TECHNICAL METHODS AND APPROACH DOCUMENT

City of Tacoma Watershed Planning Project

Prepared for

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CHAPTER 1. INTRODUCTION

The Tacoma Watershed Insights web application (also referred to as Tacoma watershed tool, or tool) allows for City of Tacoma users to assess and plan stormwater best management practices (BMPs) across the city. It consists of components to explore existing BMPs, view water quality and flow-control performance of BMPs under different climate conditions, help prioritize locations for new facilities, and investigate scenarios for new BMP locations.

This report describes the technical basis and methods used to develop the tool. It is organized into the following chapters.

1. Introduction
2. Best Management Practice (BMP) Performance Module – Module for predicting the performance of BMP strategies. Includes documentation on pollutant loading, hydrology calculations, and influent-effluent relationships.
3. Cost Module - a lifecycle cost calculator that analyzes capital costs, operations and maintenance costs, with facility lifespan providing the net present costs of different facility types.
4. Watershed Prioritization Module – A graphic multi-criteria decision analysis (MCDA) interface that assists users in identifying and prioritizing areas of high priority for stormwater actions.
5. System Architecture

These components represent the core technical features of the tool. The chapters below document the assumptions and technical methods used to develop these features.

CHAPTER 2. BMP PERFORMANCE

2.1 Introduction

This section describes the technical basis and assumptions to be used for the Best Management Practice (BMP) Performance Module of the Tacoma Watershed Planning Project tool.

2.1.1 Components

2.1.1.1 Chemicals of Concern

Eight chemicals of concern (COCs) have been selected for this study as summarized in Table 2-1. Chemicals of Concern below.

Table 2-1. Chemicals of Concern

Parameter	Group	EIM Parameter CAS
Bis(2-ethylhexyl)phthalate- Water - Total	Phthalate	117-81-7
Copper - Water - Total	Metal	7440-50-8
Phenanthrene - Water - Total	LPAH	85-01-8
Pyrene - Water - Total	HPAH	129-00-0
Total Nitrogen - Water - Total	Nutrient	NA
Total Phosphorus - Water - Total	Nutrient	7723-14-0
Total Suspended Solids - Water - Total	Conventional	NA
Zinc - Water - Total	Metal	7440-66-6

2.1.1.2 BMPs

Best management practices (BMPs) to be evaluated include both structural and non-structural BMPs. These are described below.

Structural BMPs refer to BMPs that capture stormwater and improve water quality or hydrology. Facility type names shown in Table 2 conform with the names used in their asset management database.

Table 2-2. Structural BMP Definitions

Facility Type	Description
Filterra/Vegetated box	Manufactured devices with high rate filtration media that support plants.
Media Filter	Manufactured devices with high-rate filtration media consisting of a variety of inert and sorptive media types and configurations (e.g., cartridge filters, upflow filters, membrane filters, vertical bed filters).
Oil-water Separator	Manufactured devices including oil/water separators and baffle chambers designed for removing floatables and coarse solids.
Pervious Pavement	Full-depth pervious concrete, porous asphalt, paving stones or bricks, reinforced turf rings, and other permeable surface designed to replace traditional pavement.
Pond/wet vault	Surface wet pond with a permanent pool of water, may include underground wet vaults.
Bioretention	Shallow, vegetated basins with a variety of planting/filtration media and often including underdrains.
Sand Filter	Filter bed with granular media, typically sand.
Swale	Shallow, vegetated channel, also called bioswale or vegetated swale.
Swirl Separator	Manufactured devices providing gravitational settling using swirl concentrators, screens, and baffles. Also referred to as hydrodynamic separators (HDS).
Dry Extended Detention Basin/Tank	Dry extended detention including grass-lined and concrete lined basins that are designed to empty after a storm.
Trench	Filter bed with granular media, typically sand. Full infiltration
Vault	Concrete-lined basins that drain after a storm.

In addition to the structural BMPs shown in Table 2, non-structural BMPs will be included as described in Section 6 of this document.

2.2 Hydrologic Simulation

Continuous hydrologic simulation will be performed for historic and future climate scenarios. The results of these simulations will be used to calculate inflow to BMPs as well as annual runoff rates.

2.2.1 Data Sources

2.2.1.1 Precipitation

The tool will use a region-wide, simulated precipitation dataset developed by the University of Washington Climate Impacts Group (Mauger et al., 2018). This dataset contains modeled hourly precipitation using the Geophysical Fluid Dynamics Laboratory (GFDL) Climate Model version 3 (CM3) and the Representative Concentration Pathways (RCP) 8.5 scenario. This is the regional climate model dataset that was used by King County for their most recent update of intensity-duration-frequency curves for design of stormwater facilities.

The GFDL model was chosen by CIG due to its ability to accurately model winter storm drivers, important for stormwater applications. Combined with the higher emissions scenario, this modeling scenario represents the upper end of expected future climate changes effects.

CIG downscaled climate model results using a statistical-dynamical approach to capture the expected changes in extreme events as well as the different drivers of rainfall that affect the Puget Sound Region. Regional simulations were performed using the Weather Research and Forecasting community mesoscale model. This resulted in hourly rainfall predictions at an approximately 12 km grid size across Puget Sound. Predictions were bias-corrected on a quantile-mapping basis (individual mean bias corrections for precipitation in each quantile range) using the historic (1970-2005) WRF data. Four runoff scenarios/epochs will be developed as shown in Table 3.

Table 2-3. Historic and Future Climate Precipitation Scenarios

Scenario	Begin	End
Historic	January 1, 1970	December 31, 1999
2030s	January 1, 2000	December 31, 2039
2050s	January 1, 2040	December 31, 2069
2080s	January 1, 2070	December 31, 2099

2.2.1.2 Potential Evapotranspiration

Evapotranspiration includes evaporation directly from soil layers and vegetation as well as transpiration through plants. For runoff calculations, evapotranspiration is used to account for direct loss of water from stored water and loss of water from transpiration.

For this modeling effort, monthly values of potential evapotranspiration (PET) from the TerraClimate long-term monthly dataset. PET values were calculated for the study area for the period 1970-2000 as shown in Table 4.

Table 2-4. Terra Climate Monthly Potential Evapotranspiration, Tacoma, Washington

Month	Monthly PET *(mm)*	Monthly PET *(in)*
Jan	185	7.3
Feb	278	11.0
Mar	496	19.5
Apr	720	28.4
May	1000	39.4
Jun	1148	45.2
Jul	1334	52.5
Aug	1198	47.2
Sep	795	31.3
Oct	425	16.7
Nov	233	9.2
Dec	163	6.4

2.2.1.3 Hydrologic Response Units

Modeling will be performed on discretized landscape units based on common soils, land cover, and slope characteristics known as hydrologic response units (HRUs). The HRU approach provides a computationally efficient method of pre-computing hydrologic response for later use. Results for a particular watershed can be calculated by summing or averaging the results for individual HRUs.

Each combination of parameters was modeled in separate batched simulations. HRUs were designated by a three-digit number according to the following convention:

- First digit: Hydrologic Soil Group Number (0 = A/B, 1 = C, 2 = Saturated)
- Second digit: Land cover (0=Forest, 1=Pasture, 2=Lawn, 5=Impervious)
- Third Digit: Slope (0=Flat, 1=Mod, 2=Steep)

For example, a site with Type C soils, with forested land cover, on a moderate slope would be represented by 101. This schema allowed for HRUs to be stored as an eight-bit unsigned integer on a raster image, minimizing storage size.

2.2.1.4 HSPF Parameters

A set of regional HSPF regional calibration factors for the Puget Lowlands Ecoregion were developed the USGS in the 1990s (Dinicola, 1990) and updated by Clear Creek Solutions for use within WWHM (Department of Ecology, 2014). These parameters, referred to as the 'default parameters' by Ecology will be used in this study. Parameters are provided in Appendix A

2.3 Hydrologic Performance

2.3.1 Long-Term Volume Capture Performance

Hydrologic performance refers to: (1) the long-term volume captured and retained by a BMP (i.e., lost to infiltration, ET, harvesting, diversion, or another pathway), (2) long-term volume captured and treated by a BMP, and (3) long-term volume bypassed or overflowing (not captured). To complete the water balance, the sum of these three pathways equals the total inflow volume to the BMP.

The approach uses long-term capture nomographs to determine the estimated hydrologic performance. A nomograph is a chart that relates BMP design attributes like volume, drawdown time, and design flowrate, with pre-computed values for long-term hydrologic performance. Each point on these charts is the result of a continuous simulation model run for 20-30 years.

The Modeling Engine supports two primary BMP sizing and design paradigms:

- Volume-based nomographs. The capture efficiency is a function of the normalized BMP storage volume and the drawdown time for the stored water to be fully drained or otherwise treated.

- Flow-based nomographs. The capture efficiency is a function of the flow-through capacity for providing treatment and the time of concentration of the tributary area.

The modeling approach allows for separate sets of nomographs to be consulted for any given climate scenario depending on the sizing paradigm for a given facility type. These nomographs are created by running batches of long-term continuous simulations for BMPs with various storage volumes and drawdown times (for volume-based BMPs) or various flow rates and watershed time of concentration (Tc) values (for flow-based BMPs).

This methodology for determining long-term percent capture was previously used for the Puget Sound Partnership BMP Performance tool (Nilsen and Koryto, 2017). It was first developed and technically vetted for the National Cooperative Highway Research Program (Taylor et. al, 2016).

This approach is intended to facilitate the rapid estimation of long-term volume capture performance of structural stormwater BMP facilities, it is not intended to assess adequacy of design or to perform detailed BMP sizing.

2.3.1.1 Nomograph Preparation

Volume-Based Nomographs

Volume-based nomographs encode three pieces of information about the BMP facility:

1. Ratio of the volume capacity provided by the BMP design to the Design Capture Volume (DCV) for the tributary area. This value is a unitless ratio. The equation for the DCV of the tributary area is:

$$V_{dc} = \sum A_n \cdot Q_{91,n}$$

Where: V_{dc} = Design Capture Volume *(ft^3)*

A_n = Watershed area comprised of a particular HRU *(ft^2)*

$Q_{91,n}$ = 91^{st} percentile, 24-hour runoff depth for a particular HRU *(ft)*

The ratio is the actual volume of the BMP divided by the DCV of the tributary area. So, if a BMP is designed exactly to the DCV then it would have a ratio of 1.0, and a BMP sized to smaller than the DCV would have a ratio of less than 1.

2. Drawdown time of the facility. This is computed differently for different types of BMPs. In general, this is computed as the volume divided by the relevant discharge rate. The units for this value are hours.

3. Long-term capture efficiency resulting from many years of continuous simulation for a given facility relative size and drawdown time.

The three dimensions of data can be represented in a nomograph plot as shown below in Error! Reference source not found..

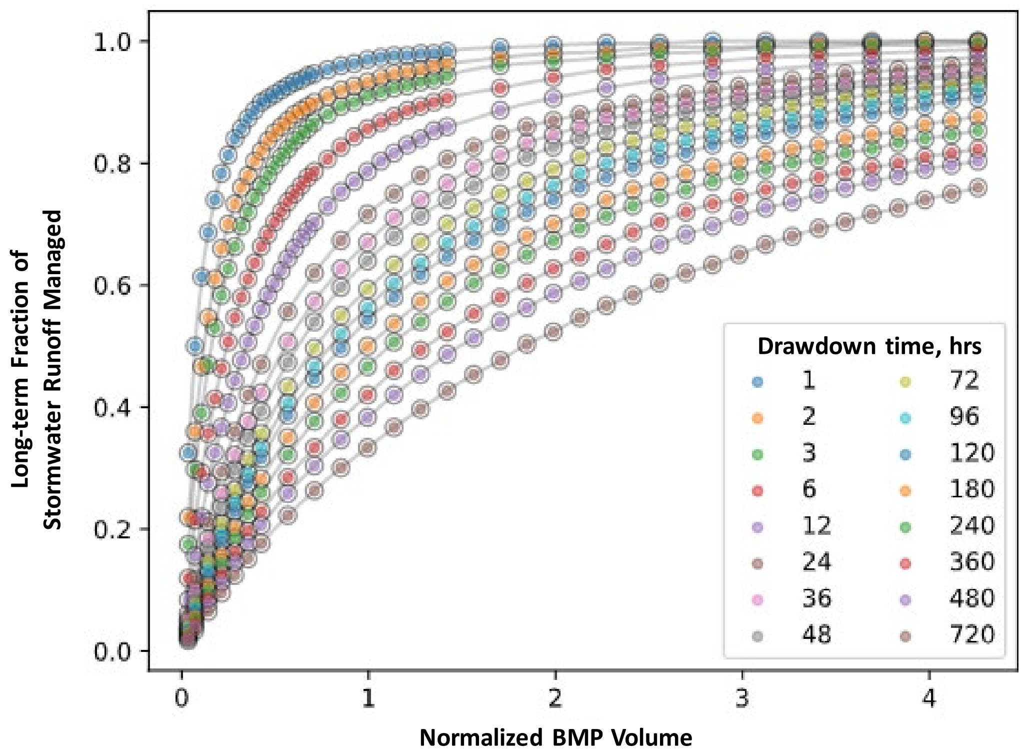

Figure 2-1. Example of a capture efficiency nomograph for a volume-based BMP with a constant drawdown time.

The process for nomograph development for each climate scenario includes:

1. Define a representative unit tributary area (typically one acre). Determine the DCV produced from this tributary area for each impervious HRU.
2. Produce a continuous timeseries of discharge from this area over a long-term period.
3. Perform batch simulations consisting of relevant combinations of BMP volume and drawdown time, representing the range of expected values (one simulation for each combination of HRU, drawdown time, and BMP volume). Produce a continuous timeseries of BMP storage and discharge using the same long-term period as in Step 2.
4. Extract the long-term capture efficiency from each run. Load these results into a standard data table to support lookups and interpolation.

Flow-Based Nomographs This nomograph type encodes two pieces of information about facilities designed with a flow-based sizing approach:

1. Effective design intensity of the facility. This value relates the treatment rate provided by the facility to the effective area of the tributary area it is meant to treat. The units for this value are inches per hour. The equation for the design intensity is:

$$I_d = \frac{\sum(A_n \cdot q_{91,n})}{\sum A_n}$$

Where: I_d = Design intensity *(in/hr)*

$q_{91,n}$ = 91st percentile discharge for a particular HRU *(in/hr)*

A_n = Watershed area comprised of a particular HRU *(ft²)*

2. Long-term capture efficiency resulting from continuous simulation for a given facility design intensity and its adjacent land surface Tc.

The three dimensions of data can be represented in a nomograph plot as shown below in Figure 2-2.

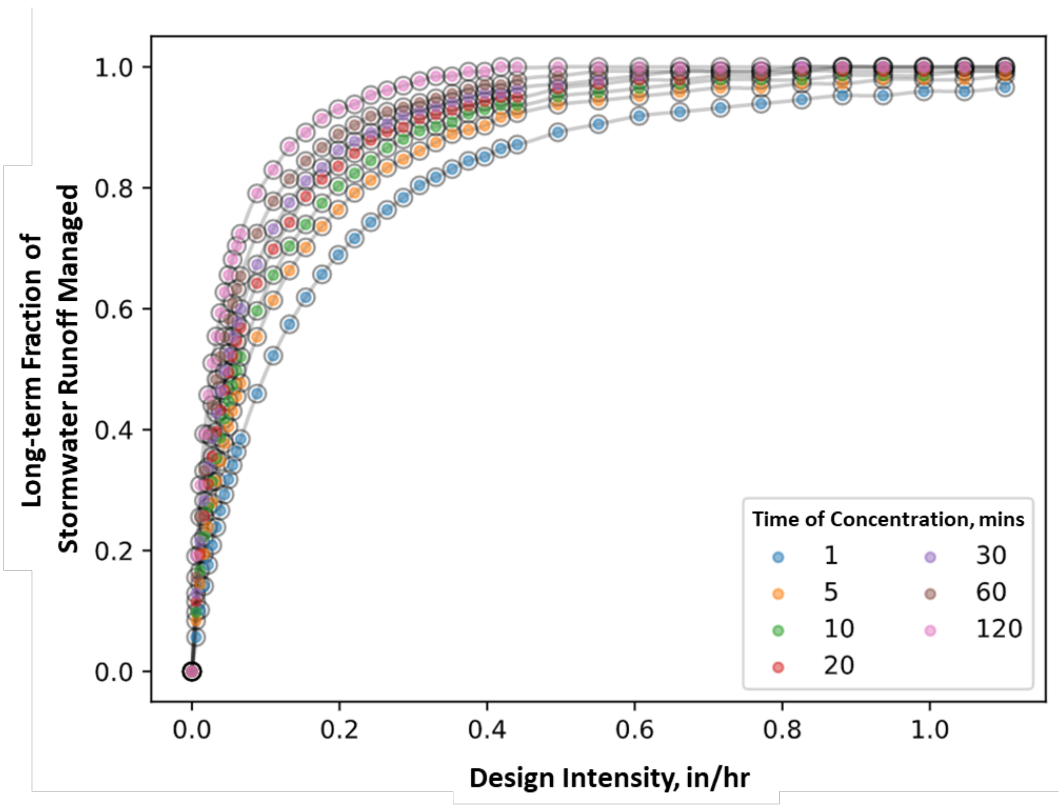

Figure 2-2. Capture efficiency nomograph for a flow-based BMP.

2.3.1.2 Nomograph Solution Approaches

The nomograph solution approach relies on the definition of distinct 'compartments' within a BMP. Each facility may be composed of one or two compartments, and the volume managed by each compartment is either counted as 'treated/detained' and discharged downstream or it is counted as infiltrated and is eliminated from the water balance.

This compartment-based approach allows the Modeling Engine to calculate BMP capture for a wide variety of facility configurations. **Table 2-5** shows the modeled BMP types mapped to their respective treatment solution approaches. The table indicates whether the facility has one or two-compartments and which nomograph type is being used to calculate wet-weather volume capture performance.

Table 2-5. Structural facility types & solution approach table

Tacoma GIS Facility Type	Modeled BMP Name	Pseudocode Mapping to Tacoma Asset Management Type	No. of Compart-ments	Compartments
Bioretention	Bioretention with Partial Infiltration	`INFILTRATED == "Partial"`	2	Volume-Based Infiltration & Treatment
Tank	Dry Extended Detention Basin / Tank	`Hand selected by City of Tacoma Staff (see Appendix B)`	2	Volume-Based Infiltration & Treatment / Detention
Tank	Flow Duration Control Tank	`Hand selected by City of Tacoma Staff (see Appendix B)`	2	Volume-Based Infiltration & Treatment / Detention
Bioretention	Bioretention with Full Infiltration	`INFILTRATED == "FULL"`	1	Volume-Based Infiltration
Trench	Infiltration Basin / Trench		1	Volume-Based Infiltration
Pervious Pavement	Pervious Pavement with Full Infiltration	`INFILTRATED == "FULL"`	1	Volume-Based Infiltration
Pervious Pavement	Pervious Pavement with Partial Infiltration		2	Volume-Based Infiltration & Treatment
Sand Filter	Sand Filter		1	Volume-Based Treatment
Bioretention	Bioretention with No Infiltration		1	Flow-Based Treatment
Vegetated Box	Filterra / Vegetated Box		1	Flow-Based Treatment
Media Filter	Cartridge Media Filter	`FACILITYDETAIL in [Bayfilter, FloGard Perk Filter, Stormfilter]`	1	Flow-Based Treatment
Media Filter	Media Filter		1	Flow-Based Treatment
Oil Water Separator	Oil-water Separator		1	Flow-Based Treatment

Tacoma GIS Facility Type	Modeled BMP Name	Pseudocode Mapping to Tacoma Asset Management Type	No. of Compart-ments	Compartments
Swirl Separator	Hydrodynamic Separator		1	Flow-Based Treatment
Swale	Vegetated Swale		2[1]	Volume-Based Infiltration & Flow-Based Treatment
Vault	Bioretention with Full Infiltration	`FACILITYDETAIl = “silva cell”`	1	Volume-Based Infiltration
Vault	Wet Vault	`FACILITYDETAIl in [combined, wet]`	2	Volume-Based Infiltration & Treatment / Detention
Vault	Dry Extended Detention Basin/Tank		2	Volume-Based Infiltration & Treatment / Detention
Pond	Detention Pond	`Hand selected by City of Tacoma Staff (see Appendix B)`	2	Volume-Based Infiltration & Treatment / Detention
Pond	Infiltration Pond	`Hand selected by City of Tacoma Staff (see Appendix B)`	1	Volume-Based Infiltration
Pond	Wet Pond	`Hand selected by City of Tacoma Staff (see Appendix B)`	1	Volume-Based Treatment
Pond	Wetland Pond	`Hand selected by City of Tacoma Staff (see Appendix B)`	1	Volume-Based Treatment

1 Vegetated Swales and Filter Strips perform ‘incidental infiltration’ due to their un-lined design. This is discussed further in the ‘hybrid flow and infiltration’ discussion below.

Single-Compartment Volume-Based Nomograph Traversal. This is the simplest case for volume-based facilities, such as an infiltration basin, lined bioretention, bioretention with no underdrain, permeable pavement, and several other types. For a single compartment BMP, the normalized BMP volume is determined as the ratio of the facility’s total volume to the DCV of the tributary area. BMP input parameters are structured so that the drawdown time can be inferred from available design information such as facility depth, total volume, and underlying infiltration rate so that the correct curve can be chosen from the nomograph.

Figure 2-3 illustrates an example solution for an infiltration facility with a six-hour draw-down time whose total volume is equal to the DCV of the tributary area. In this case, the modeling module would estimate that the facility achieves approximately 85% of long-term runoff volume infiltration.

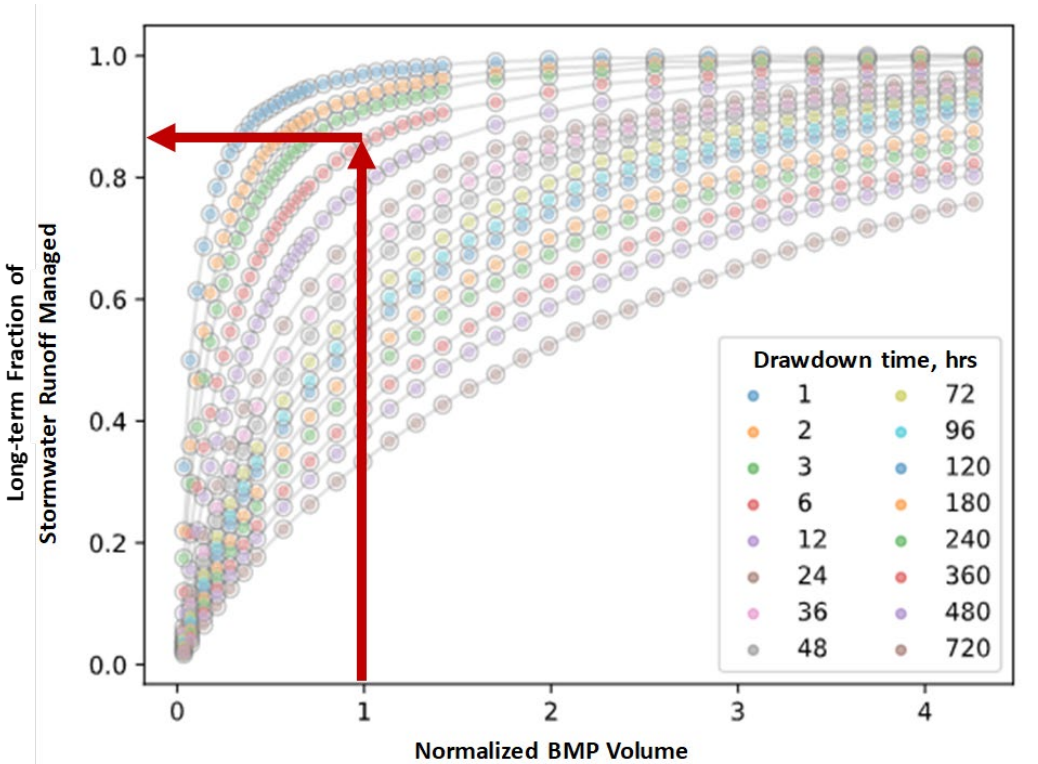

Figure 2-3. Single compartment volume-based nomograph solution example

Two-Compartment Volume-Based Nomograph Traversal. This type of BMP solution is used for volume-based facilities that are capable of both infiltration and treatment of inflowing stormwater. Common examples of this type of BMP include bioretention facilities with a raised underdrain and extended dry detention facilities. These facility types may perform volume infiltration via infiltration into the native soil and may discharge treated flow via elevated underdrains or outlet structures.

The first nomograph traversal is for the infiltration compartment since these facilities fill from the bottom and infiltration typically begins to occur before treated discharge. The following figure illustrates the traversal process for a two-compartment facility in which each compartment is sized to be 50% of the design volume. In this case, the drawdown time is 24 hours for the infiltration compartment and 3 hours for the treatment compartment. The following steps demonstrate the traversal process which is illustrated below in **Figure 2-4**.

Determine the infiltration capture performance by traversing 0.5 units along the x-axis and locate the correct trace for the 24-hour drawdown time of the infiltration compartment. The value is approximately 48% of long-term capture. This is shown in brown in the figure below.

Translate horizontally to the trace for the next compartment which draws down in 3 hours. The second compartment trace is shown in green in the figure below.

Follow the green 3-hour drawdown trace up the nomograph for 0.5 units of x-axis distance.

In this example, about 83% of long-term capture is achieved by both compartments working in concert. Infiltration accounts for 48% (from step 1), treatment accounts for 35% (83% - 48%), and 17% is bypassed (100% - 83%).

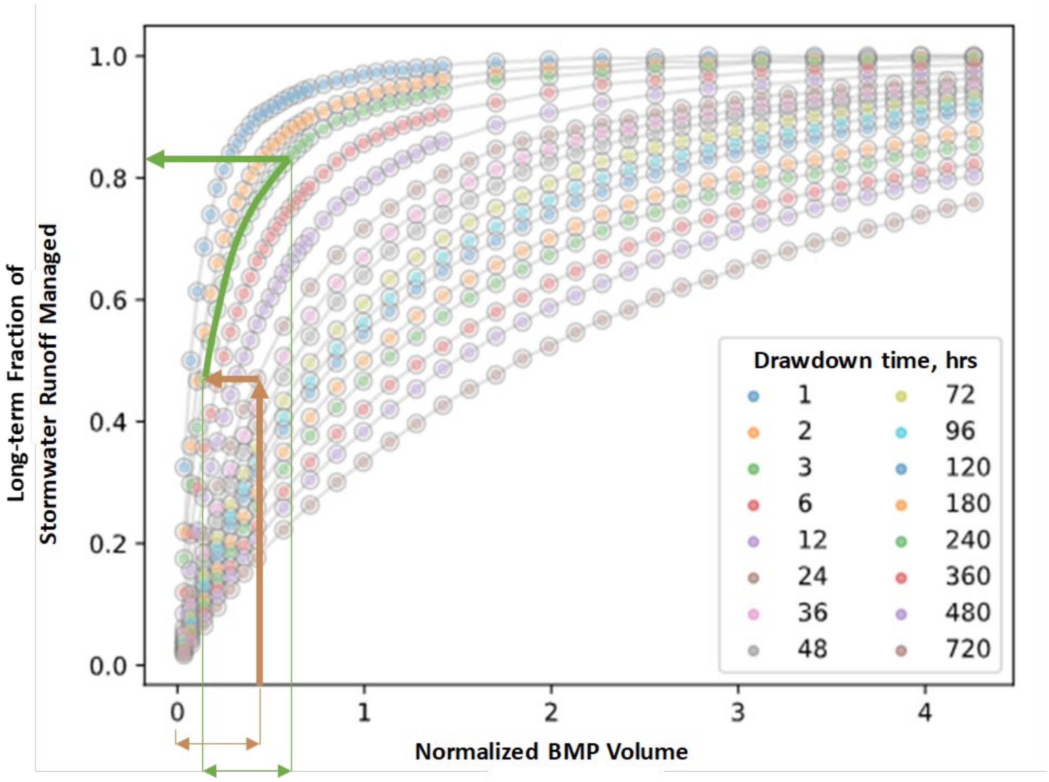

Figure 2-4: Two-compartment nomograph traversal. In this case both compartments have the same volume capture capacity (0.5 Design Volumes) but they have different drawdown times.

For some BMP types, such as extended detention with permeable bottoms, there is not a defined infiltration compartment. Instead, infiltration occurs simultaneously with treatment. For these BMPs, the facility is divided into two parallel compartments with equal drawdown time. The volume in each compartment is prorated based on the ratio of the discharge rate from each compartment. For example, a hypothetical detention basin with a DCV ratio of 1.0 has a treated surface discharge rate of 0.35 cfs and an infiltration discharge rate of 0.15 cfs. The basin is divided into two parallel compartments, a treatment compartment with a DCV ratio of 0.7 and 0.35 cfs discharge rate and a infiltration compartment with a DCV ratio of 0.3 and 0.15 cfs discharge rate. Each compartment is analyzed individually (in parallel) and then the results are summed.

Single-Compartment Flow-Based Nomograph Traversal. This is the simplest case for flow-based BMPs. It is based on the flow rate of the facility. This nomograph is useful for modeling facilities such as an HDS unit or a proprietary flow-through biofilter since these facilities do not perform stormwater volume infiltration. In the example nomograph below (Figure 2-5) a facility with a design treatment intensity of 0.2 inches per hour is expected to manage 83% of long-term runoff.

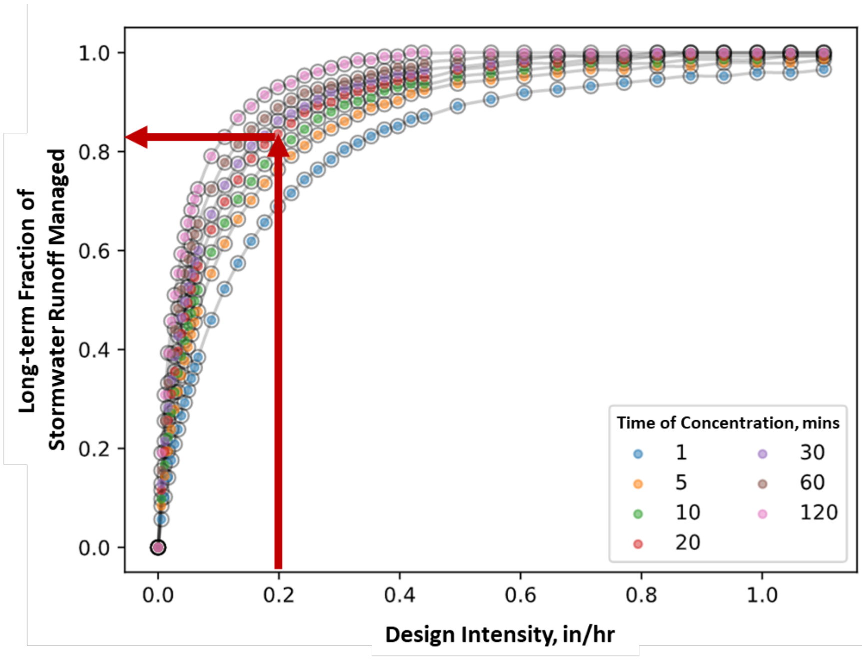

Figure 2-5. Single compartment flow-based nomograph solution

Hybrid Flow-Based Nomograph Traversal. This volume capture solution applies only to facilities that are both unlined and flow-based facilities like a typical vegetated swale. These facilities are often sized and designed as flow-based facilities, but they may provide incidental volume reduction via infiltration depending on underlying soil conditions. For these facilities, the nomograph solution for capture is:

1. Consult the relevant flow-based nomograph to compute the total long-term capture volume.

2. Utilize the facility volume, depth, and underlying soil group to estimate the total storage volume and drawdown time for the facility.

3. Consult the relevant volume-based nomograph to calculate the long-term retained volume.

4. Calculate the treated and discharged volume as the difference between the total long-term capture volume and the retained volume.

This approach helps ensure that the overall long-term volume capture is consistent with the flow-based nomograph traversal result but allows for a portion of the capture volume to be counted as infiltration to better represent the incidental infiltration performance of these facilities.

Nested BMPs. The nomograph solution supports regional BMPs that receive discharge from BMPs in their upstream catchments. This means that upstream facilities that achieve long-term volume capture and attenuation will affect the potential volume capture performance of downstream facilities since that volume, or a portion of that volume, was removed from the system. It should be noted that in practice BMPs are typically only nested once, such as in a distributed BMP upstream of a centralized BMP, and more deeply nested facility configurations are uncommon.

This approach implements a corrective algorithm to track and correct the impacts of upstream infiltration and detention when applying nomograph traversal capture solutions in nested BMP configurations. This effectively treats upstream BMPs similarly to the first compartment in a two compartment BMP, described above. Therefore, the downstream BMP traverses the nomograph curve further to the right, where the slopes are lower (somewhat less capture per unit of volume provided). Comparisons between this algorithm and an explicit continuous simulation analysis in EPA SWMM 5.1 are within 5% of long-term capture efficiency, long-term volume infiltration performance, and long-term treatment performance for equivalent BMP configurations.

2.3.2 Simplified Treatment Volume Capture Performance

The approach allows for a simplified method to model catchments with many treatment facilities for which individual facility delineations are not available, or to model facilities where specific design parameters are unknown. The user can enter the fractions of the site treated by given types of BMP and enter the long-term fraction of runoff volume retained and treated by the facility. This method requires the user to delineate the overall site treated area, but uses the user-entered values for percent of volume treated and retained rather than nomographs.

2.4 Water Quality Performance

2.4.1 Statistical Analysis Approach

Water quality performance estimates will be derived from the International Stormwater BMP Database (IBMPDB) (http://bmpdatabase.org/, accessed 2025). Analysis will be based on the distribution of paired influent and effluent water quality concentrations for individual events by BMP category as reported in the database. This approach follows a similar study performed for the Puget Sound Partnership, evaluating the performance of water quality BMPs (Nilsen and Koryto 2017).

The water quality BMP types used by Tacoma GIS and the modeled BMP types from the previous section are mapped to the types in the IBMPDB according to Table 2-6 below. BMP types that are modeled to achieve pollutant load reductions only via infiltration only (volume reduction) are not included in the table.

Table 2-6. Facility Type Cross-Walk

Tacoma GIS Facility Type	Modeled BMP Type	IBMPDB Type
Bioretention	Bioretention with Partial Infiltration	Bioretention
Vegetated Box	Filterra/Vegetated Box	Bioretention
Bioretention	Bioretention with No Infiltration	Bioretention
Pond	Detention Pond	Detention Basin
Tank	Dry Extended Detention Basin/Tank	Detention Basin
Tank	Flow Duration Control Tank	Detention Basin
Swale	Vegetated Swale	Grass Swale
Vegetated Box	Filterra/Vegetated Box High Rate	High Rate Biofiltration
Bioretention	Bioretention with High Rate Media and Partial Infiltration	High Rate Biofiltration
Bioretention	Bioretention with High Rate Media and No Infiltration	High Rate Biofiltration
Media Filter	Cartridge Media Filter	High Rate Media Filtration
Media Filter	Media Filter High Rate	High Rate Media Filtration
Swirl Separator	Hydrodynamic Separator	Hydrodynamic Separation Devices
Oil Water Separator	Oil-Water Separator	Oil/Grit Separators and Baffle Boxes
Pervious Pavement	Pervious Pavement with Partial Infiltration	Porous Pavement/Porous Asphalt
Pond	Wet Pond	Retention Pond
Vault	Wet Vault	Retention Pond
Sand Filter	Sand Filter	Sand Media Filter
Pond	Wetland Pond	Wetland Basin
Bioretention	Bioretention with Full Infiltration	*These BMP types achieve load reductions via infiltration rather than by discharging treated effluent. They are not analyzed further in this section.*
Trench	Infiltration Basin/Trench	
Pond	Infiltration Pond	
Pervious Pavement	Pervious Pavement with Full Infiltration	

To examine the relationship between influent and effluent data for each distinct combination of pollutant and BMP category, we started with two hypothesis tests: the Wilcoxon signed-rank test and the Kendall rank correlation coefficient. Next, we applied regression analysis using the Kendall-Theil Robust Line, which helped us identify whether the data showed a linear, log-linear, or logarithmic connection between influent and effluent concentrations. The results from the Kendall Robust Line-Regression are displayed in Appendix C.

The pollutants and BMPs analyzed are summarized in Table 2-7.

Table 2-7. Pollutants and BMPs Analyzed

Pollutants Evaluated	IBMPDB Type Evaluated	BMP Code
Total Phosphorus (TP) Total Nitrogen (TN)[1] Total Suspended Solids (TSS) Total Zinc (TZn) Total Copper (TCu)	Bioretention	BR
	Grass Swale	BS
	Detention Basin	DB
	Hydrodynamic Separation Devices	HDS
	High Rate Biofiltration	HRBF
	High Rate Media Filtration	HRMF
	Sand Media Filter	MF
	Oil/Grit Separators and Baffle Boxes	OGS
	Porous Pavement	PP
	Retention Pond	RP
	Wetland Basin	WB

2.4.1.1 Data Sufficiency

Only paired data were included in the data analysis, meaning that storms without both influent and effluent observations were omitted. Also, only data from studies with median influent concentrations representative of the Puget Sound urban area are included. Outfall monitoring data were downloaded from Ecology's Municipal Stormwater Permit Outfall database[2]. These data were accessed and downloaded from the data portal on the Washington State Open Data Portal website in November 2025.

Utilizing the characteristics of the lognormal distribution, the 10^{th} and 90^{th} percentiles of urban runoff concentrations were computed for each pollutant and were used to define the representative influent concentrations as summarized in Table 2-8 below. This range was used to select BMP studies from the IBMPDB with median influent concentrations that fall within this range.

[1] Since TN is rarely reported, this parameter includes samples reported as TN as well as the sum of samples reporting to total Kjeldahl nitrogen (TKN) and nitrate plus nitrite (NOx)
[2] https://data.wa.gov/Natural-Resources-Environment/Municipal-Stormwater-Permit-Outfall-Data/d958-q2ci/about_data

Table 2-8. Representative Range of Influent BMP Influent Concentrations.

Pollutant	Units	Count	10th Percentile	Median	90th Percentile
Total Copper	ug/L	661	3.23	10.82	36.21
Total Nitrogen[1]	mg/L	574	0.2	0.89	3.92
Total Phosphorus	mg/L	607	0.02	0.09	0.35
Total Suspended Solids	mg/L	631	2.61	18.97	137.98
Total Zinc	ug/L	636	17.72	63.31	226.13

1. Total Nitrogen was estimated as the sum of TKN and nitrate/nitrite as N from the EIM for samples taken from the same location on the same day.

With the screening of BMP studies based on influent/effluent data pairs and representative influent concentrations, the inventory of available data is summarized in Table 2-9 below. BMP type and pollutant combinations with fewer than 2 distinct studies and 20 paired datapoints were removed from the analysis. These criteria eliminated the Porous Pavement(PP) and Total Nitrogen pair.

Table 2-9. BMP Data Inventory after Screening for Influent/Effluent Data Pairs and Representative Influent Quality.

	Total Copper		Total Nitrogen		Total Phosphorus		Total Suspended Solids		Total Zinc	
BMP Code	Data Count	N Studies	Data Count	N Studies	Data Count	N Studies	Data Count	N Studies	Data Count	N Studies
BR	372	27	298	29	546	44	537	40	361	26
BS	262	24	365	25	450	33	449	34	309	31
DB	254	26	272	28	433	47	448	47	284	30
HDS	208	15	161	8	299	23	450	28	262	20
HRBF	48	5	37	2	100	6	104	6	54	5
HRMF	322	18	110	5	393	22	436	21	388	22
MF	309	21	281	20	335	24	365	28	335	24
OGS	90	9	55	5	100	8	177	14	88	8
PP	139	7	18	1	288	11	302	11	159	9
RP	1186	50	1492	44	1576	69	1658	68	1386	58
WB	348	10	1160	21	1084	30	880	29	412	15

The screened data from BMPDB was used to analyze the relationship between influent concentrations (C_{inf}) and effluent concentrations (C_{eff}) using a multi-step process. This process is shown in Figure 2-6 and consists of 4 steps:

1. Determine if sufficient paired data for analysis exist
2. Determine if there is a statistical difference between C_{inf} and C_{eff}

3. Determine if a monotonic relationship between C_{inf} and C_{eff} exists
4. Conduct linear and log-linear regression between C_{inf} and C_{eff} and develop functional relationship

Since water quality data are often highly variable and positively skewed, nonparametric statistics were selected over parametric statistics for this analysis. The Wilcoxon signed rank test was used to evaluate whether the influent and effluent concentrations are statistically different and the Kendall's tau correlation coefficient was used to evaluate whether a monotonic relationship exists.

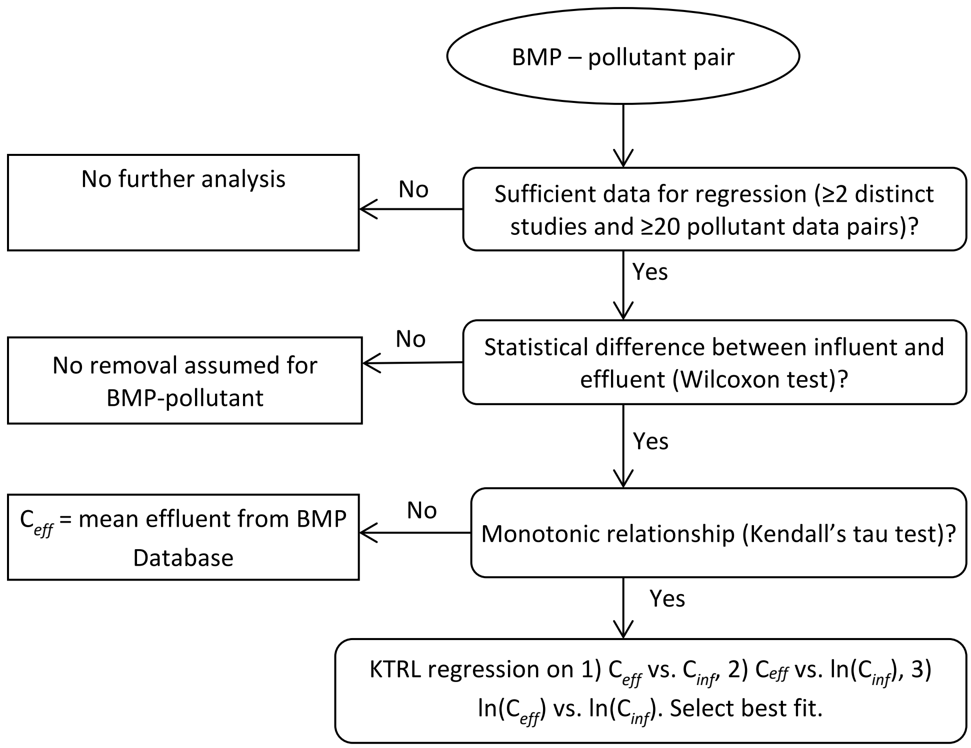

Figure 2-6. Analysis process for influent-effluent regression

If the Wilcoxon test found a statistically significant difference between the influent and effluent concentrations, and the Kendall's tau test found that a monotonic relationship exists, regression equations were developed using the Kendall-Theil Robust Line (KTRL). Linear, log-linear, and log-log relationships were evaluated and the best-fit equation was used selected based on the median absolute deviation. Statistical significance for all analyses was determined at a level of $\alpha = 0.10$. The analysis results are presented and discussed in the next section.

2.4.1.2 Paired difference test

The non-parametric Wilcoxon signed-rank test was used to verify a statistical difference between influent and effluent quality for each BMP-pollutant pair to determine if removal of a pollutant was occurring or not. Because this test requires an approximately symmetric distribution, the data were log-transformed prior to performing the analysis. As shown in Table 2-10, most BMP-pollutant combinations show statistically significant concentration reductions ($p<0.1$; failing combinations are shown bolded). Only relationships that show a statistically distinct difference between influent and effluent were used.

Table 2-10. Wilcoxon Signed-Rank Test Results

BMP Code	Wilcoxon P-values by BMP Type (bold values indicate statistically insignificant removals)				
	Total Copper	**Total Nitrogen**	**Total Phosphorus**	**Total Suspended Solids**	**Total Zinc**
BR	<0.0001	0.0005	<0.0001	<0.0001	<0.0001
BS	<0.0001	**0.7222**	<0.0001	<0.0001	<0.0001
DB	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
HDS	<0.0001	0.0725	<0.0001	<0.0001	<0.0001
HRBF	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
HRMF	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
MF	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
OGS	<0.0001	0.0278	<0.0001	<0.0001	0.0025
PP	0.0114	--	<0.0001	<0.0001	<0.0001
RP	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
WB	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

2.4.1.3 Monotonicity test

Next, data will be tested for monotonicity (e.g. a nondecreasing function). To evaluate whether effluent concentrations are monotonically related to influent concentrations, the Kendall's rank correlation test was applied to each BMP-pollutant combination that showed a statistically significant difference between influent and effluent concentrations in Table 2-10 The Kendall's tau correlation coefficients and p-values are shown in Table 2-11. All BMP-pollutant combinations with adequate data and significant concentration reductions show statistically significant monotonic correlation between influent and effluent. These results indicate that functional relationships between influent and effluent concentrations may exist. However, several of the correlation coefficients are low (e.g., <0.4), which indicates a relatively weak monotonic correlation for some BMP-pollutant combinations. Only monotonic relationships were used.

Table 2-11. Kendall's Rank Correlation Test Results

BMP Code	Kendall's Tau Correlation Coefficients (and p-values) by BMP Type (bold values indicate statistically insignificant correlation)				
	Total Copper	**Total Nitrogen**	**Total Phosphorus**	**Total Suspended Solids**	**Total Zinc**
BR	0.4038 (<0.0001)	0.4172 (<0.0001)	0.2767 (<0.0001)	0.0816 (0.0052)	0.1894 (<0.0001)
BS	0.5502 (<0.0001)	**--**	0.4319 (<0.0001)	0.3750 (<0.0001)	0.5246 (<0.0001)

BMP Code	Kendall's Tau Correlation Coefficients (and p-values) by BMP Type (bold values indicate statistically insignificant correlation)				
	Total Copper	**Total Nitrogen**	**Total Phosphorus**	**Total Suspended Solids**	**Total Zinc**
DB	0.6863 (<0.0001)	0.6029 (<0.0001)	0.5156 (<0.0001)	0.4563 (<0.0001)	0.5518 (<0.0001)
HDS	0.7250 (<0.0001)	0.6581 (<0.0001)	0.6892 (<0.0001)	0.6223 (<0.0001)	0.7065 (<0.0001)
HRBF	0.6849 (<0.0001)	0.4539 (<0.0001)	0.4877 (<0.0001)	0.3775 (<0.0001)	0.7474 (<0.0001)
HRMF	0.6003 (<0.0001)	0.6722 (<0.0001)	0.6721 (<0.0001)	0.4199 (<0.0001)	0.5799 (<0.0001)
MF	0.4833 (<0.0001)	0.6384 (<0.0001)	0.5415 (<0.0001)	0.3996 (<0.0001)	0.3565 (<0.0001)
OGS	0.7145 (<0.0001)	0.6579 (<0.0001)	0.7835 (<0.0001)	0.6358 (<0.0001)	0.5741 (<0.0001)
PP	0.3302 (<0.0001)	--	0.3323 (<0.0001)	0.3662 (<0.0001)	0.3243 (<0.0001)
RP	0.4405 (<0.0001)	0.4132 (<0.0001)	0.4768 (<0.0001)	0.2988 (<0.0001)	0.3182 (<0.0001)
WB	0.4534 (<0.0001)	0.3828 (<0.0001)	0.4541 (<0.0001)	0.4813 (<0.0001)	0.3379 (<0.0001)

2.4.1.4 Regression

Finally, a regression relationship between influent and effluent concentrations was developed using the non-parametric Kendall-Theil Robust Line regression. This approach was chosen to handle data outliers better than other regression methods, such as ordinary least-squares regression.

Based on the results of the Wilcoxon and Kendall's tau tests, several BMPs appear to provide statistically significant reductions in pollutant concentrations along with monotonic influent/effluent relationships. These results together indicate that a functional relationship may exist that can be used to predict effluent concentrations from influent concentrations. The Kendall-Thiel Robust Line (KTRL) was used to approximate functional relationships. The KTRL is a non-parametric, linear regression approach that is resistant to the influence of potential outliers in the underlying data set. It is based on the Theil slope, which is the median of all possible pairwise slopes between two data sets. A y-intercept is then calculated according to the formula:

$$b = median(C_{eff}) - m * median(C_{inf})$$

Where b is intercept, m is the median of all possible pairwise slopes, C_{eff} is the effluent quality data set, and C_{inf} is the influent quality data set.

Due to the typical positive skew of stormwater quality data, log-transforming either or both the influent and effluent data sets may be necessary to improve the linear fit. Consequently, the best-fit from three possible relationships between influent and effluent, as shown in Table 2-12, were evaluated.

Table 2-12. KTRL Equations Used for Nonparametric Regression

Data pairs plotted for KTRL Calculations	KTRL Equation Derived
C_{eff} , C_{inf}	$C_{eff} = m*C_{inf} + b$
C_{eff} , $\ln(C_{inf})$	$C_{eff} = m*\ln(C_{inf}) + b$
$\ln(C_{eff})$, $\ln(C_{inf})$	$\ln(C_{eff}) = m*\ln(C_{inf}) + b$

The median absolute deviation (MAD) was used to select the best regression equation for each BMP-pollutant combination. This statistic is defined by:

$$MAD = \ median\left(\left|C_{eff} - C_{predicted}\right| \, for\ all\ values\ of\ C_{eff}\right)$$

Where $C_{predicted}$ is the value of the C_{eff} predicted by the Kendall-Theil regression line.

Most of the BMP-pollutant combinations have the best fit after both the influent and effluent have been log-transformed and those with the highest correlation coefficients generally have lowest MAD.

Based on the various possible influent-effluent relationships considered in Table 2-12, a generalized equation was developed as follows:

$$\mathrm{C}_{eff} = \min\left[\mathrm{C}_{inf}, \max\left(\mathrm{A} + \mathrm{B} \cdot \mathrm{C}_{inf} + \mathrm{C} \cdot \ln\left(\mathrm{C}_{inf}\right) + e_{1i} + \left(\mathrm{D} \cdot \mathrm{C}_{inf}{}^{\mathrm{E}}\right) e_{2i}, DL\right)\right]$$

Where C_{eff} is the predicted effluent concentration, C_{inf} is the estimated influent concentration, A, B, C, D, and E are parameters of the equation, DL is the maximum of the minimum reported detection limits for the studies within each pollutant-BMP category, and e_{1i} and e_{2i} are the bias correction factors for untransformed and transformed effluent predictions, respectively.

The bias correction factors are computed as the mean deviation, ignoring outliers defined as any values more than 1.5 times the interquartile range (Q3 – Q1) beyond each quartile.

The resulting best-fit regression plots and KTRL parameters are provided in Appendix C.

2.4.2 Influent - Effluent performance curves

The pollutant load entering a BMP is estimated by calculating the product of the average annual influent volume and the mean COC concentration in the watershed. The BMP pollutant load reduction is calculated by the sum of:

1. **Infiltration** - The load reduced by infiltration is calculated as the watershed pollutant concentration multiplied by the volume lost to infiltration by the facility.

2. **Treatment** - The load reduced by treatment is calculated as the product of the volume treated and the reduction in concentration achieved by the facility between the influent and treated effluent.

To calculate the concentration reduction for treated water, this approach uses as input a set of influent-versus-effluent concentration curves. These define the best estimate of average effluent quality based on the average influent quality, and were determined based upon the analysis described in the previous section. An example plot representing the functional relationship between influent and effluent TSS concentration for several BMP types is shown below in Figure 2-7. The complete set of best-fit regression plots and KTRL curve parameters are provided in Appendix C.

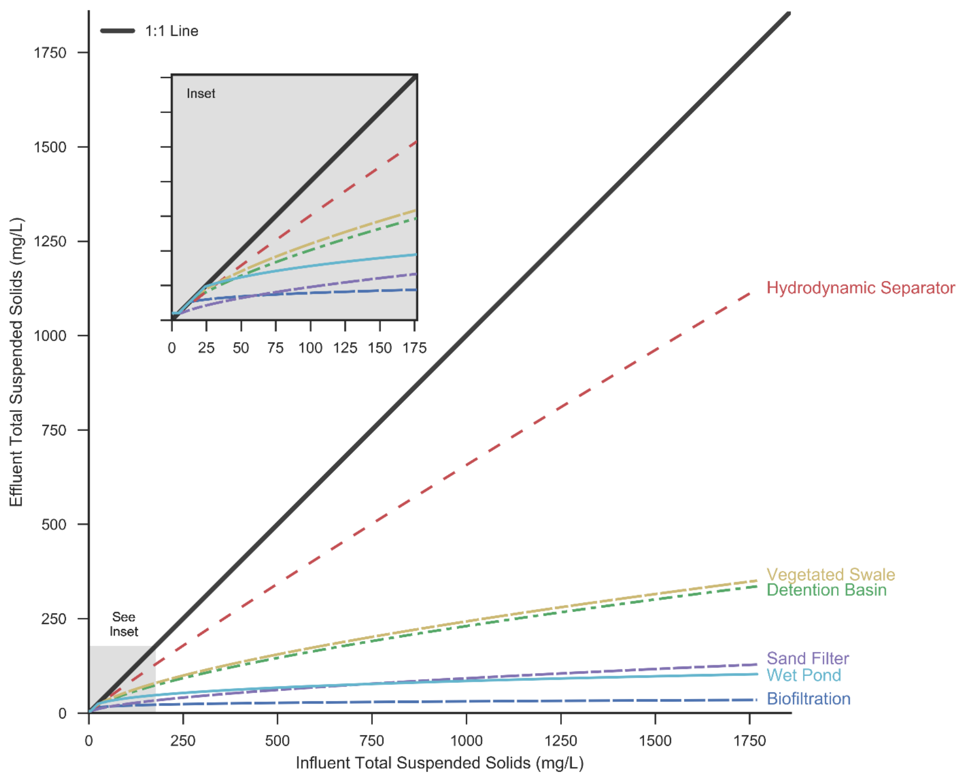

Figure 2-7. Representative Influent vs effluent curve for TSS removal by BMP type

The overall load reduction is calculated as the sum of the load removed via infiltration and the load removed via treatment. The load downstream of a BMP is calculated as the influent load minus these two components of load reduction. The effluent concentration is calculated as the load divided by the effluent volume. Bypass volume is assumed to be untreated and is assigned the contributing catchment concentration.

2.5 Performance of Source Control BMPs

2.5.1 Street Sweeping

2.5.1.1 Performance Data

Tacoma performs enhanced street sweeping across the city using regenerative air machines. Currently, all areas of the city are swept at least twice a year, with more frequent sweeping occurring for major arterials and business districts (City of Tacoma, 2017).

Tacoma has been monitoring sweeping performance in the Thea Foss watershed since 2012. A summary of monitoring results is shown in Table 7. For most COCs, the trend in removal efficiencies are relatively steady, although values fluctuate from year-to-year.

***Table* 2-13. Summary of Reduction in COC Concentrations for Street Sweeping in the Thea Foss Watershed, 2012-2021**

COC	2012	2013	2014	2015	2016	2017*	2018*	2019*	2020†	2021†	Mean Value (Tool Default)	Trend
Bis(2EH)phthalate	47%	50%	53%	55%	55%	34%	37%	42%	35%	36%	**44%**	
Indeno(1,2,3-c,d)pyrene	66%	64%	67%	68%	67%	50%	49%	49%	39%	33%	**55%**	
Phenanthrene	65%	68%	70%	70%	71%	51%	50%	51%	41%	41%	**58%**	
Pyrene	61%	69%	71%	73%	73%	54%	54%	54%	44%	43%	**60%**	
TSS	18%	20%	21%	22%	24%	18%	18%	18%	27%	26%	**21%**	
Zinc	19%	23%	27%	29%	32%	29%	30%	30%	36%	36%	**29%**	

* includes enhanced sweeping for outfalls 243, and 245

† includes enhanced sweeping for outfalls 243, 245, and 254

2.5.1.2 Tool assumptions

To calculate pollutant removal attributable to street sweeping, the tool will employ the following assumptions.

- Default removal for each COC will be set at the mean value as shown in Table 7.
- Pollutant reduction will be calculated prior to influent concentrations draining to BMPs.
- Street sweeping will be assumed to apply evenly to an entire watershed.

2.5.2 Storm Line Cleaning

Similar to Street Sweeping, Anchor QEA (2012) evaluated performance of basin-wide storm-line cleaning.

Table 2-14. Summary of Storm Line Cleaning Monitoring in the Thea Foss Watershed, 2012-2021

COC	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Mean Value (Tool Default)	Trend
Bis(2EH)phthalate	40%	52%	54%	57%	58%	56%	54%	54%	54%	55%	56%	**54%**	
Indeno(1,2,3-c,d)pyrene	76%	78%	79%	81%	80%	79%	76%	75%	74%	74%	74%	**77%**	
Phenanthrene	72%	73%	75%	77%	77%	77%	75%	74%	74%	74%	74%	**75%**	
Pyrene	77%	79%	81%	83%	83%	82%	80%	79%	79%	79%	79%	**80%**	
TSS	21%	21%	25%	28%	30%	32%	30%	30%	29%	30%	31%	**28%**	
Zinc	20%	22%	26%	28%	30%	32%	32%	33%	34%	36%	37%	**30%**	

2.5.2.1 Tool assumptions

To calculate pollutant removal attributable to line cleaning, the tool will employ the following assumptions.

- Default removal for each COC will be set at the mean value as shown in Table 8.
- Pollutant reduction will occur after to effluent concentrations discharging from BMPs.
- Storm line cleaning will be assumed to apply evenly to an entire watershed.

CHAPTER 3. COST MODULE

3.1 Introduction

This section describes the development of a lifecycle module for selected stormwater facility types. This module incorporates capital costs, operations and maintenance costs, and lifespan, to provide the present costs of various facility types.

3.2 Parameters

The cost module contains parameters that can be adjusted by the user. Global parameters are set for the tool as a whole and apply to all cost calculations. Asset specific parameters are used to calculate costs for a specific asset and should be based on the specific attributes of an asset.

3.2.1 Global Parameters

The following parameters apply to all cost calculations in the tool. These are adjusted at a global level so costs of specific assets can be compared to one another.

- **Cost Basis Year**: The reference year for inflation adjustment (i.e. what year should dollar values be reported in).
- **Discount Rate:** The interest rate used to determine the present value of future cash flows. The discount rate in the tool has been initialized with the 30-year rate published in the White House Office of Management and Budget (OMB) Circular A-94 (OMB, 2023) This rate corresponds to the long-term nominal interest rate on US Treasury notes and bonds.
- **Inflation Rate**: This is the annual inflation rate to be applied to purchases and services. The inflation rate has been initialized with the long-term inflation rate published by the Congressional Budget Office (2023)
- **Planning Horizon**: This is the total time-period in years over which future cash flows will be considered.

3.2.2 Asset Specific Parameters

The following parameters apply to a specific asset. These are adjusted on a per asset basis, based on that asset's characteristics.

- **Capital Costs**: These are the initial costs required for constructing and installing an asset. Capital costs may include property acquisition costs depending on the scenario.
- **Capital Cost Basis Year**: This refers to the reference year used to express the capital costs. For example, if capital costs were calculated in 2020 dollars, the user would input 2020 for the Capital Cost Basis Year.
- **Install Year**: The year when the asset was constructed.

- **Lifespan**: The expected duration of facility service before it requires replacement or significant overhaul.
- **O&M Cost Basis Year**: This is the base year from which the annual operation and maintenance costs are calculated.
- **O&M Costs per Year:** The reference year used to express operation and maintenance costs.
- **Replacement Cost**: The cost to replace or significantly overhaul an asset beyond routine maintenance (e.g., media replacement in a bioretention facility).

3.2.3 Reference Costs

To assist with estimation of costs, unit costs for facilities were adapted from the King County Water Quality Benefit Evaluation (WQBE) program (Hadler and others, 2022). This study used data from a number of sources including King County Wastewater Treatment Division and the Washington State Department of Ecology to create cost curves, which are based on the predicted costs of different water quality actions. Unit cost curves were developed for both capital and operations and maintenance costs.

Cost curves were mapped to Tacoma's facility type definitions as shown in Table 3-1.

Table 3-1. Facility types and corresponding unit cost curves

Facility Type	Corresponding King County Unit Cost Curves
Bioretention	WQBE 01_Rain Garden Installation on Property
Bioretention	WQBE_03A_Bioretention Underdrain on Property
Bioretention	WQBE_03Aa_Bioretention Underdrain with Property Cost
Bioretention	WQBE_03B_Bioretention No Underdrain on Property
Bioretention	WQBE_03Bb_Bioretention No Underdrain with Property Cost
Bioretention	WQBE_03C_Bioretention Underdrain in ROW
Bioretention	WQBE_03D_Bioretention No Underdrain in ROW
Bioretention	WQBE_22A_Regional Vegetated Media SW Facility on Public Property
Bioretention	WQBE_22B_Regional Vegetated Media SW Facility with Property Cost
Media Filter	WQBE 21E_High Rate Underground Filter on Public Property
Media Filter	WQBE 21F_High Rate Underground Filter with Property Cost
Media Filter	WQBE_05A_Media Filter Drain Underdrain
Media Filter	WQBE_05B_Media Filter Drain No Underdrain
Media Filter	WQBE_21A_High Rate Underground Filter in Urban ROW PCCP
Media Filter	WQBE_21B_High Rate Underground Filter in Highway ROW PCCP
Media Filter	WQBE_21C_High Rate Underground Filter in Urban ROW HMA
Media Filter	WQBE_21D_High Rate Underground Filter in Highway ROW HMA
Pervious Pavement	WQBE_08A_Pervious Concrete Sidewalk (no sand layer)
Pervious Pavement	WQBE_08B_Porous Asphalt Driveway (with sand layer)
Pervious Pavement	WQBE_08C_Permeable Paver Driveway (with sand layer)
Pervious Pavement	WQBE_08D_Permeable Paver Plaza (no sand layer)
Pond	WQBE_12A_Detention Pond on Public Property
Pond	WQBE_12B_Detention Pond with Property Cost

Facility Type	Corresponding King County Unit Cost Curves
Pond	WQBE_13A_Infiltration Pond Till Soil on Public Property
Pond	WQBE_13B_Infiltration Pond Outwash Soil on Public Property
Pond	WQBE_13C_Infiltration Pond Till Soil with Property Cost
Pond	WQBE_13D_Infiltration Pond Outwash Soil with Property Cost
Pond	WQBE_13E_Infiltration Pond Outwash Soil with High Rate Underground Filter System on Public Property
Pond	WQBE_18A_ Wet Pond on Public Property
Pond	WQBE_18B_ Wet Pond with Property Cost
Pond	WQBE_20A_ Stormwater Treatment Wetland on Public Property
Pond	WQBE_20B_ Stormwater Treatment Wetland with Property Cost
Pond	WQBE_23_Sports Field and Park Detention
Pond	WQBE_24_Blue Roof
Swale	WQBE_04A_Bioswale in ROW
Swale	WQBE_04B_Bioswale on Public Property
Swale	WQBE_04C_Bioswale with Property Cost
Tank	WQBE_11A_Detention Vault on Public Property
Tank	WQBE_11B_Detention Vault in ROW
Tank	WQBE_11C_Detention Vault with Property Cost
Tank	WQBE_16_Cistern on Property
Vault	WQBE_14A_Infiltration Vault Till Soil on Public Property
Vault	WQBE_14B_Infiltration Vault Outwash Soil on Public Property
Vault	WQBE_14C_Infiltration Vault Till Soil in ROW
Vault	WQBE_14D_Infiltration Vault Outwash Soil in ROW
Vault	WQBE_14E_Infiltration Vault Till Soil with Property Cost
Vault	WQBE_14F_Infiltration Vault Outwash Soil with Property Cost
Vault	WQBE_14G_Infiltration Vault Outwash Soil with High Rate Underground Filter System in ROW
Vault	WQBE_19A_ Wet Vault on Public Property
Vault	WQBE_19B_ Wet Vault in ROW
Vault	WQBE_19C_ Wet Vault with Property Cost
Vegetated Box	WQBE 02A_Bioretention Planter on Property
Vegetated Box	WQBE_02B_Bioretention Planter in ROW
Vegetated Box	WQBE_02C_Bioretention Planter with Property Cost

3.2.4 Cost Calculations

3.2.4.1 Net present value

Costs are calculated as the net present value (NPV) of all capital and operations and maintenance costs. NPV is the value of a stream of benefits or costs when discounted back to a single time. The formula for calculating NPV of future outlays is:

$$NPV(i, N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

where

NPV	=	net present value of costs
R_t	=	Annual regular costs
i	=	discount rate
N	=	Number of years (planning horizon).

3.2.4.2 Inflation adjustments

Users can input capital costs and operations and maintenance costs derived in different basis years from each other. This functionality permits the user to incorporate cost estimates or actual expenditures from prior years and still be able make a comparative analysis using the tool. Costs are adjusted for inflation using the formula below:

$$V_0(1+r)^n = V_n$$

where

V_0	=	Value from previous time period
V_n	=	Current value
r	=	inflation rate
n	=	Number of years between periods

Capital costs are costs are adjusted for inflation by this formula directly. Operation and maintenance costs are first translated to the whole life-cycle value corresponding to the previous period, and then adjusted using this formula.

CHAPTER 4. WATERSHED PRIORITIZATION MODULE

4.1 Introduction

The watershed prioritization module allows users to identify and prioritize areas that are a high priority for actions to meet watershed planning goals related to water quality, habitat, and social equity. By developing a structured decision support process, decisions can be made that better allocate resources, plan for new facilities, and identify areas for preservation.

This chapter presents the methodology used to develop the watershed prioritization module. The module leverages GIS data, water quality modeling, BMP performance modeling, and multi-criteria decision analysis (MCDA). The approach presented below reconciles the complexities of watershed planning with the need for practical, science-driven decision making.

4.2 Methodology

This section described the process used to incorporate the PROMETHEE II (Preference Ranking Organization Method for Enrichment Evaluation) MCDA methodology with available spatial data. It provides an overview of the MCDA framework, development of criteria, and methods for calculating watershed metrics.

4.2.1 PROMETHEE II MCDA Overview

The PROMETHEE II is a widely used Multi-Criteria Decision Analysis (MCDA) methodology developed by Brans and Vincke (1985). This approach is primarily designed to aid decision-makers in handling complex decision problems involving multiple, often conflicting, criteria. It offers an organized framework to compare and rank various alternatives based on the decision-maker's preferences.

PROMETHEE II works by converting criteria into a comparable scale, which allows for the evaluation of alternatives based on different aspects. The methodology consists of several steps:

1. Formation of a decision matrix that contains all the alternatives and their performance on each criterion.
2. Assignment of weights to the criteria reflecting their relative importance.
3. Application of a preference function to each pair of alternatives to establish their pairwise comparison.
4. Calculation of outranking flows (positive "leaving flow" and negative "entering flow").
5. Generation of a complete or partial ranking of alternatives based on the net outranking flow (difference between positive and negative flows).

One of the primary benefits of PROMETHEE II over other MCDA methodologies is its transparency and ease of interpretation. The method uses straightforward mathematical calculations, and the decision-maker's preferences are clearly reflected in the process through weights and preference functions. This visibility of decision parameters contributes to the method's acceptability among decision-makers.

PROMETHEE II MCDA methodology has been successfully used in a wide array of fields, including environmental management, healthcare, finance, and logistics. In the context of watershed prioritization, it provides a systematic for evaluating and ranking watersheds based on multiple environmental and socio-economic criteria.

4.2.2 Decision Matrix

4.2.2.1 Criteria

The MCDA methodology in the tool uses several criteria to meet the goals of improving water quality, increasing resilience to climate change impacts, preserving and restoring critical and sensitive habitats, and implementing equity and social justice.

Watershed Planning staff identified four prioritization goals that align with the goals of the City's Watershed Plan. Goal 1 addresses water quality outcomes, focusing on pollutant concentrations and stormwater management infrastructure improvement. Goal 2 aims to increase resilience to climate change impacts by targeting areas most vulnerable to these impacts. Goal 3 centers around preserving and restoring critical and sensitive habitats. Goal 4 seeks to implement equity and social justice, with a focus on areas identified as having overlapping equity needs by other Tacoma programs. Table 4-1summarizes the subgoals, criteria, and sources of data for each goal.

Table 4-1 Watershed Planning Goals and associated Subgoals and Criteria

Goal 1: Improve Water Quality Outcomes (Clean Water Goal)		
Sub-goal	**Criteria**	**Data Source**
1.1 Prioritize areas based on pollutant concentrations	Total Nitrogen Concentration	TNC Stormwater Heatmap
	TSS Concentration	TNC Stormwater Heatmap
	Annual Runoff	TNC Stormwater Heatmap
	Imperviousness	TNC Stormwater Heatmap
1.2 Improve infrastructure in areas with inadequate stormwater management	Percent of Area Treated	Calculated in tool
	Age of Development	TNC Stormwater Heatmap

Goal 2: Increase Resilience to Climate Change Impacts (Resilient Community Goal)		
Sub-goal	**Criteria**	**Source**
2.1 Target areas most vulnerable to and at risk for climate change impacts	Urban Heat Island	City of Tacoma
	Capacity Issues Layer	City of Tacoma

Goal 3: Preserve and Restore Critical and Sensitive Habitat (Healthy Ecosystems)		
Sub-goal	**Criteria**	**Source**
3.1 Preserve and improve Natural Spaces	ES Open Space/Natural Resource Areas	City of Tacoma
	Biodiversity Corridors	City of Tacoma

Goal 4: Implement Equity and Social Justice (Healthy Neighborhoods; Equity)		
Sub-goal	**Criteria**	**Source**
4.1 Prioritize areas of overlapping equity needs as identified by other Tacoma programs	Equity Index Score	City of Tacoma
	Livability Index	City of Tacoma
4.2 Improve access to safe, high-quality roadway infrastructure (green infrastructure recommendation)	Pavement Condition Index	City of Tacoma

4.2.2.2 Direction of Criteria

The direction of the criteria—whether they are minimized or maximized—depends on the nature of the criterion itself.

For Goal 1, pollutant concentrations such as Total Nitrogen Concentration and TSS Concentration are to be minimized to improve water quality. Conversely, the Annual Runoff and the Percent of Area Treated are criteria aimed to be maximized for better stormwater management.

Under Goal 2, the Urban Heat Island effect is a criterion to be minimized to enhance climate resilience, whereas the capacity to handle climate change impacts is to be maximized.

For Goal 3, the preservation and improvement of Natural Spaces, Salmon Streams, and Biodiversity Corridors are all maximized to ensure healthy ecosystems.

Finally, in Goal 4, the Equity Index Score and Livability Index are maximized to enhance social justice and improve the quality of life in neighborhoods. In contrast, pavement condition, indicative of needed infrastructure work, is minimized to reflect improved roadway conditions. Sidewalk density is maximized to reflect better access to safe, high-quality roadway infrastructure.

4.2.2.3 Preference Function

PROMETHEE II can use several preference functions (Brans and Vincke, 1985) representing different thresholds for criteria indifferences and preferences. The decision support module uses the "Usual" preference function representing the simplest case for user preferences, whereby any difference in criteria results in a strict preference. In other words if a criterion value for one watershed exceeds another, the preference value is 1 (indicating a clear preference). If not, the preference value is 0 (indicating no preference).

4.2.2.4 Calculation of Outranking flows

Watersheds are compared to each other on a pairwise basis. A given watershed is compared to every other watershed with respect to each criterion. For each comparison, a binary (i.e. 0 or 1) value is assigned and multiplied by the weight of the criterion. This represents the positive outranking flow. This process is then repeated by comparing every other watershed back to the initial watershed. For each of these comparisons, a binary value of 0 or -1 is assigned representing whether or not another watershed is preferred to the selected watershed. This is the negative outranking flow. Positive and negative outranking flows are illustrated in Figure 4-1.

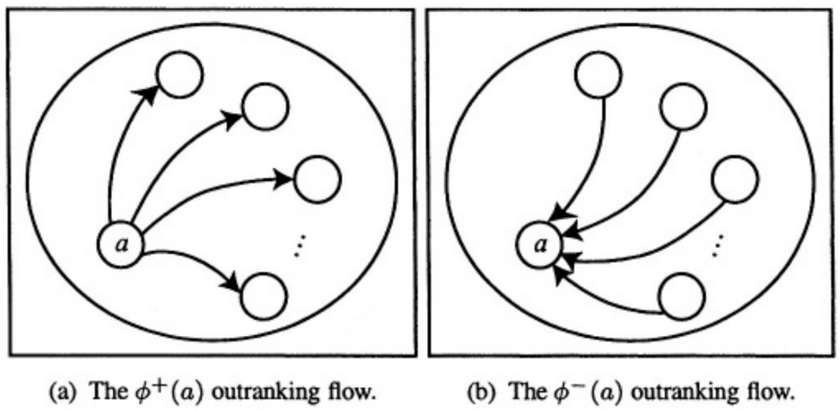

Figure 4-1 Illustration of positive and negative outranking flows (Brans and De Smet, 2016)

The positive and negative outranking flows are then summed independently for each watershed, resulting in a partial ranking of watersheds. The positive and negative outranking flows are then summed together to arrive at the final full ranking of watersheds.

4.3 Example

For example, assume a comparison of three watersheds: Watershed A, Watershed B, and Watershed C. For simplicity, assume three criteria: Total Nitrogen Concentration, Urban Heat Island, and Equity Index Score. Assume the weights of these criteria are 3, 4, and 5 respectively (as input by the user).

The preference values for Watershed A over Watershed B, calculated using the usual preference function, are as follows:

Total Nitrogen Concentration: 1 (A is better than B)

Urban Heat Island: 0 (A is equivalent to B)

Equity Index Score: 1 (A is better than B)

The positive outranking flow for Watershed A over Watershed B is:

$$(1 * 3) + (0 * 4) + (1 * 5) = 8$$

The positive outranking flow for Watershed B over Watershed A is:

(0 * 3) + (0 * 4) + (0 * 5) = 0

This would then be repeated for the watershed pairs of (A,C), (B,C), (C,A) and (C,B).

The negative outranking flow for Watershed A over Watershed B is:

(0 * 3) + (0 * 4) + (0 * 5) = 0

The negative outranking flow for Watershed B over Watershed A is:

(-1 * 3) + (0 * 4) + (-1 * 5) = -8

This would then be repeated for the watershed pairs of (A,C), (B,C), (C,A) and (C,B).

The positive and negative outranking flows are then summed, representing the net outranking flow for each watershed. Finally, watersheds are ranked based on their net outranking flows. The watershed with the highest net outranking flow is considered the best option according to the chosen criteria and weights.

CHAPTER 5. REFERENCES

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APPENDIX A

HSPF IMPLND and PERLND Factors

Table A-1 HSPF PERLND Factors

HRU	Soil	Land Cover		Slope	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC	INFEXP	INFILD	BASETP	AGWETP	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP	IWAT	RETSC
000	A/B	Forest		Flat	5	2	400	0.05	0.3	0.996	2	2	0	0	0.2	0.5	0.35	0	0.7	0.7	NA	NA
001	A/B	Forest		Mod	5	2	400	0.1	0.3	0.996	2	2	0	0	0.2	0.5	0.35	0	0.7	0.7	NA	NA
002	A/B	Forest		Steep	5	2	400	0.15	0.3	0.996	2	2	0	0	0.2	0.5	0.35	0	0.7	0.7	NA	NA
010	A/B	Pasture		Flat	5	1.5	400	0.05	0.3	0.996	2	2	0	0	0.15	0.5	0.3	0	0.7	0.4	NA	NA
011	A/B	Pasture		Mod	5	1.5	400	0.1	0.3	0.996	2	2	0	0	0.15	0.5	0.3	0	0.7	0.4	NA	NA
012	A/B	Pasture		Steep	5	1.5	400	0.15	0.3	0.996	2	2	0	0	0.15	0.5	0.3	0	0.7	0.4	NA	NA
020	A/B	Lawn		Flat	5	0.8	400	0.05	0.3	0.996	2	2	0	0	0.1	0.5	0.25	0	0.7	0.25	NA	NA
021	A/B	Lawn		Mod	5	0.8	400	0.1	0.3	0.996	2	2	0	0	0.1	0.5	0.25	0	0.7	0.25	NA	NA
022	A/B	Lawn		Steep	5	0.8	400	0.15	0.3	0.996	2	2	0	0	0.1	0.5	0.25	0	0.7	0.25	NA	NA
100	C	Forest		Flat	4.5	0.08	400	0.05	0.5	0.996	2	2	0	0	0.2	0.5	0.35	6	0.5	0.7	NA	NA
101	C	Forest		Mod	4.5	0.08	400	0.1	0.5	0.996	2	2	0	0	0.2	0.5	0.35	6	0.5	0.7	NA	NA
102	C	Forest		Steep	4.5	0.08	400	0.15	0.5	0.996	2	2	0	0	0.2	0.3	0.35	6	0.3	0.7	NA	NA
110	C	Pasture		Flat	4.5	0.06	400	0.05	0.5	0.996	2	2	0	0	0.15	0.4	0.3	6	0.5	0.4	NA	NA
111	C	Pasture		Mod	4.5	0.06	400	0.1	0.5	0.996	2	2	0	0	0.15	0.4	0.3	6	0.5	0.4	NA	NA
112	C	Pasture		Steep	4.5	0.06	400	0.15	0.5	0.996	2	2	0	0	0.15	0.25	0.3	6	0.3	0.4	NA	NA
120	C	Lawn		Flat	4.5	0.03	400	0.05	0.5	0.996	2	2	0	0	0.1	0.25	0.25	6	0.5	0.25	NA	NA
121	C	Lawn		Mod	4.5	0.03	400	0.1	0.5	0.996	2	2	0	0	0.1	0.25	0.25	6	0.5	0.25	NA	NA
122	C	Lawn		Steep	4.5	0.03	400	0.15	0.5	0.996	2	2	0	0	0.1	0.15	0.25	6	0.3	0.25	NA	NA
200	SAT	Forest		Flat	4	2	100	0.001	0.5	0.996	10	2	0	0.7	0.2	3	0.5	1	0.7	0.8	NA	NA
201	SAT	Forest		Mod	4	2	100	0.01	0.5	0.996	10	2	0	0.7	0.2	3	0.5	1	0.7	0.8	NA	NA
202	SAT	Forest		Steep	4	2	100	0.1	0.5	0.996	10	2	0	0.7	0.2	3	0.5	1	0.7	0.8	NA	NA
210	SAT	Pasture		Flat	4	1.8	100	0.001	0.5	0.996	10	2	0	0.5	0.15	3	0.5	1	0.7	0.6	NA	NA
211	SAT	Pasture		Mod	4	1.8	100	0.01	0.5	0.996	10	2	0	0.5	0.15	3	0.5	1	0.7	0.6	NA	NA
212	SAT	Pasture		Steep	4	1.8	100	0.1	0.5	0.996	10	2	0	0.5	0.15	3	0.5	1	0.7	0.6	NA	NA
220	SAT	Lawn		Flat	4	1	100	0.001	0.5	0.996	10	2	0	0.35	0.1	3	0.5	1	0.7	0.4	NA	NA
221	SAT	Lawn		Mod	4	1	100	0.01	0.5	0.996	10	2	0	0.35	0.1	3	0.5	1	0.7	0.4	NA	NA
222	SAT	Lawn		Steep	4	1	100	0.1	0.5	0.996	10	2	0	0.35	0.1	3	0.5	1	0.7	0.4	NA	NA

Table A-2 HSPF IMPLND Factors

HRU	Land Cover	Slope	LSUR	SLSUR	NSUR	RETSC
250	Impervious	Flat	400	0.01	0.1	0.1
251	Impervious	Moderate	400	0.05	0.1	0.08
252	Impervious	Steep	400	0.1	0.1	0.05

APPENDIX B

Table B-1. Tacoma GIS to Tacoma Watersheds Insights BMP Type Mapping

Tacoma GIS Facility Type	FACILITYDETAIL	INFILTRATED	FLOWCONTROLTYPE	WATERQUALITYTYPE	Modeled Facility Type
Bioretention		Full	Stream	Enhanced	Bioretention with Full Infiltration
Bioretention		Full		Basic	Bioretention with Full Infiltration
Bioretention		Full		Enhanced	Bioretention with Full Infiltration
Bioretention		Partial		Basic	Bioretention with Partial Infiltration
Bioretention		Partial			Bioretention with Partial Infiltration
Bioretention			Stream	Enhanced	Bioretention with No Infiltration
Bioretention				Enhanced	Bioretention with No Infiltration
Bioretention				Basic	Bioretention with No Infiltration
Holding Basin			IP		No Treatment
Holding Basin			Stream		No Treatment
Media Filter	Bayfilter				Cartridge Media Filter
Media Filter	Bayfilter			Basic	Cartridge Media Filter
Media Filter	FloGard Perk Filter			Basic	Cartridge Media Filter
Media Filter	MFS			Basic	Media Filter High Rate
Media Filter	Null				Media Filter High Rate
Media Filter	Stormfilter			Basic	Cartridge Media Filter
Media Filter	Stormfilter				Cartridge Media Filter
Oil Water Separator	API			Oil	Oil-Water Separator
Oil Water Separator	CP			Oil	Oil-Water Separator
Oil Water Separator	Null			Oil	Oil-Water Separator
Oil Water Separator	Null				Oil-Water Separator
Oil Water Separator	Spill Control				Oil-Water Separator
Pervious Pavement	Asphalt	Full			Pervious Pavement with Full Infiltration
Pervious Pavement	Asphalt	Full		Basic	Pervious Pavement with Full Infiltration
Pervious Pavement	Block/Brick	Full		Basic	Pervious Pavement with Full Infiltration
Pervious Pavement	Block/Brick	Full	Stream		Pervious Pavement with Full Infiltration
Pervious Pavement	Concrete	Full			Pervious Pavement with Full Infiltration
Pervious Pavement	Concrete	Full	Stream		Pervious Pavement with Full Infiltration
Pervious Pavement	Concrete	Full		Basic	Pervious Pavement with Full Infiltration
Pervious Pavement	Asphalt	Partial			Pervious Pavement with Partial Infiltration
Pervious Pavement	Block/Brick	Partial			Pervious Pavement with Partial Infiltration
Pervious Pavement	Concrete	Partial			Pervious Pavement with Partial Infiltration
Pervious Pavement	Asphalt				Pervious Pavement with Partial Infiltration
Pervious Pavement	Block/Brick				Pervious Pavement with Partial Infiltration
Pervious Pavement	Concrete				Pervious Pavement with Partial Infiltration
Pond	Combined			Basic	Detention Pond
Pond	Combined		Wetland	Basic	Detention Pond
Pond	Detention				Detention Pond
Pond	Detention		IP		Detention Pond
Pond	Detention	Full	Stream		Infiltration Pond
Pond	Infiltration	Full			Infiltration Pond
Pond	Combined		IP	Basic	Detention Pond
Pond	Combined Wetland		IP	Basic	Wetland Pond
Pond	Detention		Wetland		Detention Pond
Pond	Infiltration				Infiltration Pond
Pond	Stormwater Treatment Wetland		Stream	Enhanced	Wetland Pond
Pond	Wet			Basic	Wet Pond
Pond	Wet			Pretreatment	Wet Pond

Tacoma GIS Facility Type	FACILITYDETAIL	INFILTRATED	FLOWCONTROLTYPE	WATERQUALITYTYPE	Modeled Facility Type
Pond				Basic	Wet Pond
Pond					Wet Pond
Pond	Combined Wetland	Partial	Stream	Enhanced	Wetland Pond
Pump Station					No Treatment
Sand Filter				Basic	Sand Filter
Swale	Compost-Amended Vegetated Filter Strips	Full			Vegetated Swale
Swale	Biofiltration	Partial			Vegetated Swale
Swale	Null	Partial			Vegetated Swale
Swale	Null	Partial	Stream	Enhanced	Vegetated Swale
Swale	Biofiltration			Basic	Vegetated Swale
Swale	Media Filter Strips			Basic	Vegetated Swale
Swale	Vegetated Filter Strips			Basic	Vegetated Swale
Swale				Basic	Vegetated Swale
Swale					Vegetated Swale
Swirl Separator	Aqua Swirl			Pretreatment	Hydrodynamic Separator
Swirl Separator	CDS			Pretreatment	Hydrodynamic Separator
Swirl Separator	Null			Pretreatment	Hydrodynamic Separator
Swirl Separator	Stormceptor			Pretreatment	Hydrodynamic Separator
Swirl Separator	Vortechnics			Pretreatment	Hydrodynamic Separator
Tank	Detention				Dry Extended Detention Basin/Tank
Tank	Detention		IP		Flow Duration Control Tank
Tank	Detention		Wetland		Flow Duration Control Tank
To Be Determined					No Treatment
Trench	Bottomless CB	Full			Infiltration Basin/Trench
Trench	Infiltration	Full			Infiltration Basin/Trench
Trench	Infiltration	Full		Basic	Infiltration Basin/Trench
Trench	Infiltration	Full	IP	Basic	Infiltration Basin/Trench
Trench	Null	Full			Infiltration Basin/Trench
Trench	Dispersion				Infiltration Basin/Trench
Trench	Infiltration				Infiltration Basin/Trench
Vault	Combined		IP	Basic	Wet Vault
Vault	Conveyance				Dry Extended Detention Basin/Tank
Vault	Detention		IP		Dry Extended Detention Basin/Tank
Vault	Detention				Dry Extended Detention Basin/Tank
Vault	Null			Basic	Dry Extended Detention Basin/Tank
Vault	Null				Dry Extended Detention Basin/Tank
Vault	Silva Cell			Basic	Bioretention with Full Infiltration
Vault	Wet				Wet Vault
Vault	Wet			Basic	Wet Vault
Vegetated Box	Filterra			Enhanced	Filterra/Vegetated Box High Rate
Vegetated Box	Filterra			Basic	Filterra/Vegetated Box High Rate
Vegetated Box	Filterra				Filterra/Vegetated Box High Rate
Vegetated Box	MWS			Basic	Filterra/Vegetated Box High Rate
Vegetated Box	MWS			Enhanced	Filterra/Vegetated Box High Rate
Vegetated Box	MWS				Filterra/Vegetated Box High Rate
Vegetated Box	Null			Enhanced	Filterra/Vegetated Box
Vegetated Box	Null			Basic	Filterra/Vegetated Box
Vegetated Box	Null				Filterra/Vegetated Box
Vegetated Box				Basic	Filterra/Vegetated Box

APPENDIX C

IBMPDB Influent & Effluent Curves and KTRL Parameters

Table C-1. KTRL BMP Parameters

IBMPDB BMP Code	Parameter	Unit	N	dl	A	B	e1	C	D	E	e2	MAD
BR	Copper, Total	µg/L	372	0.05					2.735	0.389	1.284	1.597
DB	Copper, Total	µg/L	254	0.05					1.182	0.826	1.018	1.363
BS	Copper, Total	µg/L	262	0.05					1.531	0.730	0.999	1.389
HRBF	Copper, Total	µg/L	48	0.05	1.033	0.364	-0.017					0.750
HRMF	Copper, Total	µg/L	322	0.05					1.354	0.727	1.057	1.338
HDS	Copper, Total	µg/L	208	0.05					1.125	0.904	1.068	1.202
MF	Copper, Total	µg/L	309	0.05					1.386	0.681	1.042	1.509
OGS	Copper, Total	µg/L	90	0.05					0.742	0.877	1.451	1.580
PP	Copper, Total	µg/L	139	0.05					2.262	0.549	1.240	1.496
RP	Copper, Total	µg/L	1186	0.05					1.522	0.566	1.236	1.720
WB	Copper, Total	µg/L	348	0.05					0.989	0.760	1.249	1.568
BR	Nitrogen, Total	mg/L	298	0.0052	0.403	0.531	-0.023					0.394
DB	Nitrogen, Total	mg/L	272	0.0052	0.214	0.728	0.033					0.299
HRBF	Nitrogen, Total	mg/L	37	0.0052	0.076	0.428	0.101					0.167
HRMF	Nitrogen, Total	mg/L	110	0.0052	-0.069	0.608	0.284					0.351
HDS	Nitrogen, Total	mg/L	161	0.0052	-0.098	0.897	0.290					0.402
MF	Nitrogen, Total	mg/L	281	0.0052	0.262	0.605	0.023					0.277
OGS	Nitrogen, Total	mg/L	55	0.0052	0.276	0.803	0.053					0.398
RP	Nitrogen, Total	mg/L	1492	0.0052	0.997		0.125	0.723				0.403
WB	Nitrogen, Total	mg/L	1160	0.0052	1.140		0.034	0.625				0.332
BR	Phosphorus as P, Total	mg/L	546	0.0025	0.394		0.052	0.088				0.139
DB	Phosphorus as P, Total	mg/L	433	0.0025	0.376		0.023	0.127				0.063
BS	Phosphorus as P, Total	mg/L	450	0.0025	0.088	0.717	-0.001					0.074
HRBF	Phosphorus as P, Total	mg/L	100	0.0025	0.010	0.400	0.003					0.015
HRMF	Phosphorus as P, Total	mg/L	393	0.0025	0.008	0.571	0.000					0.027
HDS	Phosphorus as P, Total	mg/L	299	0.0025	-0.018	0.883	0.032					0.049
MF	Phosphorus as P, Total	mg/L	335	0.0025	0.186		0.009	0.052				0.030
OGS	Phosphorus as P, Total	mg/L	100	0.0025	-0.036	0.876	0.049					0.084
PP	Phosphorus as P, Total	mg/L	288	0.0025	0.068	0.255	-0.006					0.038
RP	Phosphorus as P, Total	mg/L	1576	0.0025	0.057	0.291	-0.001					0.072
WB	Phosphorus as P, Total	mg/L	1084	0.0025	0.297		0.017	0.097				0.049
BR	Total suspended solids	mg/L	537	0.02					6.919	0.097	1.710	2.013
DB	Total suspended solids	mg/L	448	0.02					1.763	0.640	1.517	1.599
BS	Total suspended solids	mg/L	449	0.02					3.127	0.542	1.474	1.722

IBMPDB BMP Code	Parameter	Unit	N	dl	A	B	e1	C	D	E	e2	MAD
HRBF	Total suspended solids	mg/L	104	0.02	-0.354		0.308	1.212				1.356
HRMF	Total suspended solids	mg/L	436	0.02					2.254	0.518	1.272	1.752
HDS	Total suspended solids	mg/L	450	0.02					1.505	0.787	1.242	1.516
MF	Total suspended solids	mg/L	365	0.02					0.598	0.668	1.934	2.381
OGS	Total suspended solids	mg/L	177	0.02					1.054	0.848	1.240	1.466
PP	Total suspended solids	mg/L	302	0.02					3.431	0.433	1.427	1.801
RP	Total suspended solids	mg/L	1658	0.02					2.496	0.424	2.348	2.306
WB	Total suspended solids	mg/L	880	0.02					1.015	0.764	1.469	2.015
BR	Zinc, Total	µg/L	361	0.05					5.489	0.232	1.361	1.743
DB	Zinc, Total	µg/L	284	0.05					1.849	0.727	1.221	1.602
BS	Zinc, Total	µg/L	309	0.05					4.006	0.533	1.240	1.399
HRBF	Zinc, Total	µg/L	54	0.05					0.376	0.979	1.258	1.449
HRMF	Zinc, Total	µg/L	388	0.05					2.025	0.702	1.204	1.454
HDS	Zinc, Total	µg/L	262	0.05					1.356	0.877	1.098	1.236
MF	Zinc, Total	µg/L	335	0.05					1.421	0.542	1.528	2.211
OGS	Zinc, Total	µg/L	88	0.05					1.856	0.855	0.911	1.547
PP	Zinc, Total	µg/L	159	0.05					1.502	0.497	2.554	2.118
RP	Zinc, Total	µg/L	1386	0.05					3.398	0.463	1.376	1.757
WB	Zinc, Total	µg/L	412	0.05					2.004	0.633	1.369	1.697

Figure C-1. KTRL BMP Curves