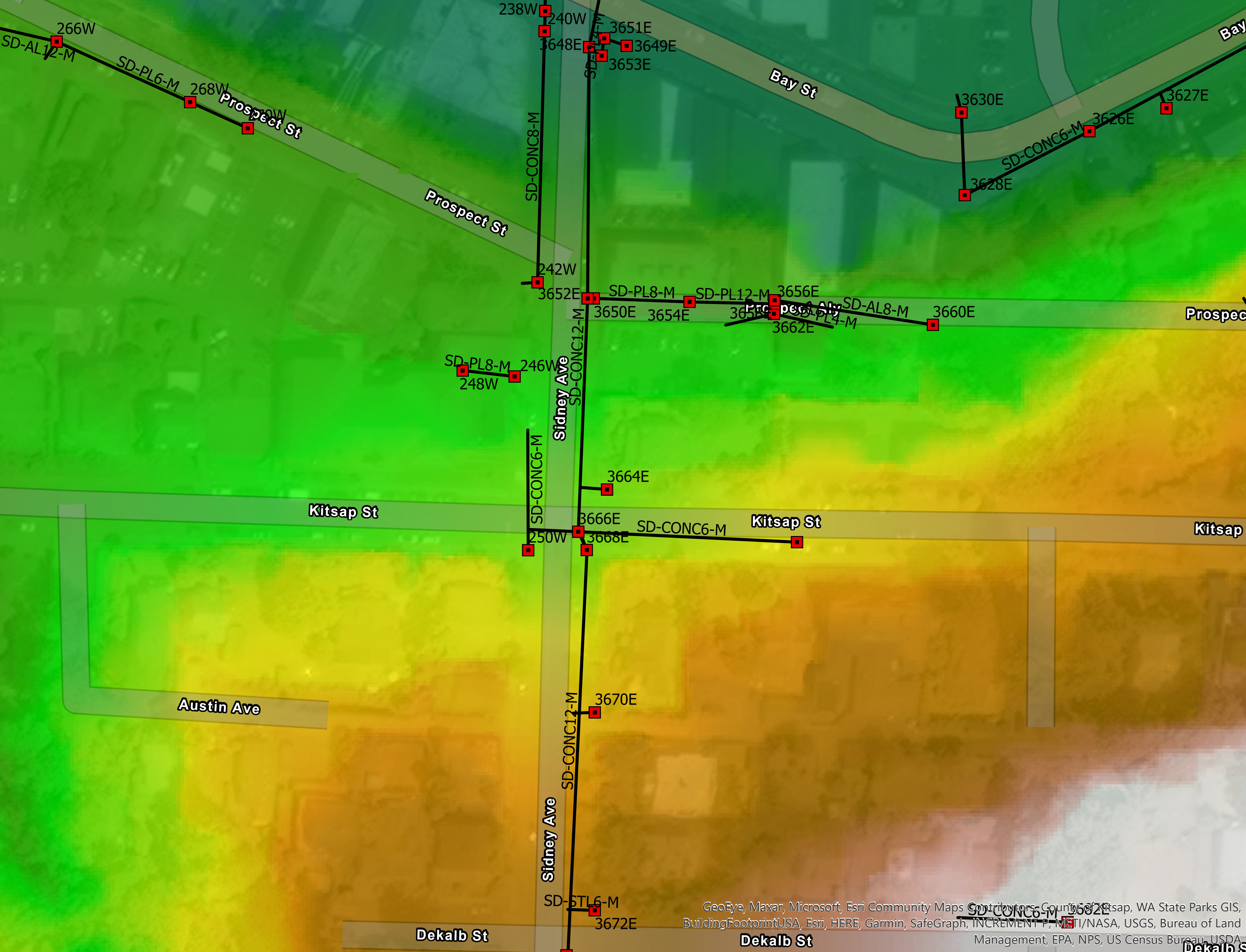
Sidney/Dekalb Basin

Nodes where TSS can be calculated	Monitoring Location	Approx. Location
4016E		Sydney Ave & Division St
4002E		Sydney Ave and Dwight St
3674E	X	Sydney Ave and Dekalb St
3666E		Sydney Ave and Kitsap St
3652E		Sydney Ave and Prospect Alley
3648E		Sidney Ave, South Side of Bay St
3646E		Sidney Ave, South Side of Bay St
3644E		Sydney Ave, North of Bay St
3642E		Sydney Ave, South of Sydney Pkwy





SD-STL6-M
3672E
Dekalb St
Dekalb St
Dekalb St
SD-CONC6-M
3682E
SD-STL6-M
272W
3676E
3674E
3678E
SD-CONC6-M
3680E
Harrison Ave
SD-STL6-M
Sidney Ave
4000E
Harrison Ave
Dwight St
Dwight St
4006E
274W
4002E
4004E
SD-CONC6-M
4008E
306W
Austin Ave
300W
SD-CONC12-M
340W
296W
298W
294W
304W
292W
338W
SD-AL12-M
302W
Austin Ave
Harrison Ave
278W
4014E
290W
288W
Sidney Ave
4016E
4020E
Division St
Division St
Division St
286W
284W
4018E
282W
SD-STL6-M
276W
GeoEye, Maxar, Microsoft, Esri Community Maps Contributors, County of Kitsap, WA State Parks GIS, BuildingFootprintUSA, Esri, HERE, Garmin, SafeGraph, INCREMENT P, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA


266W
SD-AL12-M
SD-PL6-M
268W
Prospect St
Prospect St
238W
240W
3651E
3648E
3649E
3653E
Bay St
Bay
SD-CONC8-M
3630E
3627E
3626E
SD-CONC6-M
3628E
242W
3652E
SD-PL8-M
SD-PL12-M
3656E
3650E
3654E
Prospect Aly
SD-AL8-M
3660E
SD-PL4-M
3662E
Prospec
SD-PL8-M
246W
248W
Sidney Ave
SD-CONC12-M
SD-CONC6-M
3664E
Kitsap St
3666E
SD-CONC6-M
Kitsap St
Kitsap
250W
3668E
Austin Ave
3670E
SD-CONC12-M
Sidney Ave
SD-STL6-M
3672E
Dekalb St
Dekalb St
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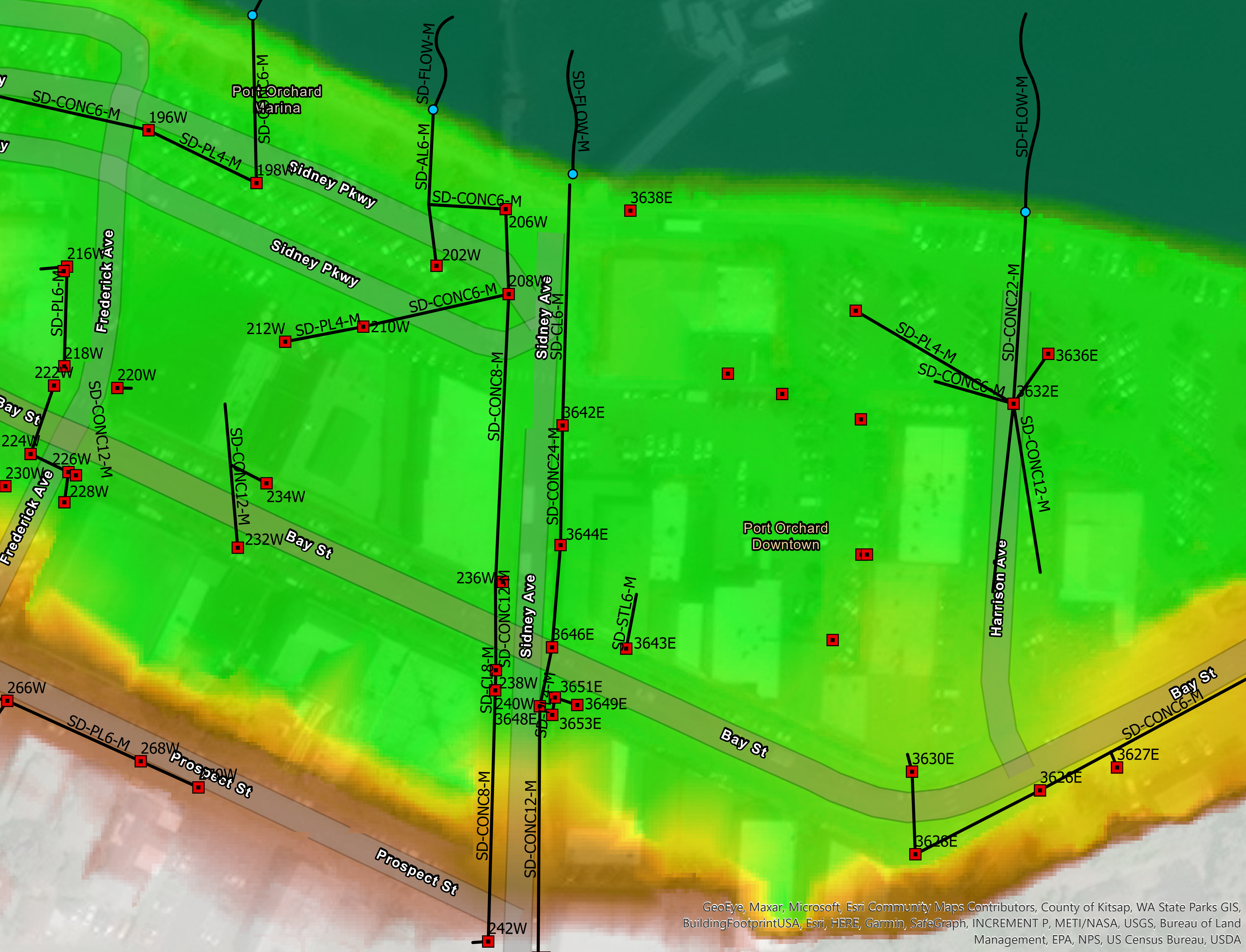
Port Orchard Marina
Port Orchard Downtown
Sidney Pkwy
Sidney Pkwy
Sidney Ave
Sidney Ave
Frederick Ave
Frederick Ave
Bay St
Bay St
Bay St
Bay St
Prospect St
Prospect St
Harrison Ave
SD-CONC6-M
SD-PL4-M
SD-FLOW-M
SD-FLOW-M
SD-FLOW-M
SD-AL6-M
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224W
226W
228W
230W
232W
234W
236W
238W
240W
242W
266W
268W
3638E
3642E
3644E
3646E
3643E
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3651E
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APPENDIX B
Minnesota Stormwater Manual Webpage

Page Content

Event mean concentrations of total suspended solids in stormwater runoff

This page provides information on **event mean concentrations** of total **suspended solids** (TSS) in urban stormwater runoff. For a discussion of TSS in stormwater runoff, including information on sources, fate, and water quality impacts, see Total Suspended Solids (TSS) in stormwater.

Summary information - total suspended solids (TSS) concentrations in stormwater runoff

Land use	Recommended emc TSS (mg/L)
Commercial	75
Industrial	93
Residential	73
Freeways/transportation	87
Mixed	76 or calculate
Open space	21
Conventional roof	< 20

- **NOTE**: For recommendations on adjusting these values or for land uses not included above, see the table Event mean concentrations for total suspended solids

Contents

Objective

Event mean concentrations (emcs) are used in models (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_models,_calculators_and_modeling) for predicting water quality impacts from stormwater runoff and stormwater **treatment practices** or **pollution prevention** practices. Pollutant loads, which are typically used to assess water quality impacts, including establishing **total maximum daily loads** (https://stormwater.pca.state.mn.us/index.php?title=Total_Maximum_Daily_Loads_(TMDLs)) (TMDLs), are a function of pollutant concentration and volume of runoff. It is therefore important to accurately determine appropriate event mean concentrations when assessing water quality impacts from stormwater runoff.

This page provides summary information that can be used for selecting or calculating appropriate emcs for total suspended solids.

Information: Many factors affect total suspended solids concentrations in stormwater. If you are unfamiliar with the concept of event mean concentrations, We recommend you first read Stormwater pollutant concentrations and event mean concentrations

Methodology

We conducted a review of literature to develop the EMCs shown on this page. Nearly all studies provided summary information; we therefore did not analyze raw data with the exception of data from Capitol Region Watershed District (https://www.capitolregionwd.org/monitoring-research/) (see discussion below) and the National Stormwater Quality Database (http://www.bmpdatabase.org/nsqd.html). We compiled the summary information into a spreadsheet and conducted simple statistical analysis of the information.

Data from the following studies were used to generate emcs for total **suspended solids**.

- National Stormwater Quality Database. This dataset provides data from several nationwide studies. We used only data from region 1, which includes Minnesota and states with similar rainfall patterns. Data were compiled for four land uses: Commercial (n=165), industrial (n=84), residential, (n=249), and open space (n=6).
- Lin (Review of Published Export Coefficient and Event Mean Concentration (EMCs) Data (https://apps.dtic.mil/dtic/tr/fulltext/u2/a430436.pdf). This report includes summaries of multiple studies conducted in North America. Data existed for all land uses included in the table presenting recommended emcs.
- Washington District Department of the Environment - Selection of Event Mean Concentrations (EMCs) (http://dcstormwaterplan.org/wp-content/uploads/AppD_EMCs_FinalCBA_12222014.pdf). This study summarized data from studies in the Washington D.C. area. Land uses included commercial, roadway/highway, industrial, forest/open, and residential.

- U.S. Environmental Protection Agency, 1983, Results of the Nationwide Urban Runoff Program—Executive summary (https://www3.epa.gov/npdes/pubs/sw_nurp_vol_1_finalreport.pdf). Land uses included commercial and residential.
- Urban Stormwater Quality, Event-Mean Concentrations, and Estimates of Stormwater Pollutant Loads, Dallas-Fort Worth Area, Texas, 1992–93 (https://pubs.usgs.gov/wri/wri984158/pdf/wri98-4158.pdf). Included commercial (n=42), residential (n=77), industrial (n=63) land uses.
- A review of sediment and nutrient concentration data from Australia for use in catchment water quality models (https://ewater.org.au/uploads/files/Water%20quality%20review_Bartley%20and%20Speirs_Final.pdf). A compilation of multiple studies from Australia. Included forest (n=68) and mixed (n=36) land uses.
- Characterization of Urban Runoff Pollution between Dissolved and Particulate Phases (https://www.hindawi.com/journals/tswj/2013/964737/). Study of five sites in China. Land uses included roof and transportation (roads).
- Quality Of Wisconsin Stormwater, 1989-94 (https://pubs.usgs.gov/of/1996/0458/report.pdf). Samples from mixed land use in Wisconsin (n=204).
- Analysis of Nonpoint Source Pollution Runoff from Urban Land Uses in South Korea (https://www.researchgate.net/publication/263627021_Analysis_of_Nonpoint_Source_Pollution_Runoff_from_Urban_Land_Uses_in_South_Korea). 23 samples in Korea from high density residential, medium desntiy residential, industrial, institutional land uses.
- Seasonal Performance Variations for Storm-Water Management Systems in Cold Climate Conditions (https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/pubs_specs_info/jee_3_09_unhsc_cold_climate.pdf). 15 samples from transportation land use in New Hampshire.
- Determination of event mean concentrations and first flush criteria in urban runoff (http://eeer.org/journal/view.php?number=374). 31 samples from transportation land use in Los Angeles.
- Multiple linear regression models of urban runoff pollutant load and event mean concentration considering rainfall variables (https://www.sciencedirect.com/science/article/pii/S1001074209602035). 45 samples from commercial, industrial, and high density land uses.
- Stormwater runoff driven phosphorus transport in an urban residential catchment: Implications for protecting water quality in urban watersheds (https://www.nature.com/articles/s41598-018-29857-x). 29 events from low density land use in Florida.
- Sources of phosphorus and street dirt from Two Urban Residential Basins in Madison, Wisconsin, 1994-95 (https://stormwater.pca.state.mn.us/images/2/2d/USGS_paper_sources_of_phosphorus.pdf). 25 samples from medium density land use in Wisconsin.
- Nutrient Sources in Urban Areas – A Literature Review (https://erams.com/co-stormwater-center/wp-content/uploads/2017/09/Nutrient_Sources_Literature_Review-2017-6-5RefUpdate.pdf). Report summarizing multiple studies in Colorado. Land uses include residential, mixed, commercial, and open space.
- Contribution of surface runoff from forested areas to the chemistry of a through-flow lake (https://link.springer.com/article/10.1007/s12665-014-3682-y). Forested land use in Poland.
- Brezonik and Stadelman (https://www.sciencedirect.com/science/article/pii/S004313540100375X), (2002). Analysis and predictive models of stormwater runoff volumes, loads, and pollutant concentrations from watersheds in the Twin Cities metropolitan area, Minnesota, USA.

In addition to the above sources, we compiled water quality monitoring data from 10 storm sewer outfalls in the Capitol Region Watershed (https://www.capitolregionwd.org/monitoring-research/) in Minnesota. The data period for each outlet varied but generally spanned the period from about 2005 to 2019. The following information was compiled for each monitoring location.

- Date
- Total suspended solids in mg/L.
- Sample type, which included runoff samples during precipitation events, snowmelt samples, and **baseflow** samples for those locations where groundwater contributed to flow.

We also downloaded the 2015 National Stormwater Quality Database (http://www.bmpdatabase.org/nsqd.html). The dataset includes information from across the U.S. We selected only data from Region 1, which includes Minnesota, for analysis. Four land uses included commercial, industrial, residential, and open space, with the number of samples for each land use varying.

For both of these data sets, we conducted simple statistical analyses.

Recommended event mean concentrations for total suspended solids

Emcs for TSS vary by land use. This section provides recommended emcs for different land uses. A discussion of factors affecting emcs (https://stormwater.pca.state.mn.us/index.php?title=Event_mean_concentrations_of_total_suspended_solids_in_stormwater_runoff#Factors_affecting_total_suspended_solid_emcs_in_stormwater_runoff) and potential adjustments to emcs (https://stormwater.pca.state.mn.us/index.php?title=Event_mean_concentrations_of_total_suspended_solids_in_stormwater_runoff#Adjusting_event_mean_concentrations) are provided in separate sections below.

Pollutant loads in stormwater runoff equal the pollutant concentration times the runoff volume. Thus, when calculating pollutant loading, it is necessary to consider not only the event mean concentration but factors affecting the volume of runoff. For most models and calculations, this requires adjusting curve numbers or runoff coefficients to account for differences in directly connected impervious surface between different land uses. There may be other adjustments to volume, such as accounting for interception by trees. See the discussion Accounting for differences in pollutant loading (https://stormwater.pca.state.mn.us/index.php?title=Event_mean_concentrations_of_total_suspended_solids_in_stormwater_runoff#Accounting_for_differences_in_pollutant_loading).

Residential land use

Studies from the literature frequently provide concentrations for residential land use or occasionally for different types of residential land use, typically low-, medium-, or high-density residential. Most studies do not define criteria for dividing residential land use into these subcategories. Various definitions can be found in the literature, including the following.

Example of residential land use

- Residential: "Residential land use means any real property or portion thereof which is used for housing human beings. This term includes property used for schools, day care centers, nursing homes, or other residential-style facilities or recreational areas." (Law Insider (https://www.lawinsider.com/dictionary/residential-land-use) accessed December 31, 2019).
- High-density residential: More than 10 units per acre; can include multiple-occupant dwellings
- Medium-density residential: 1-10 dwellings per acre; can include multiple-occupant dwellings
- Low-density residential: one dwelling per 1-5 acres; can include multiple-occupant dwellings

Note that residential land uses can include other land uses, such as commercial and industrial. Many studies therefore classify land uses as mixed or urban, even though a specific land use may dominate a particular area.

Because of the variable and arbitrary manner in which residential land use is classified, we provide a single recommended value for event mean concentrations in residential land uses. We provide additional discussion below so that users can adjust this recommended value depending on local conditions. We used the following references for generating a recommended value for residential land use.

- Wisconsin; 10 sites; n=25; median=46
- Korea; 6 sites; n=23; median=63.3
- LA; 2 sites; 4 samples; median = 91.2
- NURP median = 101
- Dallas median = 78
- China median = 68
- NSQD 250 sites; median = 92 (region 1)
- Line = 42

We chose these studies because they contained large amounts of data and they were located in humid and sub-humid areas of the U.S. The median of the above 7 values is 73 mg/L.

Information: The recommended event mean concentration for total suspended solids in residential areas is 77 mg/L

Commercial land use


Example of commercial land use

"Commercial land use is the use of land for commercial purposes including building offices, shops, resorts and restaurants as opposed to construction of a residential house" (Reference, accessed December 24, 2019) (https://www.reference.com/business-finance/commercial-land-use-d186d8d0a4ae4e72). Commercial areas considered in this analysis do not include areas used for commercial crop production.

We used the following studies in our analysis. Commercial

- NSQD; n=164; median = 97.15
- NURP median = 69
- Dallas median = 42
- L.A.; n=5; mean = 49.6
- China Median = 81
- Harper = 87.7

The median concentration from these studies is 75 mg/L.

Information: The recommended event mean concentration for total suspended solids in commercial areas is 75 mg/L

Industrial land use


Example of an industrial area

We used the following studies in our analysis.

- NSWD; n=84; median=70
- Dallas median = 104
- Korea median = 78.8; 6 sites
- LA median = 92.2; 6 sites
- Harper = 93.3
- Line = 170

The median TSS concentration from these studies is 93 mg/L. TSS concentrations do not appear to vary much across different industrial land uses, with the primary sources likely being road salt and atmospheric deposition. However, the following may contribute to higher TSS loads in industrial areas.

- Cleaning and washing operations
- Heavy vehicle traffic
- Specific industries such as food processing plants, meat packing plants and lockers, metal finishing facilities, and industries that generate or handle animal waste (including human sources)

Information: The recommended event mean concentration for total suspended solids in industrial areas is 93 mg/L

Open space

Open space consists of land that is undeveloped. Typically it will not contain buildings or other built structures. Many open spaces are accessible to the public. Open space generally consists of green space (land that is partly or completely covered with grass, trees, shrubs, or other vegetation). Abandoned parcels lacking structures may be considered open space, but it is generally more accurate to include these areas in the land use that existed prior to the parcel being vacant, or including it in adjacent land use categories. The following references were used to generate a recommended value a TSS emc for open space.

- NSQD; n=6; median = 20.5
- NURP median = 70

- Harper = 11.1

Parks and recreation areas are generally included in open space.

Information: The recommended event mean concentration for total suspended solids in open space, urban parks, and urban recreations areas is 21 mg/L


Example of open space land use

Transportation corridors, highways, and freeways

This land use includes major transportation corridors where the land use is exclusively transportation. These areas are typically highly impervious and may include only small vegetated areas consisting of swales or medians, and relatively small right-of-way areas. This land use does not include arterial streets in residential, commercial, and industrial areas. The following references were used to generate a recommended value a TSS emc for open space.

- China median=86.72
- Fort Worth median =90; n=27
- New Hampshite median = 55.54; n=27
- LA median = 87.54; n=39
- Harper = 50.3

The median value from these studies is 87 mg/L.

Information: The recommended event mean concentration for total suspended solids in transportation areas is 87 mg/L

TSS concentrations from transportation corridors are highly variable depending on inputs. The primary inputs include road salt, sediment, and vehicle-related wastes, including oil. The recommended value should be adjusted based on vehicle traffic and likely suspended solids sources and inputs.


Example of transportation land use

Roofs

Information: The recommended event mean concentration for total suspended solids in runoff from conventional (non-green) roofs is less than 20 mg/L

- Typical Roof Runoff Quality in Minneapolis and Wisconsin (https://stormwater.pca.state.mn.us/index.php?title=Typical_Roof_Runoff_Quality_in_Minneapolis_and_Wisconsin)
- View this support document (https://stormwater.pca.state.mn.us/index.php?title=File:Green_roof_pollutant_removal.docx)

Mixed land use

- DC median = 47.25; 4 sites
- Australia; n=49; median=105
- Korea median = 153.3
- Korea median =76; n=45
- WI median = 188; 2 sites
- NURP median=67
- Capitol Region Watershed District (9 outfalls) median = 97 mg/L
- Sullen median = 54.5
- L.A. median = 65.1

Overall median = 76 mg/L

An emc can be calculated if the total area of interest (A_{total}), the area of each land use in the area of interest, and the emc for each land use in the area of interest are known.

Site emc = Σ_1^n (($A_{Area\ 1}$ * $emc_{Area\ 1}$)/ (A_{total}) + ... (($A_{Area\ n}$ * $emc_{Area\ n}$) / (A_{total})

where A = area in acres.

Example calculation

- 10 acres of residential; emc = mg/L
- 10 acres of commercial; emc = mg/L
- 10 acres of industrial' emc = mg/L
- 1 acre of transportation; emc = mg/L

Overall emc = (73 * 10/31) + (75 * 10/31) + (93 * 10/31) + (1 * 10/31) = 80.5 mg/L

NOTE: To calculate loads for a mixed land use, a curve number or runoff coefficient must be calculated based on the impervious surface for each of the land uses.

Summary table for event mean concentrations by land use

Event mean concentrations for total suspended solids.
Link to this table

Land cover/land use	Range (mg/L)	Recommended value (mg/L)	Notes
Commercial	42-164	75	If applicable to models being used, adjust curve numbers/runoff coefficients when calculating loads
Industrial	70-170	93	▪ If applicable to models being used, adjust curve numbers/runoff coefficients when calculating loads
Residential	42-101	73	
High-density/Multi-family residential (https://stormwater.pca.state.mn.us/index.php?title=Event_mean_concentrations_of_total_suspended_solids_in_stormwater_runoff#Residential_land_use)		Calculate (https://stormwater.pca.state.mn.us/index.php?title=Event_mean_concentrations_of_total_suspended_solids_in_stormwater_runoff#Mixed_land_use)	▪ Insufficient information to recommend a specific emc
Medium density residential (https://stormwater.pca.state.mn.us/index.php?title=Event_mean_concentrations_of_total_suspended_solids_in_stormwater_runoff#Residential_land_use)		Calculate (https://stormwater.pca.state.mn.us/index.php?title=Event_mean_concentrations_of_total_suspended_solids_in_stormwater_runoff#Mixed_land_use)	▪ Insufficient information to recommend a specific emc
Low density residential (https://stormwater.pca.state.mn.us/index.php?title=Event_mean_concentrations_of_total_suspended_solids_in_stormwater_runoff#Residential_land_use)		Calculate (https://stormwater.pca.state.mn.us/index.php?title=Event_mean_concentrations_of_total_suspended_solids_in_stormwater_runoff#Mixed_land_use)	▪ Insufficient information to recommend a specific emc

Land cover/land use	Range (mg/L)	Recommended value (mg/L)	Notes
Freeways/transportation	50-90	87	
Mixed	47-188	76 or calculate	▪ Residential land use was the primary land use in most studies that cited values for mixed land use ▪ If the study area can be delineated into specific land uses and impervious area for each land use is know, we recommend calculating the emc
Parks and recreation		Use value for open space or calculate	▪ emc will be a function of vegetative cover
Open space	11-70	21	
Conventional roof		<20	
Institutional	17-140	80	
Forest/shrub/grassland	26-140	72	Sediment concentrations from forested areas vary widely with factors such as slope and forest condition. Concentrations may be very high, but the annual volume of runoff is typically much less than non-forested areas.
Open water and wetlands		see Notes (next column)	▪ If data exist, use the TSS concentration for the water body of interest ▪ If data for a specific water body do not exist, use data from similar lakes in the area
Cropland (row crops)	50-160		Literature review was not adequate to recommend an emc
Pasture	75-150	84	Concentrations are a function of intensity of use.

Factors affecting total suspended solid emcs in stormwater runoff

Concentrations of TSS show considerable variability within land uses. Using data from Region 1 of the National Stormwater Quality Database, mean concentrations are 50% greater than median concentrations for commercial, industrial, and residential land uses, indicating data are skewed toward higher concentrations. The mean for open space was only 7% greater than the median, indicating more uniform TSS concentrations.

Several factors affect concentrations of total suspended solids in stormwater runoff. The following bullet list summarizes some of the most important factors. Note these are general conclusions and not applicable to all local situations.

- **Rainfall intensity and depth, including the maximum intensity and timing of this maximum**. Most studies show emcs increase with rainfall intensity and depth during the initial period of runoff, but at some intensity emcs begin to decline due to dilution (Gong et al., 2016; Acharya and Piechota, 2010). Other studies show little or no effect of rain intensity (Schiff et al., 2016). During the latter part of a runoff event, TSS emcs and rain intensity are inversely related (Schiff et al., 2016).

- **Interval between runoff events**. As the number of days between runoff events increases, pollutants build up on impervious surfaces, resulting in greater TSS loading when runoff does occur. The effect on emcs is less certain and appears to vary with climate. This effect appears to be smaller in humid and sub-humid climates compared to arid and semi-arid climates (Gong et al., 2016; Acharya and Piechota, 2010; Li et. al, 2015).
- **Length of runoff event**. Typically, pollutant concentrations decrease after an initial peak associated with **first flush**. Studies suggest that, for runoff events lasting roughly 40 minutes or more, depending on intensity, TSS concentrations reach a relatively stable or slowly decreasing concentration that is 25-50% of the peak concentration (Li et. al, 2015; Schiff et al., 2016; Stenstrom and Kayhanian, 2005).
- **Nature of watershed contributing to runoff and impervious connectedness**. This effect relates to the phenomenon of **first flush** in which the greatest pollutant loading occurs in the early stages of runoff (Gong et al., 2016; Acharya and Piechota, 2010).
    - First flush is more pronounced in smaller watersheds.
    - First flush is more pronounced when the length of time between runoff events increases.
    - First flush is less pronounced when there is greater directly **connected impervious** surface, since runoff can reach a specific discharge point from greater distances.
    - First flush is more pronounced with higher rainfall intensities in the early part of a runoff event.
    - First flush is less pronounced when there is treatment up in a watershed, including **pretreatment** (https://stormwater.pca.state.mn.us/index.php?title=Pretreatment)
- **Land use**. Data on this page illustrates differences in TSS emcs between land uses. Several factors affect concentrations within a specific land use.
    - Emcs increase in areas with extensive lawns on compacted soils and where lawns are directly adjacent to impervious surfaces.
    - Emcs increase in areas with greater loading of organic debris, such as leaves and yard clippings. This is associated with seasonal effects.
    - Emcs increase in areas with heavy vehicle traffic. Vehicle debris may be an important component of TSS in these areas.
    - Emcs will be elevated in areas receiving winter applications of sand and deicers.
- **Construction activity within the watershed**. Extensive construction activity can increase emcs during the construction period, particularly in watersheds with well-connected impervious surface. Construction activity (e.g. individual residences) not covered an **NPDES** permit will contribute more sediment on a per area basis due to less stringent or no **erosion protection** (https://stormwater.pca.state.mn.us/index.php?title=Erosion_prevention_practices) or **sediment control** (https://stormwater.pca.state.mn.us/index.php?title=Sediment_control_practices) practices.

Adjusting event mean concentrations

Several factors affect emcs, as discussed above. Emcs can and should be adjusted when supporting data exist. Local monitoring data should be used to support different emcs than those recommended on this page, but the following guidelines may be used to adjust emcs.

- In areas where sand and/or deicers are applied, adjust emcs upward if calculating pollutant loads for winter and early spring.
- In areas with extensive tree canopy, adjust emcs upward if calculating pollutant loads for fall.
- Adjust emcs upward if there is extensive construction activity occurring during the period when pollutant loads are calculated.
- Adjust emcs as appropriate if certain management activities, such as street sweeping, are implemented.

Effect of emc on pollutant loading

To assess the effect of changing the TSS emc, we ran several scenarios using the Minimal Impact Design Standards Calculator (https://stormwater.pca.state.mn.us/index.php?title=MIDS_calculator). For each model run we assumed 31.9 inches of precipitation annually. We varied the emc as follows

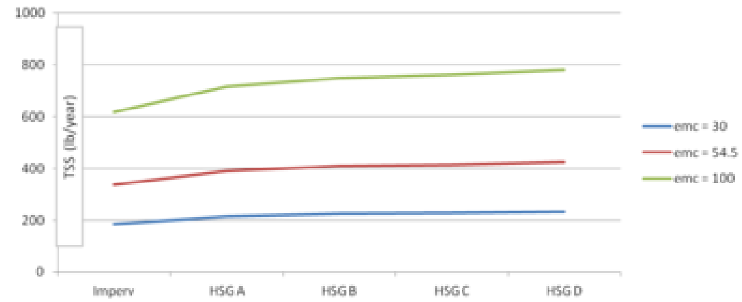
- 30 mg/L
- 54.5 mg/L (MIDS Calculator default)

- 100 mg/L

We varied land use as follows

- 1 acre of impervious
- 1 acre of impervious and 1 acre of turf on hydrologic group soil (HSG) A soil
- 1 acre of impervious and 1 acre of turf on B soil
- 1 acre of impervious and 1 acre of turf on C soil
- 1 acre of impervious and 1 acre of turf on D soil

The results, illustrated in the adjacent graph, indicate a small effect of soil. Changing the emc within a specific land use scenario, however, results in significant changes in loading. The change in loading is linear and equal to the following.



TSS loading, in pounds, for 3 different TSS emcs (30, 54.5, and 100 mg/L) and five land uses (1 acre of impervious with no pervious, and 1 acre of impervious with 1 acre of pervious turf on either HSG A, B, C, or D).

- impervious: 6.18 lbs/acre/yr increase in TSS load for each 1 mg/L increase in TSS
- A soil: 7.16 lbs/acre/yr increase in TSS load for each 1 mg/L increase in TSS
- B soil: 7.48 lbs/acre/yr increase in TSS load for each 1 mg/L increase in TSS
- C soil: 7.61 lbs/acre/yr increase in TSS load for each 1 mg/L increase in TSS
- D soil: 7.81 lbs/acre/yr increase in TSS load for each 1 mg/L increase in TSS

This exercise illustrates the importance of selecting an appropriate emc.

Accounting for differences in pollutant loading

Pollutant loads are a function of pollutant concentrations in runoff and the volume of runoff. Consequently, when calculating pollutant loads it is necessary to adjust both the emcs and volume of runoff. Volumes are typically calculated using **curve numbers** or **runoff coefficients** (https://stormwater.pca.state.mn.us/index.php?title=Runoff_coefficients_for_5_to_10_year_storms). The MPCA Simple Estimator (https://stormwater.pca.state.mn.us/index.php?title=Guidance_and_examples_for_using_the_MPCA_Estimator), for example, employs a default runoff coefficient of 0.8 for commercial areas, compared to 0.44 for residential areas. The tables below may be used to determine the proper curve number or runoff coefficient. Percent impervious can be converted to a curve number using the following formula.

$$Curvenumber = (Impervious * 98) + ((1 - impervious) * (openspacecurvenumberingoodconditionforthespecificsoil))$$

where impervious is given as a fraction (not a percent).

For example, if an area on B soils is 50 percent impervious, the curve number is given as (0.5 * 98) + ((1 - 0.50)(61)) = 79.5.

Curve numbers for urban and agricultural areas. Source: USDA Urban Hydrology for Small Watersheds - TR-55 (https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf).
Link to this table

Cover type and hydrologic condition	Soil Group A	Soil Group B	Soil Group C	Soil Group D
Open space poor condition (<50% cover)	68	79	86	89
Open space average condition (50-75% cover)	49	69	79	84
Open space good condition (>75% cover)	39	61	74	80
Impervious surfaces	98	98	98	98
Commercial (85% impervious)	89	92	94	95
Industrial (72% impervious)	81	88	91	93
Residential (65% impervious)	77	85	90	92
Residential (30% impervious)	57	72	81	86

Cover type and hydrologic condition	Soil Group A	Soil Group B	Soil Group C	Soil Group D
Residential (12% impervious)	46	65	77	82
Pervious, no vegetation (newly graded)	77	86	91	94
Fallow with residue cover	74-76	83-85	88-90	90-93
Row crop, no residue	67-72	78-81	85-88	89-91
Row crop with residue	64-71	75-80	82-87	85-90
Pasture, good condition	39	61	74	80
Pasture, poor condition	68	79	86	89
Meadow	30	58	71	78
Woods, good condition	32	58	72	79
Woods, poor condition	57	73	82	86

Runoff coefficients for different soil groups and slopes. Coefficients are for recurrence intervals less than 25 years. Source: Hydrologic Analysis and Design (4th Edition) (McCuen.
Link to this table

Land use	Soil Group A			Soil Group B			Soil Group C			Soil Group D		
	0-2%	2-6%	>6%	0-2%	2-6%	>6%	0-2%	2-6%	>6%	0-2%	2-6%	>6%
Residential (65% impervious)	0.25	0.28	0.31	0.27	0.30	0.35	0.30	0.33	0.38	0.33	0.36	0.42
Residential (30% impervious)	0.19	0.23	0.26	0.22	0.26	0.30	0.25	0.29	0.34	0.28	0.32	0.39
Residential (12% impervious)	0.14	0.19	0.22	0.17	0.21	0.26	0.20	0.25	0.31	0.24	0.29	0.35
Commercial	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Industrial	0.67	0.68	0.68	0.68	0.68	0.69	0.68	0.69	0.69	0.69	0.69	0.70
Streets	0.70	0.71	0.72	0.71	0.72	0.74	0.72	0.73	0.76	0.73	0.75	0.78
Parking	0.85	0.86	0.87	0.85	0.86	0.87	0.85	0.86	0.87	0.85	0.86	0.87
Open space	0.05	0.10	0.14	0.08	0.13	0.19	0.12	0.17	0.24	0.16	0.21	0.28
Cultivated land	0.08	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31
Pasture	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
Meadow	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
Forest	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20

There are numerous studies summarizing TSS exports for different land uses. Examples include the following.

- Shaver et al. (2007) reported export rates of 1000 lb/ac/yr for commercial, 670 lb/ac/yr for industrial, 420 lb/ac/yr for high-density residential, 250 lb/ac/yr for medium density residential, and 65 lb/ac/yr for low density residential land use.
- Using the data from the National Stormwater Quality Database, median TSS export is 242 lb/ac/yr for commercial, 193 lb/ac/yr for industrial, 76 lb/ac/yr for residential, and 35 lb/ac/yr for open space.
- Baldys et al. (1998) reported TSS export of 4430 lbs/mi^2/yr for industrial land uses, compared to 2000 lb/mi^2 for commercial land use and 1440 lb/mi^2/yr for residential land use in the Dallas-Fort Worth area

The studies illustrate the importance of estimating runoff volume, since loading from commercial areas, for example, is greater than from residential areas even though the emc for commercial areas is lower (0.20 mg/L compared to 0.325 mg/L for residential).

Example using the Minimal Impact Design Standards (MIDS) Calculator

The following example illustrates how a variable land use setting may be modeled using the MIDS Calculator (https://stormwater.pca.state.mn.us/index.php?title=MIDS_calculator).

Example MIDS Calculator with and without adjusted emcs						
Land use	% impervious	Impervious acres	Pervious acres	emc (mg/L)	Total TSS load (lb/yr)	TSS export (lb/ac/yr)
Residential (>40% canopy)	30	0.90	2.1	80	663.8	221.3
Residential (<10% canopy)	30	0.6	1.4	70	387.2	193.6
Commercial	85	0.85	0.15	75	408.8	408.8
Industrial	72	0.72	0.28	93	447.8	447.8
Open space	10	0.10	0.90	21	37.6	37.6
Total suspended solids load with adjusted emcs = 1945.2 pounds/yr						
MIDS unadjusted	39.6	3.17	4.83	54.5	1410.7	176.3

Site conditions.

- 31.9 inches annual precipitation
- B soils with turf
- 5 acres of residential consisting of the following
  - 3 acres of residential land use with high tree canopy coverage (> 50%) and 30% impervious
  - 2 acres of residential with low tree canopy coverage (<10%) and 30% impervious
- 1 acre of commercial land and 85% impervious
- 1 acre if industrial land and 72% impervious
- 1 acre of open space and 10% impervious

EMCs are as follows.

- The recommended TSS emc for residential land use is 73 mg/L. We assumed the following for the two residential areas described above.
  - For the high canopy area, we assumed 80 mg/L
  - For the low canopy area, we assumed 70 mg/L
- Commercial = 75 mg/L
- Industrial = 93 mg/L
- Open space = 21 mg/L

Total load with the variable land uses (1945.2 pounds) is much greater than the default MIDS scenario (1410.7 pounds). This is primarily due to the higher emcs and partly due to the higher impervious acreages in the variable land use scenario. The effect of impervious acreage is shown, for example, by reducing the percent impervious for industrial land use from 72% to 50%. This results in a total load of 348 pounds, or a reduction of about 100 pounds (22.3% reduction for a 22% change in impervious). This example also demonstrates the importance of accurately identifying land use within a modeled area.

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