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USER'S MANUAL

City of Tacoma Watershed Planning Project

Prepared for

City of Tacoma

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Contents

1 Introduction

This manual describes how to use the Tacoma Watershed Insights web application. This application lets users track stormwater infrastructure, assess performance, and make informed decisions regarding stormwater and water quality in Tacoma.

1.1 Purpose

The purpose of this manual is to provide a guide for users who want to learn how to navigate and use the Tacoma Watershed Insights web application. The manual covers the following topics:

- How to access and log in to the application
- How to view and explore the map and data layers
- How to use the tools and features of the application
- How to export and share data and reports

This manual is focused on the usability of the web application. It does not provide technical details about the methodology behind calculations or modeling assumptions. For information regarding these aspects, please refer to the Technical Methodology Report [1].

The manual assumes that users have a basic familiarity with web browsers and GIS concepts. The manual also provides links to external resources for further information and learning.

1.2 Key Concepts

Before using the Tacoma Watershed Insights web application, it is helpful to understand some key concepts that are used in the tool. These concepts are also referred to throughout this manual.

[1] *Technical Methods and Approach Document - City of Tacoma Watershed Planning Project.* Geosyntec Consultants, June 2023.

1.2.1 Climate Epochs

Stormwater facility results are calculated based on continuous rainfall-runoff simulation using a regional precipitation data set.[2]

Four scenarios or *climate epochs* have been developed as shown in Table 1.1.

Table 1.1: Climate Epochs

Scenario	Begin	End
1980s (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

1.2.2 Facility Types

Water quality and hydrology calculations are specific to each facility type. *Facility Type* refers to stormwater facility names used by the City of Tacoma.

Table 1.2: Facility Types contained in the Tacoma Watershed Insights application

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).

[2] Salathé, E.P., Hamlet, A.F., Mass, C.F., Lee, S-Y., Stumbaugh, M., Steed, R. 2014. Estimates of Twenty-first Century flood risk in the Pacific Northwest based on regional scale climate model simulations. J. Hydrometeorology 15(5): 1881-1899, https://doi.org/10.1175/JHM-D-13-0137.1

Facility Type	Description
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.

1.2.3 Simple vs. Detailed Facilities

In the context of the Tacoma Watershed Insights application, facilities can be modeled as one of two types: Simple and Detailed.

The Tacoma Watershed Insights application models stormwater infrastructure as either Simple or Detailed facilities based on the availability of data and the complexity of the facility’s design and operation.

1.2.3.1 Simple Facilities

By default, facilities are initially modeled as Simple Facilities unless detailed information has been entered. The Simple Facility model is used when detailed data about a facility is not available, such as the specific design parameters of the facility or the infiltration area. Simple facilities are assumed to treat or retain 91% of runoff from the effective drainage area.

1.2.3.2 Detailed Facilities

If more detailed data about a facility are available, the application can model the facility as a Detailed Facility. When the Simple Facility switch is turned off, parameters specific to the facility type become editable. Detailed Facilities provide a more accurate and comprehensive model of a facility's performance.

1.2.4 Pollutants

The Tacoma Watershed Insights application models 8 different stormwater pollutants. These are shown below.

Table 1.3: Stormwater Pollutants

Parameter	Group	EIM Parameter CAS
Bis(2-ethylhexyl) phthalate	Phthalate	117-81-7
Copper	Metal	7440-50-8
Phenanthrene	LPAH	85-01-8
Pyrene	HPAH	129-00-0
Total Nitrogen	Nutrient	None
Total Phosphorus	Nutrient	7723-14-0
Total Suspended Solids	Conventional	None
Zinc	Metal	7440-66-6

1.2.5 Subbasins

A Subbasin is a geographical area that drains into a particular receiving water or collection system node. In addition to reporting facility performance, the tool reports metrics on a subbasin level.

The subbasins used in this tool have been developed by the City of Tacoma. They are summarized in Table 1.4. Subbasins are referenced by a unique subbasin code using the subbasin code prefix shown in Table 1.4. For example, the first subbasin that is part of the Flett Creek Basin would be `FL_01`.

Table 1.4: City of Tacoma Subbasins

Basin	Number of Subbasins	Subbasin Code prefix
Flett Creek	10	`FL_`
Foss Waterway	15	`FS_`
Joes Creek	3	`JC_`
Leach Creek	6	`LC_`
Lower Puyallup	6	`LP_`
North Tacoma	11	`NT_`
Northeast Tacoma	6	`NE_`
Tideflats	6	`TF_`
Western Slopes	4	`WS_`

2 System Administration

2.1 Sign Up as a New User

You must register and be approved as a new user before using the site. To sign up, click **Login** in the upper right hand corner of the site. At the login page, click **Register** to be taken to the registration page. After entering the required details, click **Submit** to create your account. An email will be sent to your provided email address for verification.

Before you can access the site, your account must be approved by a User Admin. See the Modifying User Roles section for information on approving new users.

2.2 User Roles

Users can have one of the following roles associated with their account.

Only a User Admin or System Admin may edit user roles.

Table 2.1: Roles and Permissions

Role	Permissions
Public	None
Read-only	Read access to data via site and via token
User/Editor	All of the above, plus • access to scenarios and editing data
User Admin	All of the above, plus • access to user manager • access to application settings
System Admin	All of the above, plus • direct api access

2.3 Managing Users

Only a User Admin or System Admin may edit user roles. To approve new users and to update user roles, follow these steps.

1. Click on your profile avatar in the upper left-hand corner of the screen.
2. Select **Manage Users** from the menu.

You will be taken to the Manage Users page, where you can edit and save user role information.

3 Viewing Results with the Map Explorer

The map explorer module is the main access point for all the spatial resources that can be used to view existing infrastructure and water quality conditions.

3.1 Viewing Layers

By default, the following layers are enabled:

- Stormwater facilities
- Stormwater facility delineations
- Stormwater subbasins

To view other layers select the layer icon on the left-hand menu. A new panel will display with available layers.

Other layers that can be viewed are shown below.

Table 3.1: Map Data Layers

Category	Layer Name
Conveyances	Catchbasin Leads Regional Facility Model: Manholes Surfacewater Inlet Surfacewater Main Surfacewater Trunk
Landcover & Landuse	Land Cover Category Imperviousness Contours Runoff Terrain

Category	Layer Name
Pollutants	Total Copper Concentration Total Nitrogen Concentration Total Suspended Solids Concentration Total Zinc Concentration

3.2 Viewing Facility Overview Information

You can view summary information for a particular BMP by clicking on it from the Map Explorer. The map will zoom to the selected facility and a panel will be displayed showing information on a facility.

3.3 Viewing Facility Details

Click on **View Facility Details** from the Facility Overview Panel to see and edit particular facility attributes. In addition to the overview information displayed on the Map Explorer, you can view water quality parameters, cost analysis parameters, and detailed performance data.

3.4 Exporting Facility Details

To export detailed facility data, click on **Export Results** from the Facility Detail Page. This will export a `.csv` file with all facility attributes and performance results.

3.5 Searching for a Facility

To search for a particular facility, select the search icon on the left-hand toolbar. A panel will appear with search options. You may search by the following categories:

- **altid/node_id** - Refers to the facility id.
- **Facility Type** - Refers to the City designated facility type
- **Facility Type (WQ Modeling)** - Refers to the facility type designation used for water quality modeling

4 Results Viewer

4.1 Using the BMP Facility Results View

The BMP Facility Results View can be used to view a summary of the performance of existing BMP's. To access the viewer, select **WQ Results Viewer** from the dropdown menu at the top menu bar, or from the homepage.

You can view individual BMP results by selecting the **BMP Facility Results View** card or by selecting the icon on the left-hand menu bar. Results are summarized by climate epoch.

4.2 Using the Subbasins Results View

The water quality results viewer can be used to view the conditions of each stormwater subbasin. To access the viewer, select it from the dropdown menu at the top menu bar, or the homepage.

You can view aggregated results by subbasin by selecting the **Subbasin Results View** card or by selecting the icon on the left-hand menu bar. To view a chloropleth map of results, select the parameter to visualize from the menu next to the map.

4.3 Exporting Results

To export results from the Subbasin Results View, click the **Export** button on the table below the map. This will download a CSV file of all results. To export a selection of data, select the rows you want to export on the table, then click **Export**.

5 Editing Facility Data

5.1 Editing Water Quality Parameters

You can edit the parameters used to model facilities in the **Facility Details** view. There are several ways to navigate to this view:

- From the Map Explorer map, click on a facility to open the Facility Overview panel. Then, click on **View Facility Details** to be taken to the detail page.
- From the **Water Quality Results Viewer,** click on a BMP name in the table.

5.2 Updating from Simple to Detailed Facility

By default, most facilities are modeled as simple facilities, meaning only two parameters are used: Captured Percentage, and Retained Percentage. The Simple Facility type should be used when detailed data about a facility are not available (e.g. the facility's infiltration area).

If more detailed data are available, turn off the Simple Facility switch, and parameters specific to the facility type will be editable.

5.3 Editing Facility Type

If a Facility Type needs to be updated, select the Facility Type dropdown menu, and choose the appropriate facility type. Click **Save** to save your edits.

Warning Saving your edits does not recalculate results. To recalculate, click the **Refresh Results** button on the Facility Details Page.

5.4 Editing Life Cost Analysis Parameters

By default, facilities will not have cost parameters unless users provide cost analysis parameters. Facilities without cost data will show the following message under the Lifecycle Cost Analysis Heading:

> *Lifecycle costs are unavailable for this facility. This usually means that the "Cost Analysis Parameters" are incomplete.*

To edit lifecycle cost parameters, select the dropdown menu titled **Cost Analysis Parameters.** There, you can enter the cost analysis parameters directly for a facility. See the Cost Analysis Parameters section for descriptions of parameters.

5.4.1 Cost Estimator Tool

To assist with selection of cost analysis parameters, a cost estimator tool is available; it uses cost curves and methodology developed by King County to provide high-level cost estimates for various facilities. To use this tool, select a BMP to view the BMP facility details page. Next, click on the cost analysis parameters drop down and then click on the **King County Cost Estimator Tool.** This will open a dialog box to select and apply data from King County cost curves.

First, select the appropriate facility type under the **BMP Type** dropdown menu. This will preselect an appropriate BMP Cost Curve used by King County (**KC BMP Variation** in the tool). You can refine or change the selected cost curve under the **KC BMP Variation** menu. Cost curves that match the selected **BMP Type** will be shown in **bold**.

In order to calculate the cost parameters, you must enter a sizing parameter in the next dialog box. Depending on the cost curve selected, the dialog box will display either *area (sqft)* or *each (count).* Here, *area* refers to the footprint area of a facility (e.g. the total area of pervious pavement), or the number of facilities to be installed (e.g. number of UIC wells).

After entering the number denoting the area or number of facilities, the Capital Cost and O&M Costs will be calculated. Click *Apply to BMP Form* to apply the calculated costs to the facility. To calculate the final lifecycle cost, you will need to enter data for the following:

Install Year - The year of installation, denoting what year to apply the capital costs.

Replacement Cost - The cost to replace a facility. This cost is intended to reflect costs related to major replacement of facility components, such as replacement of soil after multiple years of use.

Lifespan Yrs - How long the facility would be operated before replacement would be necessary.

5.4.2 Global Cost Settings

In order to calculate lifecycle costs the same way for every facility, the tool uses four global cost parameters (*discount rate*, *inflation rate*, *planning horizon*, and *cost basis year*). These parameters apply to all facilities analyzed, instead of a particular facility.

To edit these global parameters, select *Settings* under your user profile in the top left portion of the screen. Individual cost parameters can be edited by clicking the edit tool to the left of each parameter name.

6 Using the Prioritization Module

The watershed prioritization module allows users to identify and prioritize areas for actions to meet watershed planning goals related to water quality, habitat, and social equity.

6.1 Selecting Project Type

The *Project Type* dialog denotes what type of project is being considered. The two choices are:

- **Retrofit** - Projects that are intended to improve water quality or hydrology. This choice gives a higher priority to subbasins that have a higher pollutant load, or do not have adequate stormwater infrastructure.
- **Preservation** - Projects that are intended to preserve an area in a subbasin with better water quality or already have adequate stormwater infrastructure.

6.2 Setting Priority Weights

The prioritization tool allows users to weight watershed management goals based on their relative importance. Weights are positive numbers

Weights can be zero or any positive number, and reflect a decision maker or stakeholders preferences. The higher the weight, the more important the criterion. Numerically, this represents a factor of preference. For example if Goal A has a weight of 1 and Goal B has a weight of 2, Goal B will be treated as twice as important as Goal A.

No constraints have been set on the scale of weights, however, it is common practice to set a total number of weighting points (e.g. 10 points) and assign weights so that the sum of weights is equal to this predetermined total.

Priority weights are assigned for each major watershed goal. Goals are comprised of subgoals and numeric metrics as described in Table 6.1:

Table 6.1: Watershed Planning Goals used in the Prioritization Module.

Goals	Sub-goals	Criteria
Goal 1: Improve Water Quality Outcomes (Clean Water Goal)	1.1 Prioritize areas based on pollutant concentrations	Total Nitrogen Concentration, TSS Concentration, Annual Runoff, Imperviousness
	1.2 Improve infrastructure in areas with inadequate stormwater management	Percent of Area Treated, Age of Development
Goal 2: Increase Resilience to Climate Change Impacts (Resilient Community Goal)	2.1 Target areas most vulnerable to and at risk for climate change impacts	Urban Heat Island, Capacity Issues Layer
Goal 3: Preserve and Restore Critical and Sensitive Habitat (Healthy Ecosystems)	3.1 Preserve and Improve Natural Spaces	ES Open Space/Natural Resource Areas, Biodiversity Corridors
Goal 4: Implement Equity and Social Justice (Healthy Neighborhoods; Equity)	4.1 Prioritize areas of overlapping equity needs as identified by other Tacoma programs	Equity Index Score, Livability Index
	4.2 Improve access to safe, high-quality roadway infrastructure (green infrastructure recommendation)	Pavement Condition Index

6.3 Viewing Prioritization Results

After selecting and submitting priority weights, results will be shown on the chloropleth map and in the *Subbasin Prioritization Results* table.

Subbasins with higher priority scores reflect a higher preference for new projects based on user weighting. Clicking on a row will highlight the selected subbasin on the map.

6.4 Downloading Prioritization Results

To understand the breakdown of attributes and weights from the prioritization module, download the results by clicking on the *Export* button. This will download a .CSV file listing subgoals, criteria, weights, direction of criteria (whether a criterion should be minimized or maximized), as well as the criterion-specific results.

7 Using the Scenario Designer

The Scenario Designer is used to create and evaluate potential new facilities or groups of facilities. It can be used to assess the potential performance of a new action, or compare various alternative actions.

7.1 Creating a New Scenario

To create a new scenario, click **Create New Scenario** in the Scenario Designer page. A new window will open with a multi-step form where you can enter information about your scenario. The first step asks for basic information about your scenario. Enter this information, then click **Next.**

7.1.1 Creating a New Delineation.

The next step is to create a new delineation. The new delineation represents the area that drains to a new facility. Enter a name for this new delineation and then click the **edit icon** on the map window.

Use the stormwater upstream trace tool in Tacoma's GIS system (AccessES) to identify the approximate upstream drainage area to the node where you plan to install the new facility. Draw the new delineation on the map. Double-click to complete the delineation. To delete a delineation after it has been completed, click the **delete icon** on the map window.

Once you have finished creating the delineation, click **Next.**

7.1.2 Creating a new facility

The final step is to create a new BMP facility. Under the **Create a BMP** section, add water quality parameters and cost analysis parameters. See the section on Editing Facility Data for instructions.

Use the map to indicate the location for the new facility. Click the **Edit Icon** in the map window and then click on your desired location on the map. Save your location by clicking on the **Accept Edits** icon. Then click **Next** under the **Create a BMP** form.

The new scenario will be summarized on the next screen. If everything looks good, click **Create Scenario** to save your scenario. On the next screen, be sure to click **Calculate Scenario WQ Results** to generate results.

Caution You must click **Calculate Scenario WQ Results** to generate performance results for your scenario.

8 Data Integrations

Facility data, subbasin data, and results can be easily integrated into other tools and applications through the **Data Integration Module.** Navigate to the module by clicking on **Profile** under the user menu in the top left corner of the application. The **Data Integration** panel is displayed below your profile information.

Data integration is performed through a REST API, which uses HTTP methods to read data from the tool.

8.1 Obtaining a read-only token

Each user is assigned a unique read-only token. This token allows the API server to identify and authorize your requests. Your read-only token will be displayed beneath your user profile.

8.2 Token Rotation

It is good practice to change your token at regular intervals, or in the event of your token being compromised. To rotate your token, click the **Rotate Token** button next to your token.

8.3 Making API Calls

All API calls are GET requests and are made in the following format:

> `https://www.tacomawatersheds.com/api/rest/{resource}/ {resource_id}/token/{toke`

In the above URL structure, `{resource}` is the data type you are requesting, `{resource_id}` is the specific ID of the resource (optional and depends on the endpoint), and `{token}` is your unique read-only token.

8.3.1 API Endpoints

This API is organized around several endpoints representing different types of resources: `tmnt_facility`, `tmnt_delineation`, `subbasin`, and `results`. All responses are provided in JSON format unless otherwise specified.

Common Parameters:

- `f`: (optional, default=json, [json, geojson]) Format of response data
- `limit`: (optional, default=1e6) Number of records to return
- `offset`: (optional, default=0) Start from index
- `epoch`: (optional, default=1980s, [all, 1980s, 2030s, 2050s, 2080s]) Climate epoch filter

Get attributes for all treatment facilities:

> `/api/rest/tmnt_facility/token/{token}?f={f}&limit={limit} &offset={offset}`

Get attributes for a specific treatment facility:

> `/api/rest/tmnt_facility/{altid}/token/{token}`

Replace `{altid}` with the specific facility id.

Get attributes for all delineations:

> `/api/rest/tmnt_delineation/token/{token}?f={f}&limit= {limit}&offset={offset}`

Get attributes for a specific delineation:

> `/api/rest/tmnt_delineation/ {altid}/token/{token}?f={f}`

Replace `{altid}` with the specific delineation id.

Get attributes for all subbasins:

> `/api/rest/subbasin/token/{token}?f={f}&limit={limit}& offset={offset}`

Get attributes for a specific subbasin:

> `/api/rest/subbasin/{subbasin_id}/token/{token}`

Replace `{subbasin_id}` with the specific subbasin id.

Get water quality results for a specific subbasin:

> `/api/rest/subbasin/wq/{subbasin_id}/token/{token}?epoch={epoch}`

Replace `{subbasin_id}` with the specific subbasin id.

Get water quality results for all subbasins:

> `/api/rest/subbasin/wq/token/{token}?f={f}&limit={limit}&offset={offset}&epoch={epoch}`

Get results:

> `/api/rest/results/token/{token}?ntype={ntype}&limit= {limit}&offset={offset}epo`

The `ntype` parameter is optional and filters the data by node type (land_surface, tmnt_facility).

8.4 How to connect Excel with Tacoma Watersheds Results

Power Query is a powerful tool within Microsoft Excel that allows you to import data from various external data sources, including RESTful APIs. This tutorial will guide you on how to connect Excel Power Query with the Tacoma Watersheds `results` API.

Before starting, make sure you have your unique read-only token from the Tacoma Watersheds API.

8.4.1 Step 1: Open Power Query

1. Open Excel, and go to the **Data** tab in the Ribbon.
2. Click on **Get Data** in the left corner of the Ribbon.
3. In the dropdown menu, select **From Other Sources**, then **From Web**.

8.4.2 Step 2: Connect to the API

1. A pop-up window will appear prompting you to enter a URL.
2. In this field, enter the following API endpoint URL:

> `https://www.tacomawatersheds.com/api/rest/results/token/{token}?ntype={ntype}limit={limit}& offset={offset}&epoch={epoch}`

Replace `{token}` with your unique read-only token and fill in the `{ntype}`, `{limit}`, `{offset}`, and `{epoch}` as per your requirements. For example, if you want to get all results for `land_surface` node type and for the `1980s` climate epoch, your URL would be:

> `https://www.tacomawatersheds.com/api/rest/results/token/ your_token?ntype=land_`
>
> Click **OK**

8.4.3 Step 3: Parse the Response

1. A new window named **Power Query Editor** will open, and Excel will show you a preview of the data.
2. If the data appears as a single column of records, click on **List** to convert it to a table. Then click on the button with two arrows on the right side of the header of the column to expand the data into a tabular format.
3. If the data is in nested JSON format, you may need to click on the double-arrow button again to fully expand the data.

8.4.4 Step 4: Load the Data

1. Once you are satisfied with the preview of the data, click on **Close & Load** in the **Home** tab.
2. Excel will create a new worksheet and load the data into a table.

9 Source Code and Deployment

9.1 Source Code Information

Source code is available for the public at the project github repository: github.com/Geosyntec/StormPiper.

The source code is licensed under the Mozilla Public License 2.0 (MPL 2.0).

9.1.1 About the MPL 2.0

The MPL 2.0 is a free and open-source software license that allows the software to be freely used, modified, and shared under specific terms. Key highlights of the MPL 2.0 include:

- **Copyleft:** Modified files must be released under the same license, but linking is allowed without affecting the rest of the project.
- **Distribution:** You can distribute the code in both source and compiled form, provided you include the license file.
- **Attribution:** The original copyright notices must be retained in redistributed code.
- **Warranty Disclaimers and Liability Limitations:** The license includes standard provisions to protect contributors from legal claims.

You can view the full text of the MPL 2.0 license and specific details regarding the StormPiper project in the GitHub repository at:

https://github.com/Geosyntec/StormPiper/blob/main/LICENSE

Please refer to the `LICENSE` file within the repository for the complete terms and conditions governing the use of the StormPiper source code.

9.2 Local Development

9.2.1 Pre-requisites

Ensure you have Git, Python, Conda, and Docker installed on your system.

9.2.2 Getting Started

Follow the steps below to get the app up and running on your system:

9.2.2.1 Clone the Repository

First, clone the StormPiper repository:

```
git clone git@github.com:Geosyntec/StormPiper.git
```

9.2.2.2 Build and Activate a Virtual Environment

Next, create a virtual environment using Conda and activate it:

```
conda create -n stormpiper python=3.11
conda activate stormpiper
```

9.2.2.3 Install the Required Dependencies

Navigate to the StormPiper directory and install the necessary dependencies:

```
cd StormPiper
pip install -r stormpiper/requirements.txt
pip install -r stormpiper/requirements_test.txt
```

9.2.3 Running the Development Server

Run the development server with the following command:

```
uvicorn stormpiper.main:app --reload --port 8000
```

You can access the documentation at `localhost:8000/docs`.

9.2.4 Making Changes and Maintenance

9.2.4.1 Running Tests

Run the tests using:

```
pytest
```

To check test coverage:

```
coverage run --branch -m pytest
coverage report -m
```

9.2.4.2 Code Formatting and Type Checks

Use the provided script to check code formatting and type declarations:

```
bash scripts/lint.sh
```

9.2.5 Docker Deployment

9.2.5.1 Building the Container

Use the following command to build the container. It runs `make clean`, `make stack`, and then `make build`:

```
make develop
```

9.2.5.2 Running the Container

Start the container with:

```
make up
```

You can access the development server at `localhost:8080`.

To silence the logs, run the container in `daemon` mode:

```
make up-d
```

9.2.5.3 Stopping the Container

Stop the container by using:

```
make down
```

9.3 Deployment

Deploying the applicaiton on your own server requires knowledge of Kubernetes. Kubernetes is an open-source container orchestration platform that automates the deployment, scaling, and management of containerized applications. It provides mechanisms for deploying and managing applications across multiple servers, ensuring high availability and scalability.

See the Kubernetes documentation on Google Cloud Plaform for more information.

9.4 Deployment configuration

See the deployment scripts on the github repo for examples on how this applicaiton was deployed: https://github.com/Geosyntec/StormPiper/tree/main/.github/workflows

10 Parameter Definitions

10.1 Facility Parameters

Table 10.1: Facility Input Data

Parameter	Description
area_sqft	The footprint area of the facility in square feet.
captured_pct	The average annual percent of stormwater captured by the facility.
depth_ft	The depth of ponding for the facility in feet.
hsg	Hydrologic Soil Group classification for native infiltration. Valid Options: A B C D
inf_rate_inhr	The infiltration rate at the facility location in inches per hour.
media_filtration_rate_inhr	The media filtration rate at the facility in inches per hour.
retained_pct	The percent of stormwater retained or infiltrated by the facility.
retention_volume_cuft	The design retention volume of the facility in cubic feet.
treatment_rate_cfs	The treatment rate of the facility in cubic feet per second.

Table 10.2: Facility Water Quality Result Parameters

Parameter	Description
DEHP_conc_mg/l_effluent	Mean annual concentration of Bis(2-ethylhexyl) phthalate (DEHP) discharged from a facility (mg/l)
DEHP_conc_mg/l_influent	Mean annual concentration of Bis(2-ethylhexyl) phthalate (DEHP) flowing to a facility (mg/l)
DEHP_load_lbs_inflow	Mean annual load of Bis(2-ethylhexyl) phthalate (DEHP) entering a facility (lbs)
DEHP_load_lbs_removed	Mean annual load of Bis(2-ethylhexyl) phthalate (DEHP) removed by a facility (lbs)
DEHP_load_lbs_total_discharged	Mean annual load of Bis(2-ethylhexyl) phthalate (DEHP) exiting a facility (lbs)
PHE_conc_mg/l_effluent	Mean annual concentration of Phenanthrene discharged from a facility (mg/l)
PHE_conc_mg/l_influent	Mean annual concentration of Phenanthrene flowing to a facility (mg/l)
PHE_load_lbs_inflow	Mean annual load of Phenanthrene entering a facility (lbs)
PHE_load_lbs_removed	Mean annual load of Phenanthrene removed by a facility (lbs)
PHE_load_lbs_total_discharged	Mean annual load of Phenanthrene exiting a facility (lbs)
PYR_conc_mg/l_effluent	Mean annual concentration of Pyrene discharged from a facility (mg/l)
PYR_conc_mg/l_influent	Mean annual concentration of Pyrene flowing to a facility (mg/l)

Parameter	Description
PYR_load_lbs_inflow	Mean annual load of Pyrene entering a facility (lbs)
PYR_load_lbs_removed	Mean annual load of Pyrene removed by a facility (lbs)
PYR_load_lbs_total_discharged	Mean annual load of Pyrene exiting a facility (lbs)
TCu_conc_ug/l_effluent	Mean annual concentration of Total Copper discharged from a facility (ug/l)
TCu_conc_ug/l_influent	Mean annual concentration of Total Copper flowing to a facility (ug/l)
TCu_load_lbs_inflow	Mean annual load of Total Copper entering a facility (lbs)
TCu_load_lbs_removed	Mean annual load of Total Copper removed by a facility (lbs)
TCu_load_lbs_total_discharged	Mean annual load of Total Copper exiting a facility (lbs)
TN_conc_mg/l_effluent	Mean annual concentration of Total Nitrogen discharged from a facility (mg/l)
TN_conc_mg/l_influent	Mean annual concentration of Total Nitrogen flowing to a facility (mg/l)
TN_load_lbs_inflow	Mean annual load of Total Nitrogen entering a facility (lbs)
TN_load_lbs_removed	Mean annual load of Total Nitrogen removed by a facility (lbs)
TN_load_lbs_total_discharged	Mean annual load of Total Nitrogen exiting a facility (lbs)
TP_conc_mg/l_effluent	Mean annual concentration of Total Phosphorus discharged from a facility (mg/l)
TP_conc_mg/l_influent	Mean annual concentration of Total Phosphorus flowing to a facility (mg/l)
TP_load_lbs_inflow	Mean annual load of Total Phosphorus entering a facility (lbs)

Parameter	Description
TP_load_lbs_removed	Mean annual load of Total Phosphorus removed by a facility (lbs)
TP_load_lbs_total_discharged	Mean annual load of Total Phosphorus exiting a facility (lbs)
TSS_conc_mg/l_effluent	Mean annual concentration of Total Suspended Solids discharged from a facility (mg/l)
TSS_conc_mg/l_influent	Mean annual concentration of Total Suspended Solids flowing to a facility (mg/l)
TSS_load_lbs_inflow	Mean annual load of Total Suspended Solids entering a facility (lbs)
TSS_load_lbs_removed	Mean annual load of Total Suspended Solids removed by a facility (lbs)
TSS_load_lbs_total_discharged	Mean annual load of Total Suspended Solids exiting a facility (lbs)
TZn_conc_ug/l_effluent	Mean annual concentration of Total Zinc discharged from a facility (ug/l)
TZn_conc_ug/l_influent	Mean annual concentration of Total Zinc flowing to a facility (ug/l)
TZn_load_lbs_inflow	Mean annual load of Total Zinc entering a facility (lbs)
TZn_load_lbs_removed	Mean annual load of Total Zinc removed by a facility (lbs)
TZn_load_lbs_total_discharged	Mean annual load of Total Zinc exiting a facility (lbs)

Table 10.3: Facility Hydrology Result Parameters

Parameter	Description
bypassed_pct	Percent of mean annual runoff bypassed by a facility

Parameter	Description
design_intensity_inhr	Design storm intensity for a flow-based facility (in/hour)
design_volume_cuft_cumul	design volume for a volume-based facility (cubic feet)
ro_coeff	Design runoff coefficient for a facility
runoff_volume_cuft_bypassed	Mean annual runoff volume bypassed by a facility (cubic feet)
runoff_volume_cuft_captured	Mean annual runoff volume captured by a facility (cubic feet)
runoff_volume_cuft_inflow	Mean annual runoff volume entering a facility (cubic feet)
runoff_volume_cuft_retained	Mean annual runoff volume retained by a facility (cubic feet)
runoff_volume_cuft_total_discharged	Mean annual runoff volume exiting a facility (cubic feet)
runoff_volume_cuft_treated	Mean annual runoff volume treated by a facility (cubic feet)

10.2 Cost Data Parameters

Table 10.4: Global Cost Parameters

Parameter	Description
cost_basis_year	The base year for the cost calculation.
discount_rate	The rate used for discounting future cash flows.
inflation_rate	The rate of inflation considered in the cost calculation.
planning_horizon_yrs	The planning horizon in years for cost calculation.

Table 10.5: Facility Cost Parameters

Parameter	Description
capital_cost	The total capital cost for the facility.
capital_cost_basis_year	The base year for the calculation of the capital cost of the facility.
install_year	The year when a facility was or will be installed.
lifespan_yrs	The expected lifespan of a facility in years.
om_cost_basis_year	The base year for the calculation of the operation and maintenance cost of the facility.
om_cost_per_yr	The operation and maintenance cost of a facility per year.
present_value_capital_cost	The present value of the capital cost of the facility.
present_value_chart_table	The present value chart table related to the facility.
present_value_cost_table	The present value cost table related to the facility.
present_value_om_cost	The present value of the operation and maintenance cost of the facility.
present_value_total_cost	The total present value cost of the facility.
replacement_cost	The cost to replace or perform major upgrade to the facility.

10.3 Subbasin Parameters

Table 10.6: Landcover parameters

Parameter	Description
lc_pasture_pct	Landcover Pasture (pct)

Parameter	Description
lc_grass_pct	Landcover Grass (pct)
lc_water_pct	Landcover Water (pct)
lc_imp_roof_pct	Landcover Impervious-roof (pct)
lc_imp_nonroof_pct	Landcover Impervious-nonRoof (pct)
lc_imp_total_pct	Landcover Impervious-total (pct)

Table 10.7: Land Use parameters

Parameter	Description
lu_resair_pct	Landuse Airport Compatibility Residential (pct)
lu_commcmu_pct	Landuse Crossroads Mixed-Use Center (pct)
lu_rgcd_pct	Landuse Downtown Regional Growth Center (pct)
lu_com_pct	Landuse General Commercial (pct)
lu_indh_pct	Landuse Heavy Industrial (pct)
lu_indl_pct	Landuse Light Industrial (pct)
lu_resl_pct	Landuse Low-Scale Residential (pct)
lu_ins_pct	Landuse Major Institutional Campus (pct)
lu_resm_pct	Landuse Mid-Scale Residential (pct)
lu_resmfhd_pct	Landuse Multi-Family (High Density) (pct)
lu_comn_pct	Landuse Neighborhood Commercial (pct)
lu_comnmu_pct	Landuse Neighborhood Mixed-Use Center (pct)
lu_os_pct	Landuse Parks and Open Space (pct)
lu_shore_pct	Landuse Shoreline (pct)
lu_rgctm_pct	Landuse Tacoma Mall Regional Growth Center (pct)

Table 10.8: Subbasin Parameters

Parameter	Description
area_acres	The total subbasin area in acres.
basicwq_area_acres	The area in acres allocated for basic water quality.
basicwq_area_pct	The percentage of total area allocated for basic water quality.
eff_area_acres	The effective impervious area within a subbasin in acres.
eff_area_pct	The percentage of total area that is effective impervious area.
enhwq_area_acres	The area in acres treated by enhanced water quality facilities.
enhwq_area_pct	The percentage of total subbasin area treated by enhanced water quality facilities.
fc_area_acres	The area in a subbasin in acres treated by flow control facilities.
fc_area_pct	The percentage of total subbasin area treated by flow control facilities.
runoff_depth_inches	Depth of runoff in inches.
runoff_volume_cuft	Volume of runoff in cubic feet.
runoff_volume_cuft_generated	Volume of runoff generated in cubic feet.
runoff_volume_cuft_reduced	Volume of runoff reduced in cubic feet.
runoff_volume_pct_reduced	The percentage of runoff volume reduced.
tmnt_facility_count	Total number of treatment facilities within a subbasin
treated_area_acres	The area in acres that has been treated by stormwater facilities
treated_area_pct	The percentage of total area that has been treated by stormwater facilities

11 Appendix A - Technical Methodology

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)*

$Q_{91,n}$ = 91st 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..

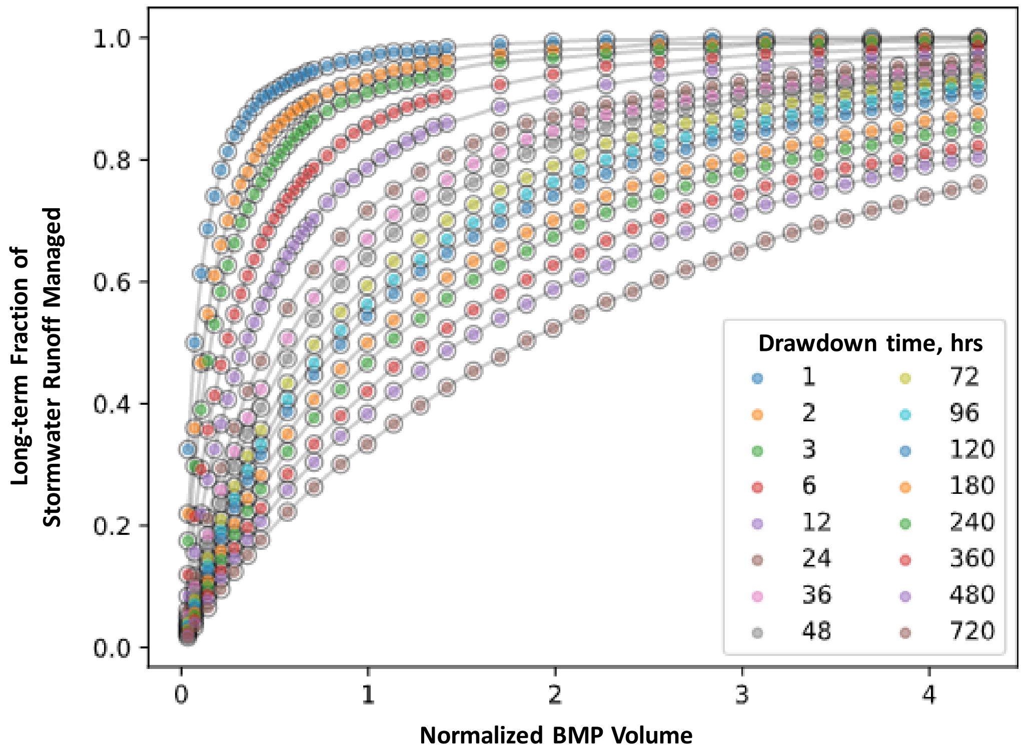


Figure 2-1. Example of a capture efficiency nomograph for a volume-based BMP with a constant drawdown time.

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:

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

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.

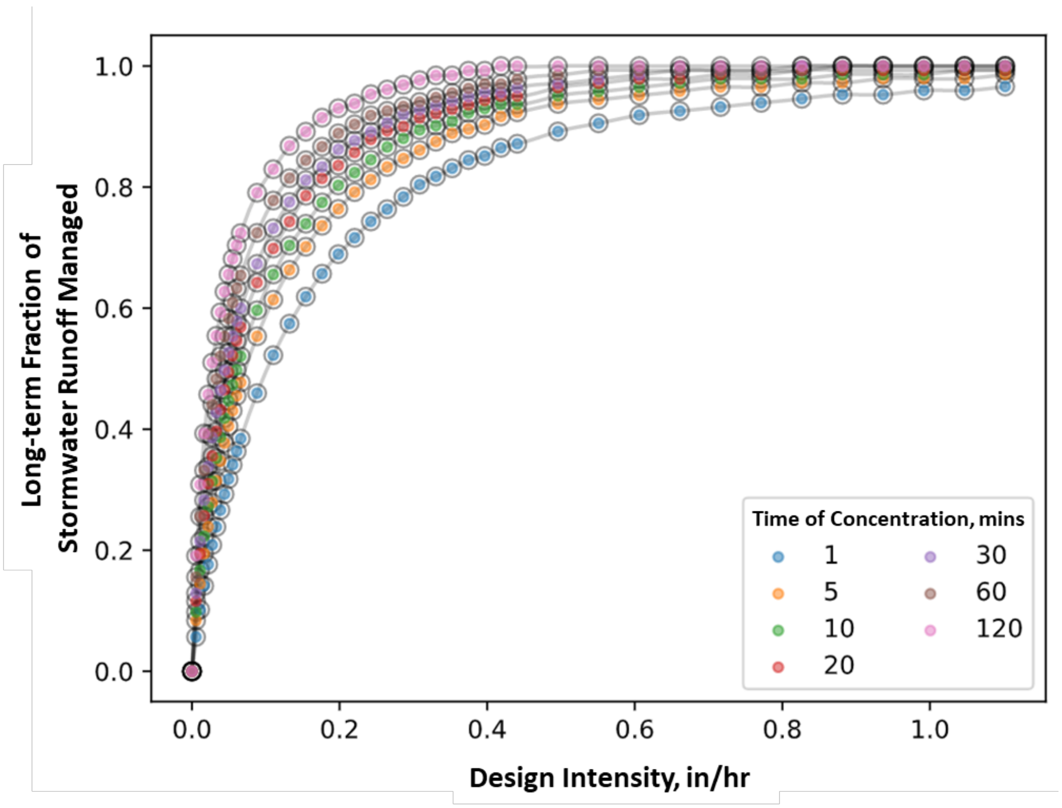


Figure 2-2. Capture efficiency nomograph for a flow-based BMP.

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

Modeled BMP Name	Pseudocode Mapping to Tacoma Asset Management Type	No. of Compartments	Volume-based Compartments	Flow-based Compartments
Bioretention with raised underdrain	FACILITYTYPE == "Bioretention" AND INFILTRATED ≠ "FULL"	2	Infiltration & Treatment	--
Dry Extended Detention Basin/Tank	FACILITYTYPE == "Tank" AND FLOWCONTROL ≠ true	2	Infiltration & Treatment/Detention	--
Flow Duration Control Tank	FACILITYTYPE == "Tank" AND FLOWCONTROL == true	2	Infiltration & Treatment/Detention	--
Bioretention with no Underdrain	FACILITYTYPE == "Bioretention" AND INFILTRATED == "FULL"	1	Infiltration	--
Infiltration Basin/Trench	FACILITYTYPE == "Trench"	1	Infiltration	--
Permeable Pavement	FACILITYTYPE == "Pervious Pavement"	1	Infiltration	--
Sand Filter	FACILITYTYPE == "Sand Filter"	1	Treatment	--
Filterra /Vegetated box	FACILITYTYPE == "Vegetated Box"	1	--	Treatment

Media Filter	FACILITYTYPE == "Media Filter"	1	--	Treatment
Oil-water Separator	FACILITYTYPE == "Oil Water Separator"	1	--	Treatment
Hydrodynamic Separator	FACILITYTYPE == "Swirl Separator"	1	--	Treatment
Vegetated Swale	FACILITYTYPE == "Swale"	2	Infiltration[1]	Treatment
Wet Pond	FACILITYTYPE == "Pond"	1	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.

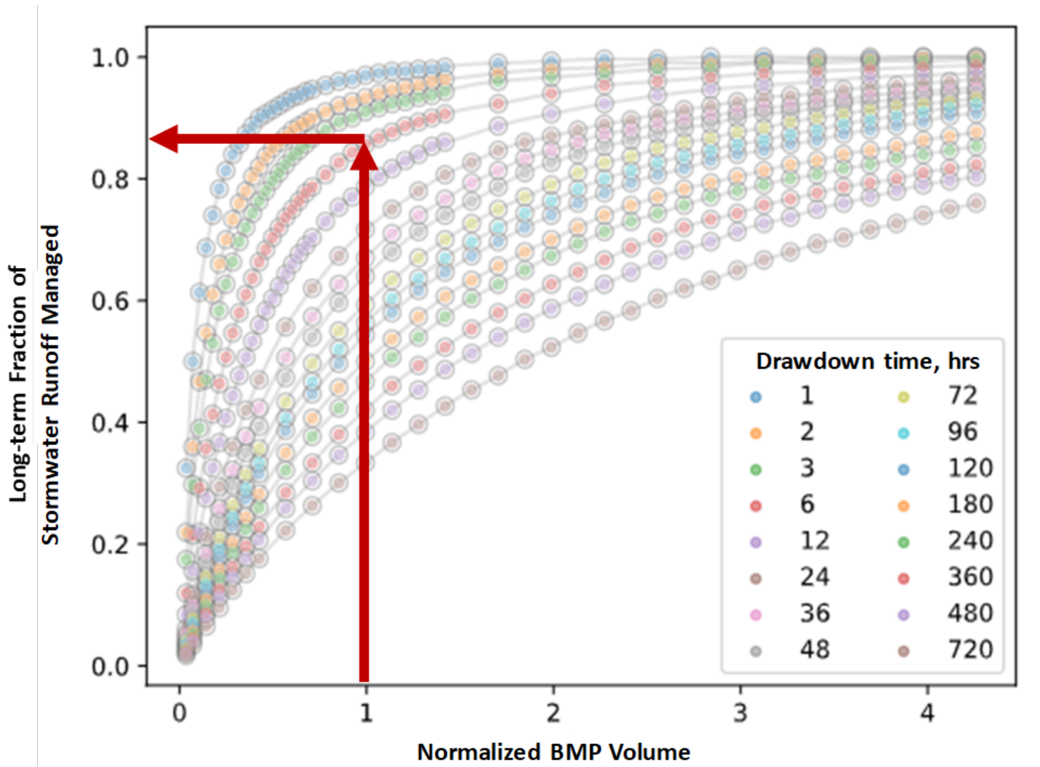


Figure 2-3. Single compartment volume-based nomograph solution example

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%).

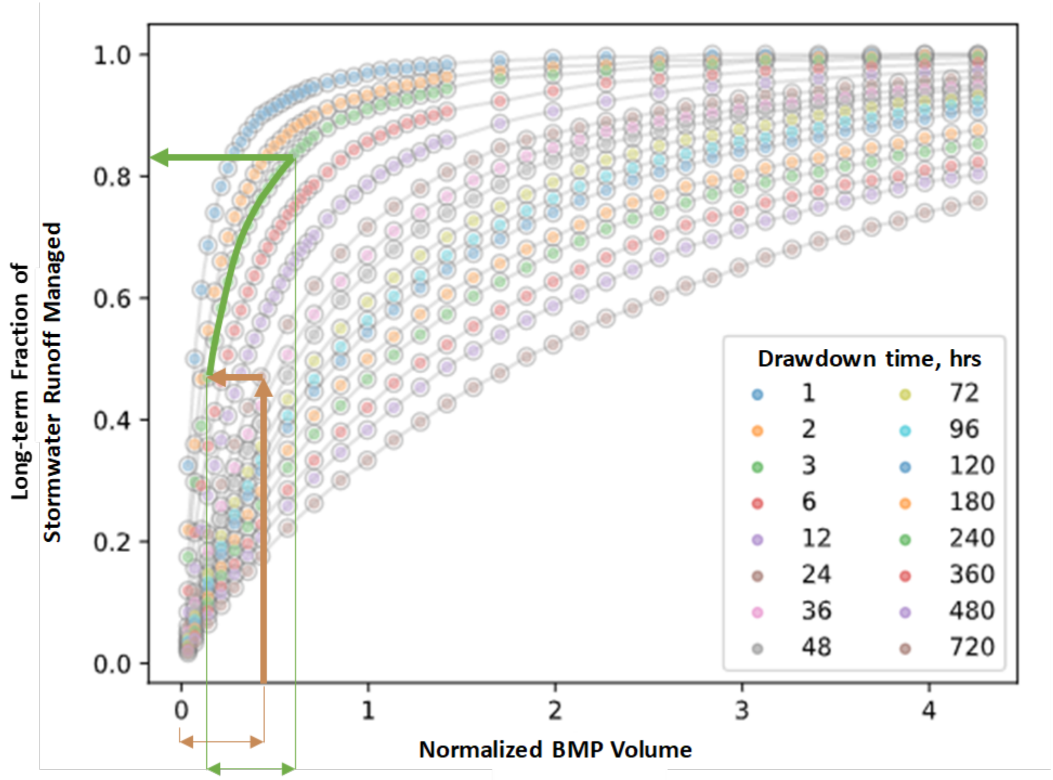


Figure 2-4: Two-compartment nomograph traversal. In this case both compartments have the same volume capture capacity (0.5 Design Volumes) but they have different drawdown times.

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.

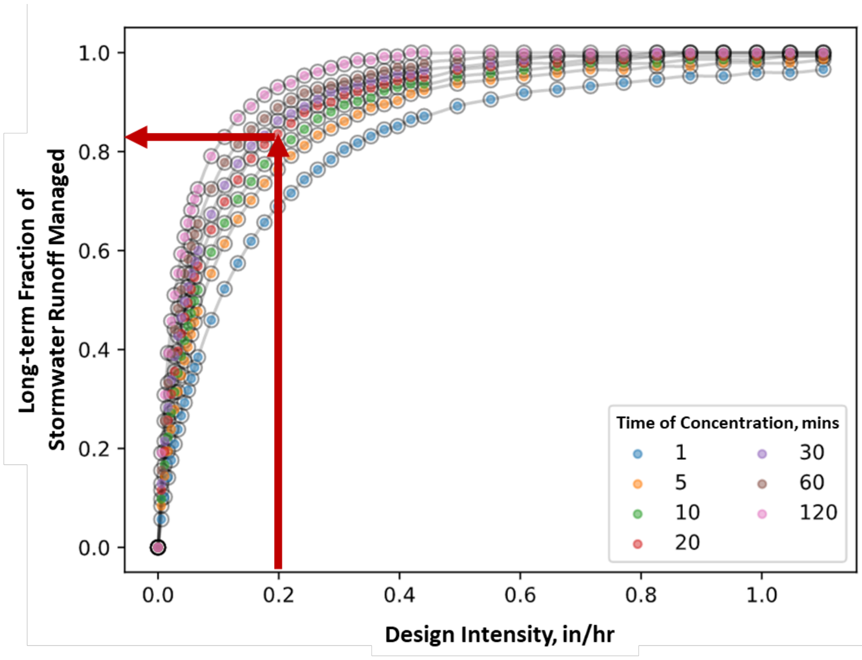


Figure 2-5. Single compartment flow-based nomograph solution

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 (http://bmpdatabase.org/), version 2021 or later. 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). Analysis steps are described below.

2.4.1.1 Data Sufficiency

In order to be used in this study, a minimum of 20 paired results must be reported with at least three distinct studies.

2.4.1.2 Paired difference test

For each BMP-pollutant combination, a parried difference test will be performed to test whether influent and effluent data represent statistically distinct populations. The Wilcoxon signed-ranked test, which is a non-parametric hypothesis test will be used. Only relationships that show a statistically distinct difference between influent and effluent will be used.

2.4.1.3 Monotonicity test

Next, data will be tested for monotonicity (e.g. a nondecreasing function) using the non-parametric Spearman’s Rho test. Only monotonic relationships will be used.

2.4.1.4 Regression

Finally, a regression relationship between influent and effluent concentrations will be 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.

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. These curves were developed based on monitoring studies in the International Stormwater BMP Database (http://bmpdatabase.org/), as prepared for the San Diego WQE (2018). An example plot representing the functional relationship between influent and effluent TSS concentration for several BMP types is shown below in Figure 2-6.

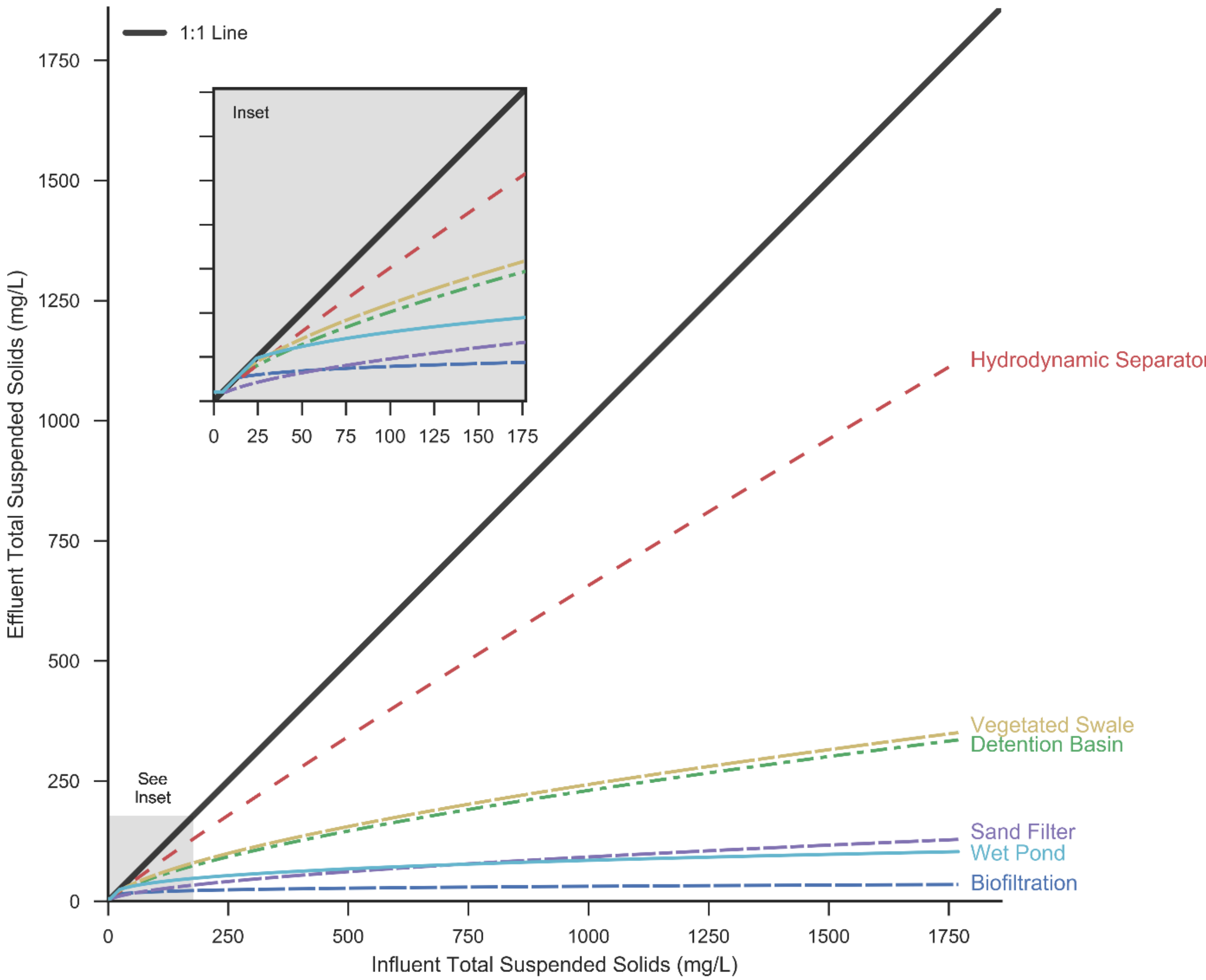


Figure 2-6. Influent vs effluent curve for TSS removal by BMP type

The load reduction mechanism(s) for each of BMP types are listed below in Table 2-6.

Table 2-6. Load reduction calculation approach for BMP types

Water Quality BMP Types	Eliminates Load (Infiltrated / diverted)	Treatment & Discharge Influent-Effluent Curve
Garden with no Underdrain	Infiltration	No treatment assumed (infiltration only)
Infiltration Basin/Trench	Infiltration	No treatment assumed (infiltration only)
Drywell	Infiltration	No treatment assumed (infiltration only)
Permeable Pavement	Infiltration	No treatment assumed (infiltration only)
Underground Infiltration	Infiltration	No treatment assumed (infiltration only)
Cisterns for Harvest and Use	Infiltration	No treatment assumed (infiltration only)
Rain Garden (bioretention with raised underdrain)	Infiltration	Biofiltration/Bioretention
Dry Extended Detention Basin/Tank	Infiltration	Detention Basin
Flow Duration Control Basin/Tank	Infiltration	Detention Basin
Vegetated Swale	Infiltration	Vegetated Swale
Rain Garden with Underdrain and Liner	No infiltration assumed	Biofiltration/Bioretention
Filterra /Vegetated box	No infiltration assumed	High Rate Biofiltration
Media Filter	No infiltration assumed	High Rate Media Filter
Other Proprietary Biotreatment	No infiltration assumed	High Rate Biofiltration
Oil-water Separator	No infiltration assumed	Oil-water separator
Sand Filters	No infiltration assumed	Sand Filter
Hydrodynamic Separator	No infiltration assumed	Hydrodynamic Separator
Wet Pond	No infiltration assumed	Wet Pond/Wetland Basin

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* 2-7. 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 2-8. 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 facilityy 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_03A_Bioretention Underdrain on Property
	WQBE_03Aa_Bioretention Underdrain with Property Cost
	WQBE_03B_Bioretention No Underdrain on Property
	WQBE_03Bb_Bioretention No Underdrain with Property Cost
	WQBE_03C_Bioretention Underdrain in ROW
	WQBE_03D_Bioretention No Underdrain in ROW
Holding Basin	WQBE_12A_Detention Pond on Public Property
	WQBE_12B_Detention Pond with Property Cost
Media Filter	WQBE_05A_Media Filter Drain Underdrain
	WQBE_05B_Media Filter Drain No Underdrain
Pervious Pavement	WQBE_08A_Pervious Concrete Sidewalk (no sand layer)
	WQBE_08B_Porous Asphalt Driveway (with sand layer)
	WQBE_08C_Permeable Paver Driveway (with sand layer)
	WQBE_08D_Permeable Paver Plaza (no sand layer)
Pond	WQBE_13A_Infiltration Pond Till Soil on Public Property
	WQBE_13B_Infiltration Pond Outwash Soil on Public Property
	WQBE_13C_Infiltration Pond Till Soil with Property Cost
	WQBE_13D_Infiltration Pond Outwash Soil with Property Cost
	WQBE_13E_Infiltration Pond Outwash Soil with High Rate Underground Filter System on Public Property
Swale	WQBE_04A_Bioswale in ROW
	WQBE_04B_Bioswale on Public Property
	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
	WQBE_16_Cistern on Property
Vault	WQBE_14A_Infiltration Vault Till Soil on Public Property
	WQBE_14B_Infiltration Vault Outwash Soil on Public Property
	WQBE_14C_Infiltration Vault Till Soil in ROW
	WQBE_14D_Infiltration Vault Outwash Soil in ROW
	WQBE_14E_Infiltration Vault Till Soil with Property Cost
	WQBE_14F_Infiltration Vault Outwash Soil with Property Cost
	WQBE_14G_Infiltration Vault Outwash Soil with High Rate Underground Filter System in ROW
Vegetated Box	WQBE 02A_Bioretention Planter on Property
	WQBE_02B_Bioretention Planter in ROW
	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 critieria, 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 Table 4-1summarizes the subgoals, critieria, 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.

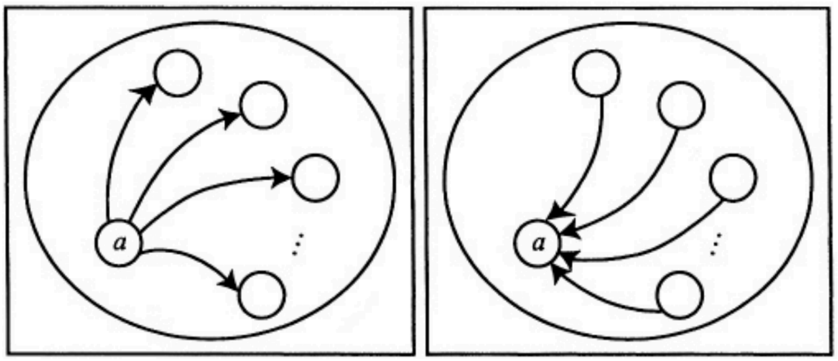
Finally, in Goal 4, the Equity Index Score and Livability Index are maximized to enhance social justice and improve the quality of life in neighborhoods. In contrast, pavement condition, indicative of needed infrastructure work, is minimized to reflect improved roadway conditions. Sidewalk density is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



(a) The $\phi^{+}(a)$ outranking flow. (b) The $\phi^{-}(a)$ outranking flow.

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.

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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
000	A/B	Forest		Flat	5	2	400	0.05	0.3	0.996	2	2	0	0
001	A/B	Forest		Mod	5	2	400	0.1	0.3	0.996	2	2	0	0
002	A/B	Forest		Steep	5	2	400	0.15	0.3	0.996	2	2	0	0
010	A/B	Pasture		Flat	5	1.5	400	0.05	0.3	0.996	2	2	0	0
011	A/B	Pasture		Mod	5	1.5	400	0.1	0.3	0.996	2	2	0	0
012	A/B	Pasture		Steep	5	1.5	400	0.15	0.3	0.996	2	2	0	0
020	A/B	Lawn		Flat	5	0.8	400	0.05	0.3	0.996	2	2	0	0
021	A/B	Lawn		Mod	5	0.8	400	0.1	0.3	0.996	2	2	0	0
022	A/B	Lawn		Steep	5	0.8	400	0.15	0.3	0.996	2	2	0	0
100	C	Forest		Flat	4.5	0.08	400	0.05	0.5	0.996	2	2	0	0
101	C	Forest		Mod	4.5	0.08	400	0.1	0.5	0.996	2	2	0	0
102	C	Forest		Steep	4.5	0.08	400	0.15	0.5	0.996	2	2	0	0
110	C	Pasture		Flat	4.5	0.06	400	0.05	0.5	0.996	2	2	0	0
111	C	Pasture		Mod	4.5	0.06	400	0.1	0.5	0.996	2	2	0	0
112	C	Pasture		Steep	4.5	0.06	400	0.15	0.5	0.996	2	2	0	0
120	C	Lawn		Flat	4.5	0.03	400	0.05	0.5	0.996	2	2	0	0
121	C	Lawn		Mod	4.5	0.03	400	0.1	0.5	0.996	2	2	0	0
122	C	Lawn		Steep	4.5	0.03	400	0.15	0.5	0.996	2	2	0	0
200	SAT	Forest		Flat	4	2	100	0.001	0.5	0.996	10	2	0	0.7
201	SAT	Forest		Mod	4	2	100	0.01	0.5	0.996	10	2	0	0.7
202	SAT	Forest		Steep	4	2	100	0.1	0.5	0.996	10	2	0	0.7
210	SAT	Pasture		Flat	4	1.8	100	0.001	0.5	0.996	10	2	0	0.5
211	SAT	Pasture		Mod	4	1.8	100	0.01	0.5	0.996	10	2	0	0.5
212	SAT	Pasture		Steep	4	1.8	100	0.1	0.5	0.996	10	2	0	0.5
220	SAT	Lawn		Flat	4	1	100	0.001	0.5	0.996	10	2	0	0.35
221	SAT	Lawn		Mod	4	1	100	0.01	0.5	0.996	10	2	0	0.35
222	SAT	Lawn		Steep	4	1	100	0.1	0.5	0.996	10	2	0	0.35

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

12 Appendix B - King County Unit Cost Basis

DRAFT
TECHNICAL MEMORANDUM

Date: March 11, 2022

To: Carly Greyell, King County Department of Natural Resources and Parks, Water and Land Resources Division

From: Edith Hadler, HDR Engineering, Inc.
John Lenth, Herrera Environmental Consultants, Inc.
Olivia Wright, Herrera Environmental Consultants, Inc.

Subject: Unit Cost Basis for Water Quality Benefits Evaluation (431-TM1)

CONTENTS

TABLES

ATTACHMENTS

Glossary of Terms

AACE	Association for the Advancement of Cost Engineering
BMP	best management practice
BOE	Basis of Estimate
CCI	Construction Cost Index
County	King County
CSO	combined sewer overflow
DNR	(Washington State) Department of Natural Resources
Ecology	Washington State Department of Ecology
ENR	*Engineering News-Record*
FV	future value
GSI	green stormwater infrastructure
Herrera	Herrera Environmental Consultants, Inc.
LCC	life-cycle cost
LCCA	life-cycle cost analysis
LTCP	Long-Term Control Plan
NPV	net present value
O&M	operations and maintenance
PDF	Portable Document Format
PRISM	Project Reporting and Information System Management
PV	present value
RKI	Robin Kirschbaum Inc.
ROW	right-of-way
SDOT	Seattle Department of Transportation
SF	square foot/feet
SPU	Seattle Public Utilities
SUSTAIN	System for Urban Stormwater Treatment and Analysis Integration Model
TM	technical memorandum
UIC	underground injection control
WQBE	Water Quality Benefits Evaluation
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation
WTD	(King County) Wastewater Treatment Division

PURPOSE AND BACKGROUND

The King County Wastewater Treatment Division (WTD) is developing the Water Quality Benefits Evaluation (WQBE) toolkit to inform King County (County) decision-making processes regarding selection of cost-effective water quality improvement investments, reducing pollutant load, and improving ecological and human-health outcomes. This toolkit will be applied to a suite of potential projects and programs that could improve water quality and could be implemented in the areas draining to the WTD service area receiving waters. The results of the evaluation of the projects and programs will provide information about the multiple water quality benefits of potential WTD investments within the context of potential regional investments in other areas of the drainage basins. This information will provide technical support for County discussions with stakeholders, regulators, and decision makers related to water quality investments and policies. The toolkit will also be adaptable and designed to respond to the values supported by the region and WTD ratepayers (including those identified by the Regional Engagement effort of the Clean Water Plan) and future strategic planning needs at the division and department levels (including Clean Water Healthy Habitat).

The WQBE toolkit is being developed in two phases over a period extending from 2020 through 2022. During Phase 1 (2020), a preliminary set of models was developed. In Phase 2 (2021–2022), these models are being further calibrated and refined to support County planning efforts (e.g., Clean Water Plan and Combined Sewer Overflow [CSO] Long-Term Control Plan [LTCP] efforts). Implementation of preliminary analyses using the WQBE toolkit will be performed during its development phases; once finalized, the WQBE toolkit will be used to support a wide range of future planning efforts by the County and potentially other municipalities within the County's jurisdictional borders.

To support preliminary model development in Phase 1, the Herrera Environmental Consultants, Inc. (Herrera) team developed a suite of "Actions" comprising structural practices that improve water quality. These Actions provide the unit building blocks ("Unit Actions") that were aggregated and combined to develop water quality "Programs," or groups of Actions that can be implemented to improve water quality over a broad geographic area. Fact Sheets were developed to document the defining characteristics of each Action and Program, including costs, performance, and modeling inputs. Subsequent work in Phase 1 included modeling these Programs to identify the most cost-effective combinations of Actions or "Packages" for reducing pollutant loads or stormwater volumes.

The Herrera team documented the process used to develop Phase 1 Actions and Programs for the WQBE toolkit in a technical memorandum (420-TM1). This document provided guidance for interpreting the Action and Program Fact Sheets, while supporting detailed documentation on the technical basis of the Fact Sheet content is provided as a series of appendices.

This technical memorandum (431-TM1) documents the methodology and approach used to develop cost estimates for the Phase 1 Actions. It specifically provides revised cost assumptions for each Action that were developed for Phase 2 based on lessons learned from Phase 1.

Cost Estimating Methodology and Approach

This section provides an overview of the methodology and approach used to estimate direct construction cost, indirect non-construction cost, project cost, and life-cycle cost (LCC) for each Action.

Overview

The estimating methodology used to generate planning-level cost estimates is based on an order-of-magnitude cost estimate with planning-level, conceptual scope, and limited conceptual design provided by Herrera and Robin Kirschbaum Inc. (RKI) consultants including design assumptions and dimensions. This was augmented by information from the *King County Surface Water Design Manual*, *City of Seattle Stormwater Manual*, Washington State Department of Ecology (Ecology) *Stormwater Management Manual for Western Washington*, and historical agency and proprietary design and detail information from online sources. General and specific assumptions that influence the cost estimates are documented in the cost spreadsheet for each Action.

The Herrera team developed a suite of Actions comprising structural and non-structural practices that improve water quality. These Actions will be modeled in the System for Urban Stormwater Treatment and Analysis Integration Model (SUSTAIN) to identify the most cost-effective combinations of Actions for reducing pollutant loads and/or stormwater volumes.

A "Unit Action" represents a typical vertical profile, areal footprint, and associated design-drainage area for a specific Action being modeled in SUSTAIN. These Unit Actions need to be a representative footprint of an Action defined to be compatible with the SUSTAIN model. Cost optimization is used to determine the collective sizes and/or number of Unit Actions required to achieve a certain pollutant load reduction target. Each Unit Action has an associated total implementation cost.

This cost estimating effort focuses on the capital and operations and maintenance (O&M) costs for the Unit Actions. The programmatic costs associated with executing groups of Unit Actions within a Program will be defined after further development of the SUSTAIN model is completed and is a future scope element.

Planning-level cost estimates were developed for the Unit Actions and variations listed in Table 1.

Table 1. WQBE Actions and Variations.

Action	Description
Green Stormwater Infrastructure (GSI)	
Rain Garden Installation	WQBE_01_Rain Garden Installation on Property
Bioretention Planter	WQBE_02A_Bioretention Planter on Property
	WQBE_02B_Bioretention Planter in ROW
	WQBE_02C_Bioretention Planter with Property Cost
Bioretention Installation	WQBE_03A_Bioretention Underdrain on Property
	WQBE_03Aa_Bioretention Underdrain with Property Cost
	WQBE_03B_Bioretention No Underdrain on Property
	WQBE_03Bb_Bioretention No Underdrain with Property Cost
	WQBE_03C_Bioretention Underdrain in ROW
	WQBE_03D_Bioretention No Underdrain in ROW
Bioswale Installation	WQBE_04A_Bioswale in ROW
	WQBE_04B_Bioswale on Public Property
	WQBE_04C_Bioswale with Property Cost
Media Filter Drains	WQBE_05A_Media Filter Drain Underdrain
	WQBE_05B_Media Filter Drain No Underdrain
Drywell	WQBE_06A_Drywell on Property
	WQBE_06B_Drywell with Bioretention Planter on Property
Deep UIC Wells	WQBE_07A_Deep UIC Well on Property
	WQBE_07B_Deep UIC Well in ROW
	WQBE_07C_Deep UIC Well with Property Cost
	WQBE_07D_Deep UIC Well with Filter in ROW
	WQBE_07E_Deep UIC Well with Bioretention Planter in ROW
Permeable Pavement	WQBE_08A_Pervious Concrete Sidewalk (no sand layer)
	WQBE_08B_Porous Asphalt Driveway (with sand layer)
	WQBE_08C_Permeable Paver Driveway (with sand layer)
	WQBE_08D_Permeable Paver Plaza (no sand layer)
Stormwater Retention/Detention/Infiltration	
Depaving (Removal of Impervious Surfaces)	WQBE_9A_Removal of Impervious Surfaces on Property (wheel strips)
	WQBE_9B_Removal of Impervious Surfaces on Property (no wheel strips)
Stormwater Treatment Wetland	WQBE_20A_ Stormwater Treatment Wetland on Public Property
Detention Vault	WQBE_11A_Detention Vault on Public Property
	WQBE_11B_Detention Vault in ROW
	WQBE_11C_Detention Vault with Property Cost

Table 1 (continued). WQBE Actions and Variations.	
Action	**Description**
Detention Pond	WQBE_12A_Detention Pond on Public Property
	WQBE_12B_Detention Pond with Property Cost
Infiltration Pond	WQBE_13A_Infiltration Pond Till Soil on Public Property
	WQBE_13B_Infiltration Pond Outwash Soil on Public Property
	WQBE_13C_Infiltration Pond Till Soil with Property Cost
	WQBE_13D_Infiltration Pond Outwash Soil with Property Cost
	WQBE_13E_Infiltration Pond Outwash Soil with High Rate Underground Filter on Public Property
Infiltration Vault	WQBE_14A_Infiltration Vault Till Soil on Public Property
	WQBE_14B_Infiltration Vault Outwash Soil on Public Property
	WQBE_14C_Infiltration Vault Till Soil in ROW
	WQBE_14D_Infiltration Vault Outwash Soil in ROW
	WQBE_14E_Infiltration Vault Till Soil with Property Cost
	WQBE_14F_Infiltration Vault Outwash Soil with Property Cost
	WQBE_14G_Infiltration Vault Outwash Soil with High Rate Underground Filter on Public Property
Cistern	WQBE_16_Cistern on Property
Gray Stormwater Treatment	
Wet Pond	WQBE_18A_ Wet Pond on Public Property
	WQBE_18B_ Wet Pond with Property Cost
Wet Vault	WQBE_19A_ Wet Vault on Public Property
	WQBE_19B_ Wet Vault in ROW
	WQBE_19C_ Wet Vault with Property Cost
Stormwater Treatment Wetland	WQBE_20A_ Stormwater Treatment Wetland on Public Property
	WQBE_20B_ Stormwater Treatment Wetland with Property Cost
High Rate Underground Filter System installation	WQBE_21A_High Rate Underground Filter in Urban ROW PCCP
	WQBE_21B_High Rate Underground Filter in Highway ROW PCCP
	WQBE_21C_High Rate Underground Filter in Urban ROW HMA
	WQBE_21D_High Rate Underground Filter in Highway ROW HMA
	WQBE_21E_High Rate Underground Filter on Public Property
	WQBE_21F_High Rate Underground Filter with Property Cost
Regional Vegetated Media	WQBE_22A_Regional Vegetated Media Stormwater Facility on Public Property
	WQBE_22B_Regional Vegetated Media Stormwater Facility with Property Cost

Estimating Basis

Action unit costs were developed from a conceptual design basis combined with accepted design practice and engineering judgment. Differing approaches and assumptions may also meet an acceptable standard of care but may have a significant effect upon cost development. Cost modeling assumptions were developed for each Action to guide the cost development process and maintain consistency with accepted design practices and the WQBE goals. Cost modeling assumption definitions include:

- Design standards (e.g., *King County Surface Water Design Manual*, *City of Seattle Stormwater Manual*, Ecology *Stormwater Management Manual of Western Washington*, etc.)
- Facility assumptions (e.g., treatment media type and depth, drains, piping, location and surface restoration, etc.)
- Facility location and area (e.g., urban roadway, residential property, etc.)

Refer to the Basis of Estimate (BOE) documentation in Attachment A for initial preliminary concept and site assumptions that were used in cost model development. The Unit Action cost estimate spreadsheets contain BOE information for the following:

- Design basis (specific to cost assumptions)
- Planning basis
- Cost basis
- Allowances
- Estimating assumptions
- Contingency
- Management reserve
- Benchmarking

The BOE is considered a "living document" and information provided may be updated when the Unit Action definition or approach undergo changes or are further defined.

Cost Estimate Development

Cost estimates were developed in general conformance with the Association for the Advancement of Cost Engineering (AACE) and King County WTD estimating guidelines. AACE classifies estimates into five class types as outlined in AACE Recommended Practice 18R-97. The cost estimate classification varies, depending upon the project definition and primary estimating characteristics. The estimate classification is distinguished by the degree of project definition and the intended purpose or use of the estimate. The AACE guideline matrix for estimate classification system is provided in Table 2 below.

Table 2. AACE Estimate Class and Characteristics

AACE Estimate	Degree of Project Definition	Typical Estimate Purpose	AACE Expected Accuracy Range
Class 5 (Pre-Class 5)	0% to 2%	Conceptual screening	-50% to +100%
Class 4	1% to 15%	Concept study, order of magnitude, feasibility study	-30% to +50%
Class 3	10% to 40%	Budget, authorization, control	-20% to +30%
Class 2	30% to 70%	Control	-15% to +20%
Class 1	70% to 100%	Check estimate, bid/tender, change order	-10% to +15%

Source: AACE International, 2005.

In addition to the estimate classes listed above, AACE recognizes that special considerations apply when developing costs intended for planning-level screening or long-range strategic planning. These estimates were designated as Class 10 estimates in AACE publication RP111r-20 and were designated as Pre-Class 5 by the CSO Long-Term Control Planning team. Class 5 and Pre-Class 5 (AACE Class 10) estimates are assigned the same accuracy range, contingency, and uncertainty allowances as the AACE Class 5 estimate. The distinguishing feature between an AACE Class 5 estimate and a Pre-Class 5 estimate is that traditionally, a Class 5 estimate is prepared for a near-term project. Pre-Class 5 estimates are prepared to provide planning-level comparisons or conceptual screening for projects that may be constructed 10 years or more in the future.

The WQBE Unit Action cost estimates were designated and prepared as Pre-Class 5 estimates to provide for comparison and screening between different Unit Actions or a suite of Actions. Table 2 lists the allowances and expected accuracy range for the AACE estimate classes. For the purpose of this TM, Pre-Class 5 and Class 5 estimates are assigned the same estimating characteristics and may be used interchangeably.

Cost estimates for the WQBE toolkit were developed in two phases. In Phase 1, Action total project cost estimates were initially developed to support Phase 1 modeling. Phase 2 of the cost estimating was focused on refining the total project and life-cycle costs to reflect a programmatic approach to the Actions. These Unit Action costs provide reasonable estimates of project costs, while also accounting for contingency and uncertainty. Including contingency and other allowances in the project costs includes risk and uncertainty in cost-effectiveness determinations. In both Phases 1 and 2, costs were determined using the WTD cost estimating tool, hereafter called the WTD cost estimate sheet, a Microsoft Excel workbook used to capture, organize, and develop the estimate from project components and assumptions. The WTD cost estimate sheet was selected for use in the WQBE toolkit to provide consistency in how the cost estimates were developed to allow for cost comparisons across the alternatives developed for the CSO LTCP and CSO Water Quality and Optimization programs.

A workshop was conducted following the initial cost development to review the assumptions and methodologies used in developing Phase 1 estimates. Details regarding the workshop as they relate to water quality development are provided in Section 1.2 of Appendix B. A summary of the estimating cost refinements that were identified and implemented with WQBE Phase 2 cost development is listed below. WQBE Phase 2 cost refinements include:

- Revising the estimate class to Pre-Class 5 (AACE Class 10) to capture the long-term planning window associated with WQBE Action development and to be consistent with the CSO LTCP estimate development.

- Revisiting the cost contingency and indeterminates allowance multipliers. The multipliers were evaluated based on specific complexity and assumed project complexity associated with the Actions. Complexity assignments based on Action categories are described within subsequent sections in this TM. Specific contingency factors, uncertainty factors, and complexity factor assignments are detailed within each Action estimate within the Basis of Estimate tab.

- Property costs were initially referenced from appraised land values within the Seattle area. Land costs were revisited to provide land values outside of the Seattle area and that were more reflective of costs within King County.

- The Actions were scaled within the WTD workbook to provide indirect costs that were more reflective of the anticipated cost for a suite of Actions or anticipated Program size.

To remain consistent with the CSO LTCP cost estimate development, the total project cost for each Action was used to update the LCC model workbooks. The LCCs (described in further detail in subsequent sections) were estimated for each Action.

The design basis, developed by Herrera and RKI, was used to develop a cost concept for each Action. The design basis included concept scope and description, preliminary design assumptions, dimensions, and design standards. Refer to Appendix B for details on the design assumptions used for developing the Action cost models. The design basis was used to develop the quantities and estimated construction costs for each Action. Cost allowances were assigned where there was insufficient information to develop quantities within the estimate.

The design basis was augmented using referenced requirements from the following sources:

- *King County Surface Water Design Manual*
- *City of Seattle Stormwater Manual*
- Ecology *Stormwater Management Manual for Western Washington*
- Historical agency and vendor design and detail information

A BOE summary sheet (within the spreadsheet cost estimating tool) was prepared to document key estimating assumptions, design details, estimating factors, and exclusions for each Action. A copy of the BOE summary sheet is provided with the cost spreadsheets in Attachment A.

Total Project Cost Estimates

The WTD cost estimating spreadsheet was used to develop a total project cost for each Action. The total project cost consists of:

- Direct construction cost, which represents the probable cost of construction
- Indirect or non-construction costs, which represent design, permitting, real estate, and other costs associated with the development and administration of a project

Direct Construction Cost

This section describes the methodologies and assumptions used to estimate direct construction costs for the Unit Actions. Direct construction costs represent the costs associated with physical construction of a project and include:

- Subtotal construction costs, which is also called the probable cost of construction bid. The subtotal construction costs include:
    - Contractor overhead and profit and general conditions (included in line-item unit prices)
    - Contractor bonds and insurance (included in line-item unit prices)
    - Contractor mobilization and demobilization (10 percent) based on County experience
- Allowance for indeterminates or design allowance for undefined scope work. The amount is based on a percentage of the subtotal construction costs assigned based on Action type and anticipated complexity as follows:

  - 15 percent for Green Stormwater Infrastructure (GSI) Actions
  - 20 percent for Stormwater Retention/Detention/Infiltration and Gray Stormwater Treatment Actions
  - 25 percent for the Regional Vegetated Media Stormwater Facility (regional facility) Action
- Street use permits: Seattle Department of Transportation (SDOT) street use permit fees for work within Seattle right-of-way (ROW) (varies by Unit Action).
- Project contingency multipliers were assigned based on anticipated project complexity and the level of uncertainty as follows:
  - 15 percent for GSI Actions
  - 25 percent for Stormwater Retention/Detention/Infiltration and Gray Stormwater Treatment Actions
  - 30 percent for the Regional Vegetated Media Stormwater Facility (regional facility) Action

Additional Construction Costs

Additional direct construction costs are included within the WTD cost estimate model and reflect the cost of markups and contingencies in addition to the calculated subtotal of construction costs. These costs include:

- Construction change order allowance (10 percent) based on County experience
- Retail sales tax (10.1 percent) in Seattle
- Outside agency construction (e.g., utility relocations; user-defined, varies by Unit Action)

Year of Construction Cost

Engineering News-Record (ENR) monitors construction costs across the country. The ENR Construction Cost Index (CCI) averages the cost of a set amount of labor and materials over a 20-city average of labor rates and material costs. In addition, ENR has specific CCI average values for the Seattle area.

To maintain estimating consistency between Unit Actions, all costs were escalated to August 2019 dollars using Seattle ENR CCI values. Should a Unit Action be selected for future development, it is recommended that construction costs be adjusted to the projected mid-year of construction.

Indirect Non-Construction Costs

Indirect costs represent "soft costs," which are costs outside of those that are directly part of the construction (or installation), but are required to complete the construction. Examples of indirect costs include design, permitting, real estate procurement, etc. WTD tracked indirect project costs for completed capital improvement projects using its Project Reporting and Information System Management (PRISM) Database. In 2011 WTD updated its WTD cost estimate sheet to incorporate indirect project cost information from the PRISM database. The WTD PRISM cost database information, built into the WTD cost estimating sheet, was used to estimate indirect costs for each Action using the conveyance project type.

WTD gathered indirect project cost data from the PRISM database for 53 projects that were over $1 million in construction cost and from 27 baselined projects that were under $1 million in construction costs. The costs from these referenced key projects were used to develop indirect project costs based on project construction costs. Table 3 depicts how the WTD cost estimate sheet assigns indirect project costs as a percentage of the Action's subtotal of construction cost.

Table 3. WQBE Indirect Costs Assigned Based on Subtotal Construction Cost.

Subtotal Construction Cost Range	Indirect Costs Assigned (%)
$1,000,000–$5,000,000	82.12%
$5,000,000–$10,000,000	68.36%
More than $10,000,000	61.17%

The WTD cost estimate spreadsheet assigns indirect costs based on a percentage of a project's subtotal construction costs. The indirect cost model within the estimate spreadsheet was developed and intended for use on large, capital improvement projects. The projects used to develop the indirect cost model generally had construction cost ranges shown in Table 3 above. Singularly, the subtotal construction cost for each WQBE Action is less than the WTD cost estimate spreadsheet's indirect cost tool was intended to model. However, while the WQBE Action unit costs are discrete, it is anticipated that each Action will be part of a larger project, suite of combined Actions, or installed as part of a Program. Indirect costs for the WQBE Actions were assigned using a scaled subtotal construction cost assuming the total project or Program cost ranges listed below:

- Indirect costs for GSI Actions were based on $20 million to $25 million construction cost. The subtotal cost range was selected as typical for a GSI Program.
- Indirect costs for Stormwater Retention/Detention/Infiltration and Gray Stormwater Treatment Actions were based on $10 million to $15 million subtotal construction cost. The construction cost range was selected as a typical project size for this type of Action.

In addition to project type and estimated construction cost, the following series of project calibrations were selected in the cost model to develop an indirect cost profile:

- Initiatives (art, sustainability): determined that the Actions would not be considered eligible for the initiatives
- Operations support
- Facility inspection used
- In-house legal used
- Modeling used
- Water and Land Resources Division support used

The WTD cost estimate sheet assigned indirect costs as a percentage of the estimated subtotal construction cost based on a developed cost profile from the following nine key PRISM categories:

- Design Engineering
- Construction Management
- Permitting and Licenses
- Operations Support
- Community Relations
- Environmental Planning and Management
- Real Estate: Permitting, Right-of-Way, and Monitoring
- Project Management
- Project Controls

The WTD cost estimate sheet cost model profile assigns indirect costs based on project complexity within the key PRISM categories. There are four complexity levels within the PRISM categories:

- Low complexity indicates a simplified or straightforward cost profile. For example, the Rain Garden Action, which uses a simple, preapproved design with little permitting required, was assigned a low complexity profile.

- Routine complexity indicates typical design or duties without unique issues or concerns. For example, the Detention Vault Action was assumed to require typical design and construction monitoring. While the Action requires permitting, no unique permitting issues were anticipated with this installation. The Detention Vault Action was assigned a routine complexity profile.

- Moderate complexity indicates that there will be elevated costs or concerns associated that are higher than normally found with that type of project. For example, the Stormwater Treatment Wetland Action was assumed to require elevated support for permitting, and environmental planning and management. The Stormwater Treatment Wetland Action was assigned a moderate complexity profile.

- High complexity indicates that the project may have risks associated with it that can require intense support or concerns that may cause significant delivery and schedule delays. For example, a tunnel project that crosses a bay or requires disturbance along the shoreline area may require extensive permitting, have elevated risk associated with the construction, or may require extensive community-relations outreach. The tunnel project may be assigned a high complexity profile. None of the WQBE Phase 2 Actions were considered to have a high complexity profile.

The cost model was established to calculate the indirect cost for each of the key PRISM categories' project complexity with baseline costs set at the "Routine" complexity setting. Indirect costs within each key category were refined (increased or decreased) for each Action by selecting a lower or higher complexity input value. Complexity factors for the WQBE Action units were assigned based on the following:

- Low complexity for GSI Actions

- Routine complexity for Stormwater Retention/Detention/Infiltration and Gray Stormwater Treatment Actions

- Moderate complexity for Regional Vegetated Media (regional) Action

The complexity factors used in developing the cost model for each Action were documented in the BOE assumptions.

Real Estate Costs

The WQBE Actions represent high-level concepts and it is unknown where construction will occur. In determining real estate costs, the following sources were considered:

- WTD appraised land values from the CSO LTCP cost estimates were used to determine property costs from the Seattle area.

- Assessed land costs from areas within King County that were outside of the Seattle area were obtained from the King County Department of Assessments appraised land values.

An average land cost of $54 per square foot (SF) was assigned for acquisition based on an average of Seattle area land costs and assessed land costs in King County outside of the Seattle area. The overall project contingencies are applied to the property costs. Real estate cost assumptions, where used, are documented in the estimate spreadsheet for each Unit Action.

Total Project Costs

Total project costs were estimated for each Unit Action by summing the direct construction costs and indirect non-construction costs using the WTD cost estimating tool. The summary sheet provides a summary of costs for each Unit Action that includes the following information:

- Total direct construction costs, which includes:
  - Estimated probable cost of construction bid (directly estimated using engineered quantities and unit pricing analysis)
  - Additional direct cost
  - Additional construction costs (from PRISM and user-defined allowances)
  - Other capital charges (from PRISM)
- Total indirect non-construction costs (from PRISM and user-defined allowances):
  - Design and construction consulting services
  - Permitting and agency support
  - ROW
  - WTD staff labor
  - Miscellaneous services and materials
  - Non-WTD support
- Total project cost, which includes both direct and indirect construction costs

As detailed under the Cost Estimate Development section, the WQBE estimates were prepared as Pre-Class 5 estimates intended for planning-level screening or alternative comparison for long-range strategic planning. Attachment A contains Portable Document Format (PDF) files of the WTD estimating spreadsheet tool for each of the Unit Actions' cost estimates.

Life-Cycle Cost

A life-cycle cost analysis (LCCA) was prepared using the WTD LCC Model to provide an evaluation of the developed concepts over an established analysis period. The LCCA considers initial capital costs and future costs, such as capital replacement and O&M costs. A 30-year analysis period was selected for the LCCA.

For the WQBE Actions, the LCC was the total project capital cost plus the net present value (NPV) of ongoing capital replacement and O&M over the analysis period of the project. Project LCCs combine capital replacement and O&M costs to allow reasonable comparisons between concepts with high project costs and those with high O&M costs. Project LCCs were estimated by considering:

- Total project cost comprising both direct construction cost and indirect project costs
- Capital replacement cost, which was the cost to replace components during the life-cycle period
- Annual O&M costs, which included labor, chemicals, supplies, and energy costs

The LCCA estimates are to be considered preliminary level (Pre-Class 5) because of the limited information available and the planning-level engineering that has occurred.

Life-Cycle Cost Analysis Assumptions

The following general assumptions were used in the WTD LCC Model:

- Initial capital cost:
    - Initial capital cost is input into the WTD LCC Model as total project cost and not construction cost. Indirect non-construction cost is estimated using the WTD PRISM database program and cost model and not estimated using standard WTD LCC Model assumptions.
    - Initial capital cost was assumed to occur in a single year.
    - If capital costs are incurred over multiple years (large projects), total project cost was entered into the WTD LCC Model as a fraction of the total project cost depending on the number of years for implementation. For example, if a Program is implemented over 10 years, 1/10 of the total project cost will be entered into the WTD LCC Model for each year for 10 years. The first year will be listed as initial capital cost, and subsequent years will be entered as one-time capital replacements.

- Capital replacement cost:
  - Capital replacement is input into the WTD LCC Model as total project cost and not construction cost. Indirect non-construction cost is estimated using the WTD PRISM database program and cost model and not estimated using standard WTD LCC Model assumptions. Indirect non-construction cost (ancillary cost) for capital replacement was manually adjusted to $0 in the WTD LCC Model.
  - If capital replacement (or Program implementation cost) occurs more frequently than every 5 years, annual cost was manually entered into the WTD LCC Model because the WTD LCC Model is not set up for less than 5-year increments.

The following is a general representation of how NPV is calculated within the WTD LCC Model:

$$Project\ Net\ Present\ Value\ (NPV) =$$

$$PV\ (Initial\ Capital\ Costs) + PV(Capital\ Replacment\ Costs) + PV(O\&M\ Costs)$$

In general, future values (FVs) are converted to present values (PVs) by the following equation:

$$PV = FV\frac{FV}{(1+i)^n}$$

Where: i = annual interest rate (provided by County), n = year of expenditure.

- Life-cycle assumptions:
  - Period: 30 years
  - Initial year of operations: 2021
  - Year of analysis: 2019
  - Construction start: 2020
- Cost assumptions:
  - Cost estimate dollar basis year: 2019
  - General conditions markup: 0 percent (general conditions markup was included in the project costs prior to entry into the WTD LCC Model)
  - Construction cost escalation: 3.5 percent
- O&M and general cost escalation:
  - Projects: 3.0 percent

- Programs: 3.5 percent (because it is associated with Program implementation and not necessarily O&M)
- O&M labor rate growth: 3.2 percent
- Direct labor rate as of year of analysis: $47.97
- Washington (retail) sales tax: 10.1 percent
- Project cost contingency allowance: 0 percent (because project costs are entered into the WTD LCC Model and not construction costs)
- WTD labor overhead: 150 percent (this is a County-controlled rate applied to raw labor costs calculated for O&M activities)
- The O&M labor cost formula is listed below:

$$O\&M\ Labor\ Costs\ =$$

$$Labor\ Hours\ per\ Year\ \times Direct\ Labor\ Rate\ \times WTD\ Overhead\ Rate$$

- Financial assumptions:
  - Percent financed of each capital activity:
    - Projects: 60.0 percent
    - Financing interest rate: 5.25 percent
    - Financing maturity: 30 years
    - Financing costs, capitalized: 2.0 percent
- Economic assumptions:
  - Discount rate, WTD (cost of capital): 5.25 percent. The discount rate accounts for both inflation and the time value of money.
  - WTD real discounted rate: 2.18 percent (if O&M escalation is 3.0 percent) or 1.69 percent (if O&M escalation is 3.5 percent).[1]

[1] Real discount rate of 2.18 percent is the default value in the WTD LCC Model; this is estimated based on a WTD financing interest rate of 5.25 percent and 3 percent annual inflation for O&M and general cost escalation. A real discount rate of 1.69 percent is used when O&M and general cost escalation is assumed to be 3.5 percent annual inflation (instead of 3 percent). It was generally assumed 3.5 percent annual O&M and general cost escalation for Programs to be consistent with 3.5 percent annual construction cost

- Annual growth in electricity consumption: 1.0 percent

Attachment A contains a PDF file of the WTD LCC Model and a Microsoft Excel workbook for each of the Unit Actions' LCC estimate.

Operations and Maintenance Cost

Annual O&M cost was estimated for each Unit Action and generally included the following:

- O&M activities were based on the type of activity provided in the most current version of the Cost and Modeling Assumptions worksheet. Activity sources included:
  - *King County Surface Water Design Manual*, 2016
  - *City of Seattle Stormwater Manual*, 2016
  - Ecology *Stormwater Management Manual for Western Washington*, 2019
  - Kitsap County *Manchester Stormwater Retrofit Drainage Report*, 2014
- Annual labor hours required by maintenance crews for cleanup after major storm events or for periodic inspections and remediation of materials (grass, plantings, permeable pavement, concrete cracks and joints, etc.) and regular maintenance activities for the specific Unit Action, where applicable.
- Annual material replacement, such as plant replacement, grass seed mix, mulch, etc. for the specific Unit Action, where applicable.
- Annual equipment rentals needed to perform maintenance activities for the specific Action, where applicable. Equipment rates were obtained from EquipmentWatch™ (Rental Rate Blue Book®) adjusted for Seattle pricing.

Capital Replacement Cost

Capital replacement cost (items requiring replacement prior to the 30-year life of the Unit Action) was estimated for each Unit Action and generally assumed the following:

- Complete replacement of vegetation along with soils that had been compacted every 10 years, where applicable
- Complete replacement of access gates every 10 years, where applicable

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escalation because Programs generally do not have an O&M component, and it was generally assumed 3 percent annual O&M and general cost escalation (default value in WTD LCC Model) for projects because they include an O&M component.

- Complete replacement of mechanical equipment (e.g., flow restrictor, access hatch, outlet structure, baffle, etc.) every 20 years, where applicable

Capital replacement costs were estimated for each Unit Action by summing the construction costs of the specific line items assumed for replacement for the specified interval (e.g., 10 years), including mobilization/demobilization, and then converting the construction cost into project cost by multiplying the subtotal by the ratio of total project cost (excluding land acquisition) to total construction cost for the Unit Action (see equation below). Capital replacement is input into the WTD LCC Model as total project cost and not construction cost. The formula for capital replacement cost is shown below:

$$Total\ Capital\ Replacement\ Project\ Cost =$$

$$Total\ Capital\ Replacement\ Construction\ Cost \times \frac{Total\ Project\ Cost\ (excluding\ land\ acquisition)}{Total\ Construction\ Cost}$$

Total Life-Cycle Cost

Total LCC for each Unit Action was estimated using the WTD LCC Model. Costs were entered into the WTD LCC Model for initial capital (project), capital replacement, and O&M. Total LCC is presented as NPV over 30-year life using the WTD discount rate.

COST SOURCES

This section explains the process used to collect cost information for costs in support of the WQBE toolkit (construction, Program, and O&M costs). The costs for each Unit Action were characterized for each unit (see definition at end of document) of an Action, or the footprint of the Unit Action designed specifically for compatibility with the SUSTAIN model. Costs for the Unit Action items are to be considered preliminary, planning-level costs based on limited or generalized engineering design assumptions.

The following sources were used to develop unit prices using cost data representative of the Seattle/King County region and reviewed to gather data to support development of costs for the Unit Actions. All costs reflect owner's anticipated construction costs (construction contractor pricing) in 2019 dollars:

- **Tabula costing tool (Version 3.1.2):** The County developed Tabula to provide planning-level construction cost estimates for conveyance, tunnel, and storage facilities. The County last updated this program in 2010 with costs based on 2008 dollars (King County, 2010).

- **Seattle Public Utilities (SPU) cost estimating guide:** The SPU estimating guide provides unit cost information for typical elements within public works infrastructure projects and for building construction. Costs within this sheet were based on 2017 dollars (SPU, 2017).

- **Washington State Department of Transportation (WSDOT) unit bid analysis:** The WSDOT unit bid analysis database contains a bid history for standard unit bid prices from WSDOT projects. This tool contains cost information for excavation, conveyance, best management practices (BMPs), or other typical roadway construction items. The WSDOT database search can be limited to projects within western Washington or other nearby localities, such as the Olympic Peninsula (WSDOT, 2019).

- **Puget Sound BMP cost database:** The Puget Sound BMP cost database report contains cost information from the Puget Sound region for stormwater treatment and BMP elements (e.g., wet ponds, porous pavement, cisterns, constructed wetlands, etc.). Costs from this database report are based on 2012 dollars.

- **King County TMs and reports:** King County TMs (e.g., Legacy Load Removal and the University GSI projects) and existing reports (e.g., Puget Sound BMP Cost Database, Water Resource Inventory Area [WRIA] 9 reports, and University Green Stormwater Infrastructure with GSI cost benchmarking by CH2M Hill) contain both estimated construction costs and historical maintenance cost data. Construction and other cost data within the reports are based on various dates and any applied escalation or inflationary values should be considered on a case-by-case basis.

- **Internet sources:** Internet websites and online data sources were used to estimate specialty costs associated with the GSI Program costs, such as the RainWise Cistern cost from approved vendors listed on the RainWise website at https://www.kingcounty.gov/services/environment/stewardship/nw-yard-and-garden/rain-barrels.aspx.

  Online sources were also used to estimate O&M costs and specialty item costs such as blue roofs and cisterns. Website and online data sources used are as detailed in the Cost Source column of the Cost Data Summary (Table 4).

- **Contractor and vendor quotes:** Vendor quotes were used to calculate bid costs or to verify reported unit cost data for specialty items, such as proprietary stormwater treatment (i.e., Filterra), odor control, and large-value maintenance equipment purchases. Vendor quotes reflect current market conditions at the time the quote was obtained. Quotes should be adjusted to account for installation costs and labor, shipping and handling, and contractor markup and profit.

- **Estimator and agency historical databases:** VMS, Herrera, King County (WTD), SPU, Washington State Department of Natural Resources (DNR), Kitsap County, and other agencies within the Puget Sound area maintain and may post contractor bid prices for publicly bid projects. Bid costs from these sources were used to fill in data gaps from the other sources or for specialty work (e.g., Maury Island Natural Area Derelict Piling Removal from DNR for creosote pile removal, Manchester Stormwater Retrofit Phase 2 from Kitsap County, RainWise participation and historical participation rates from SPU and WTD, etc.) obtained from other sources. Data obtained from these sources were reviewed to ensure that the quantities and other project parameters were relevant. Costs obtained from these sources were based on various dates and any applied escalation or inflationary values were considered on a case-by-case basis.

- **EquipmentWatch™:** HDR Engineering, Inc. maintains a subscription to EquipmentWatch™, which provides access to Rental Rate Blue Book® pricing. The pricing is kept current by extensive ongoing research. This pricing tool is an industry standard for determining equipment values for both use and rental. The rates can be applied across the country or can be adjusted for a specific region, such as the Seattle area. Additional information on EquipmentWatch™ can be found on its website at <equipmentwatch.com>.

- **RSMeans:** RSMeans, an industry resource used in estimating construction costs, was another source of productivity information that was cross referenced for validation (Gordian, 2018). RSMeans researches data to provide construction costs for materials, labor, transportation costs, and equipment rental rates. The rates can be applied across the country or can be adjusted for a specific region, such as the Seattle area. Additional information on RSMeans can be found on its website at <www.RSMeans.com>.

- **Labor rates:** Craft rates and related benefits were estimated using current prevailing wage rates for King County. These labor rates include base wage rate, all applicable fringe benefits, unemployment insurance, and payroll taxes. Workers' compensation insurance is included separately in each work activity based on risk histories.

Cost Source Data Summary

The cost sources used in development of the Unit Action costs are summarized in Table 4 below. Where appropriate, costs were benchmarked using the County's CSO LTCP unit price estimates to maintain estimating cost consistency between the Programs. The cost estimates and estimating approaches used for the WQBE Phase 1 Actions were evaluated against peer projects and programs. The results are documented within the Program Cost Benchmarking Technical Memorandum (hereafter called the Benchmarking TM), prepared by Lotus Water. A copy of the Benchmarking TM is provided as Attachment B and supplemental analysis to the Benchmarking TM is in Attachment C. WQBE Phase 1 Action direct and indirect cost assumptions were evaluated for appropriateness and for cost sensitivity and the results documented in the Evaluation of Water Quality Benefit (WQBE) Project Cost Sensitivity for SUSTAIN Modeling Technical Memo (hereafter called the WQBE Cost Sensitivity TM). A copy of the WQBE Cost Sensitivity TM is provided as Attachment D.

Table 4. Cost Data Summary.

Action	Cost Source
Rain Garden Installation	• King County University GSI, Puget Sound BMP cost database, WSDOT unit bid analysis, SPU cost estimating guide, Tabula, estimator and historical databases • Equipment rates from RSMeans and personnel costs from Washington State prevailing wage rates • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019
Bioretention Planter	• King County University GSI, Puget Sound BMP cost database, WSDOT unit bid analysis, SPU cost estimating guide, Tabula, estimator and historical databases • Equipment rates from RSMeans and personnel costs from Washington State prevailing wage rates • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019
Bioretention	• King County University GSI, Puget Sound BMP cost database, WSDOT unit bid analysis, SPU cost estimating guide, Tabula, estimator and historical databases • Equipment rates from RSMeans and personnel costs from Washington State prevailing wage rates • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019
Bioswale (treatment)	• Construction costs based on WRIA 9 Reports, WSDOT Unit Bid Analysis, SPU/County and estimator and historical databases • Equipment rates from RSMeans and personnel costs from Washington State prevailing wage rates • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019
Media Filter Drains	• King County University GSI, Puget Sound BMP cost database, WSDOT unit bid analysis, SPU cost estimating guide, Tabula, estimator and historical databases • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019
Drywell	• King County University GSI, Puget Sound BMP cost database, WSDOT unit bid analysis, SPU cost estimating guide, Tabula, estimator and historical databases • O&M guidelines per *King County Surface Water Design Manual*, 2016

Table 4 (continued). Cost Data Summary

Action	Cost Source
Deep UIC Wells	• Construction costs based on University GSI report, Puget Sound BMP cost database, and estimator and historical cost database • O&M guidelines per *King County Surface Water Design Manual*, 2016
Permeable Pavement	• Construction costs based on University GSI report and estimator and historical cost database • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019
	• Construction costs based on University GSI report, Puget Sound BMP cost database, WSDOT unit cost database, and estimator and historical cost database • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019
Depaving (Removal of Impervious Surface)	• Construction costs based on SPU/County and estimator and historical database • O&M minimal and based on professional judgment
Detention Vault	• Construction costs based on WSDOT Unit Bid Analysis, tabula, SPU cost estimating guide, vendor quotes, SPU/County and estimator and historical databases • Equipment rates from RSMeans and personnel costs from Washington State prevailing wage rates • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019
Detention Pond	• Construction costs based on WSDOT Unit Bid Analysis, tabula, SPU cost estimating guide, vendor quotes, SPU/County and estimator and historical databases • Equipment rates from RSMeans and personnel costs from Washington State prevailing wage rates • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019
Infiltration Pond	• King County University GSI, Puget Sound BMP cost database, WSDOT unit bid analysis, SPU cost estimating guide, Tabula, estimator and historical databases • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019
Infiltration Vault	• Construction costs based on WSDOT Unit Bid Analysis, tabula, SPU cost estimating guide, vendor quotes, SPU/County and estimator and historical databases • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019
Cistern	• RainWise cost based on average rebate amount per cistern for 60 gal, 250 gal, and 600 gal vendor info from <https://www.700milliongallons.org/rainwise/>. • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019 and *King County Surface Water Design Manual*, 2016

Table 4 (continued). Cost Data Summary

Action	Cost Source
Wet Pond	• King County University GSI, Puget Sound BMP cost database, WSDOT unit bid analysis, SPU cost estimating guide, Tabula, estimator and historical databases • Equipment rates from RSMeans and personnel costs from Washington State prevailing wage rates • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019
Wet Vault	• Construction costs based on WSDOT Unit Bid Analysis, tabula, SPU cost estimating guide, vendor quotes, SPU/County and estimator and historical databases • O&M guidelines per *Stormwater Management Manual for Western Washington*, 2019
Stormwater Treatment Wetland	• Construction costs based on Manchester Stormwater Retrofit (Kitsap County), King County University GSI, Puget Sound BMP cost database, WSDOT unit bid analysis, SPU cost estimating guide, Puget Sound BMP Cost Database, SPU/County and estimator and historical databases • Equipment rates from RSMeans and personnel costs from Washington State prevailing wage rates • O&M guidelines per *King County Surface Water Design Manual*, 2016
High Rate Underground Filter System	• Construction cost based on vendor quotes and estimator and historical databases • Equipment rates from EquipmentWatch™ (Blue Book®) and personnel costs from LCC model • O&M guidelines per Kitsap County *Operations and Maintenance Manual: Manchester Stormwater Park*, 2015

SUMMARY OF COSTS BY UNIT ACTION

A summary of the costs for each Unit Action is provided in Table 5. The Unit Action drainage area assumptions are summarized in Table 4 of Appendix B. These cost estimates were designated as Pre-Class 5 estimates and are assigned the AACE expected accuracy range of -50% to +100% (see Table 2). This range can be applied to the total project costs.

Table 5. Costs by Unit Action.

Action	Description	Action Unit	Total Direct Construction Cost (a)	Property Acquisition Cost (b)	Total Indirect Non-Construction Cost (c)	Total Project Cost (d)	O&M Costs (Annual) (e)	Net Present Value 30-year Life-Cycle Cost (2019)
Equations						(a)+(b)+(c)		PV(d)+PV(e)
Green Stormwater Infrastructure (GSI)								
Rain Garden Installation	WQBE 01_Rain Garden Installation on Property	25 SF	$17,000	$0	$7,000	$24,000	$2,800	$82,000
Bioretention Planter Installation	WQBE 02A_Bioretention Planter on Property	25 SF	$29,000	$0	$13,000	$42,000	$2,800	$100,000
	WQBE_02B_Bioretention Planter in ROW	25 SF	$39,000	$0	$17,000	$56,000	$2,800	$114,000
	WQBE_02C_Bioretention Planter with Property Cost	25 SF	$29,000	$1,400	$15,000	$44,000	$2,800	$102,000
Bioretention Installation	WQBE_03A_Bioretention Underdrain on Property	85 SF	$59,000	$0	$26,000	$85,000	$2,800	$175,000
	WQBE_03Aa_Bioretention Underdrain with Property Cost	85 SF	$59,000	$14,000	$42,000	$100,000	$2,800	$190,000
	WQBE_03B_Bioretention No Underdrain on Property	85 SF	$57,000	$0	$25,000	$83,000	$2,800	$173,000
	WQBE_03Bb_Bioretention No Underdrain with Property Cost	85 SF	$57,000	$14,000	$41,000	$98,000	$2,800	$188,000

	WQBE_03C_Bioretention Underdrain in ROW	85 SF	$97,000	$0	$42,000	$139,000	$2,800	$230,000
	WQBE_03D_Bioretention No Underdrain in ROW	85 SF	$94,000	$0	$41,000	$135,000	$2,800	$226,000

Table 5 (continued). Costs by Unit Action.

Action	Description	Action Unit	Total Direct Construction Cost	Property Acquisition	Total Indirect Non-Construction Costs	Total Project Cost	O&M Costs (Annual)	Net Present Value 30-year Life-Cycle Cost (2019)
Bioswale Installation	WQBE_04A_Bioswale in ROW	200 SF	$29,000	$0	$12,000	$41,000	$2,600	$111,000
	WQBE_04B_Bioswale on Public Property	200 SF	$14,000	$0	$6,000	$20,000	$2,600	$89,000
	WQBE_04C_Bioswale with Property Cost	200 SF	$14,000	$40,000	$52,000	$66,000	$2,600	$135,000
Media Filter Drains	WQBE_05A_Media Filter Drain Underdrain	200 SF	$24,000	$0	$10,000	$34,000	$2,300	$116,000
	WQBE_05B_Media Filter Drain No Underdrain	200 SF	$21,000	$0	$9,000	$30,000	$2,300	$113,000
Drywell	WQBE_06_Drywell on Property	1 Each	$11,000	$0	$5,000	$16,000	$1,800	$53,000
	WQBE_06B_Drywell with Bioretention Planter on Property	1 Each	$50,000	$0	$22,000	$72,000	$1,900	$112,000
Deep UIC Well	WQBE_07A_Deep UIC Well on Property	1 Each	$32,000	$0	$14,000	$46,000	$2,000	$86,000
	WQBE_07B_Deep UIC Well in ROW	1 Each	$46,000	$0	$20,000	$66,000	$2,000	$106,000
	WQBE_07C_Deep UIC Well with Property Cost	1 Each	$32,000	$1,400	$16,000	$48,000	$2,000	$88,000
	WQBE_07D_Deep UIC Well with Filter in ROW	1 Each	$142,000	$0	$62,000	$204,000	$4,900	$303,000
	WQBE_07E_Deep UIC Well with Bioretention Planter in ROW	1 Each	$762,000	$0	$333,000	$1,095,000	$6,800	$1,239,000

Table 5 (continued). Costs by Unit Action.								
Action	**Description**	**Action Unit**	**Total Direct Construction Cost**	**Property Acquisition**	**Total Indirect Non-Construction Costs**	**Total Project Cost**	**O&M Costs (Annual)**	**Net Present Value 30-year Life-Cycle Cost (2019)**
	WQBE_07F_Deep UIC Well with Bioretention Planter on Property	1 Each	$650,000	$0	$287,000	$938,000	$6,800	$1,083,000
Permeable Pavement	WQBE_08A_Pervious Concrete Sidewalk (no sand layer)	200 SF	$8,000	$0	$4,000	$12,000	$2,100	$78,000
	WQBE_08B_Porous Asphalt Driveway (with sand layer)	200 SF	$4,000	$0	$2,000	$6,000	$2,200	$60,000
	WQBE_08C_Permeable Paver Driveway (with sand layer)	200 SF	$3,000	$0	$1,000	$4,000	$2,100	$55,000
	WQBE_08D_Permeable Paver Plaza (no sand layer)	200 SF	$3,000	$0	$1,000	$4,000	$2,100	$54,000
Depaving (Removal of Impervious Surfaces)	WQBE_9A_Removal of Impervious Surfaces on Property (wheel strips)	100 SF	$1,000	$0	$1,000	$2,000	$600	$15,000
	WQBE_9B_Removal of Impervious Surfaces on Property (no wheel strips)	100 SF	$1,000	$0	$1,000	$2,000	$600	$15,000
Stormwater Retention/Detention/Infiltration								
Detention Vault	WQBE_11A_Detention Vault on Public Property	1 each	$3,519,000	$0	$2,710,000	$6,229,000	$4,900	$6,352,000
	WQBE_11B_Detention Vault in ROW	1 each	$4,473,000	$0	$3,130,500	$7,603,000	$4,900	$7,727,000
	WQBE_11C_Detention Vault with Property Cost	1 each	$3,519,000	$589,000	$3,446,000	$6,965,000	$4,900	$7,085,000
Detention Pond	WQBE_12A_Detention Pond on Public Property	1 each	$617,000	$0	$484,000	$1,102,000	$9,400	$1,473,000
	WQBE_12B_Detention Pond with Property Cost	1 each	$617,000	$1,073,000	$1,826,000	$2,443,000	$9,400	$2,807,000

Table 5 (continued). Costs by Unit Action.

Action	Description	Action Unit	Total Direct Construction Cost	Property Acquisition	Total Indirect Non-Construction Costs	Total Project Cost	O&M Costs (Annual)	Net Present Value 30-year Life-Cycle Cost (2019)
Infiltration Pond	WQBE_13A_Infiltration Pond Till Soil on Public Property	1 each	$395,000	$0	$310,000	$705,000	$5,500	$971,000
	WQBE_13B_Infiltration Pond Outwash Soil on Public Property	1 each	$352,000	$0	$276,000	$629,000	$3,500	$836,000
	WQBE_13C_Infiltration Pond Till Soil with Property Cost	1 each	$395,000	$903,000	$1,439,000	$1,834,000	$5,500	$2,094,000
	WQBE_13D_Infiltration Pond Outwash Soil with Property Cost	1 each	$352,000	$903,000	$1,405,000	$1,758,000	$3,500	$1,959,000
	WQBE_13E_Infiltration Pond Outwash Soil with High Rate Underground Filter System on Public Property	1 each	$424,000	$0	$332,000	$756,000	$6,400	$1,033,000
Infiltration Vault	WQBE_14A_Infiltration Vault Till Soil on Public Property	1 each	$2,577,000	$0	$2,012,000	$4,589,000	$4,900	$4,721,000
	WQBE_14B_Infiltration Vault Outwash Soil on Public Property	1 each	$2,009,000	$0	$1,562,000	$3,572,000	$4,900	$3,709,000
	WQBE_14C_Infiltration Vault Till Soil in ROW	1 each	$3,008,000	$0	$2,245,000	$5,253,000	$4,900	$5,384,000
	WQBE_14D_Infiltration Vault Outwash Soil in ROW	1 each	$2,351,000	$0	$1,769,000	$4,120,000	$4,900	$4,257,000
	WQBE_14E_Infiltration Vault Till Soil with Property Cost	1 each	$2,577,000	$533,000	$2,679,000	$5,256,000	$4,900	$5,385,000
	WQBE_14F_Infiltration Vault Outwash Soil with Property Cost	1 each	$2,009,000	$533,000	$2,229,000	$4,238,000	$4,900	$4,372,000
	WQBE_14G_Infiltration Vault Outwash Soil with High Rate Underground Filter System in ROW	1 Each	$2,368,000	$0	$1,795,000	$4,163,000	$7,800	$4,376,000

Table 5 (continued). Costs by Unit Action.

Action	Description	Action Unit	Total Direct Construction Cost	Property Acquisition	Total Indirect Non-Construction Costs	Total Project Cost	O&M Costs (Annual)	Net Present Value 30-year Life-Cycle Cost (2019)
Cistern	WQBE_16_Cistern on Property	1 each	$18,000	$0	$8,000	$26,000	$2,100	$70,000
Gray Stormwater Treatment								
Wet Pond	WQBE_18A_ Wet Pond on Public Property	553 SF	$383,000	$0	$300,000	$683,000	$2,000	$852,000
	WQBE_18B_ Wet Pond with Property Cost	553 SF	$383,000	$718,000	$1,198,000	$1,581,000	$2,000	$1,745,000
Wet Vault	WQBE_19A_ Wet Vault on Public Property	1 each	$2,852,000	$0	$2,203,000	$5,055,000	$2,900	$5,125,000
	WQBE_19B_ Wet Vault in ROW	1 each	$3,314,000	$0	$2,493,000	$5,806,000	$2,900	$5,874,000
	WQBE_19C_ Wet Vault with Property Cost	1 each	$2,852,000	$538,000	$2,876,000	$5,728,000	$2,900	$5,795,000
Stormwater Treatment Wetland	WQBE_20A_ Stormwater Treatment Wetland on Public Property	503 SF	$360,000	$0	$282,000	$642,000	$2,300	$817,000
	WQBE_20B_ Stormwater Treatment Wetland with Property Cost	503 SF	$360,000	$678,000	$1,130,000	$1,489,000	$2,300	$1,659,000
High Rate Underground Filter System	WQBE_21A_High Rate Underground Filter in Urban ROW PCCP	1 each	$120,000	$0	$75,000	$195,000	$2,900	$254,000
	WQBE_21B_High Rate Underground Filter in Highway ROW PCCP	1 each	$89,000	$0	$56,000	$145,000	$2,900	$204,000
	WQBE_21C_High Rate Underground Filter in Urban ROW HMA	1 each	$86,000	$0	$54,000	$140,000	$2,900	$199,000

Table 5 (continued). Costs by Unit Action.								
Action	**Description**	**Action Unit**	**Total Direct Construction Cost**	**Property Acquisition**	**Total Indirect Non-Construction Costs**	**Total Project Cost**	**O&M Costs (Annual)**	**Net Present Value 30-year Life-Cycle Cost (2019)**
	WQBE_21D_High Rate Underground Filter in Highway ROW HMA	1 each	$79,000	$0	$50,000	$129,000	$2,900	$188,000
	WQBE 21E_High Rate Underground Filter on Public Property	1 each	$64,000	$0	$42,000	$106,000	$2,900	$165,000
	WQBE 21F_High Rate Underground Filter with Property Cost	1 each	$64,000	$900	$43,000	$107,000	$2,900	$166,000
Regional Vegetated Media	WQBE_22A_Regional Vegetated Media SW Facility on Public Property	5,940 SF	$2,965,000	$0	$3,073,000	$6,038,000	$12,000	$6,562,000
	WQBE_22B_Regional Vegetated Media SW Facility with Property Cost	5,940 SF	$2,965,000	$910,760	$4,259,000	$7,224,000	$12,000	$7,741,000

WQBE Program Terminology

Action: Individual structural and non-structural best management practices (BMPs) or activities to improve water quality (e.g., rain gardens, wet ponds, street sweeping).

Assessment point: Location where a management objective is evaluated during optimization.

Basin: Grouping of catchments and subbasins that represent the primary discharge points and spatial scale for the Tier 2 SUSTAIN optimization.

Basis of Estimate (BOE): Document that details the premise, or basis, from which critical aspects of a project cost estimate were developed including cost and labor estimates, material availability, any assumptions or deviations, any studies or analysis used as a reference, and any other details which impacted the cost estimates.

Catchment: Delineation of drainage areas for the Loading Simulation Program in C++ (LSPC) baseline pollutant loading model and serving as the scale of individual Tier 1 SUSTAIN cost-optimization.

Package: Point on a SUSTAIN cost-effectiveness curve that identifies a specific level of implementation of a Program (e.g., 200 unit rain gardens and 50 unit permeable pavement installations in specified subbasins that represent a cost-effective implementation of a green stormwater infrastructure [GSI] incentive program in the Lake Washington basin).

Programs will be evaluated with the SUSTAIN models by generating a Package of representative Actions optimized for stormwater volume or pollutant load reductions at an assessment point. Previously defined projects could also be incorporated into the SUSTAIN models and included in optimization evaluations as desired.

Program: Group of Unit Actions that could be implemented to improve water quality over a broad geographic area, such as a GSI incentive program in unincorporated areas within the Lake Washington basin or a roadway stormwater treatment program on County-owned roads within the Green/Duwamish basin.

Project: Individual Action or related group of Actions at a specific geographic location for which detailed, spatially explicit characteristics are defined (e.g., a rain garden installation on a specified property or within a small defined area).

Subbasin: Grouping of catchments for which SUSTAIN model output will be reported to inform causal model inputs.

Unit Action: Representative vertical profile, areal footprint, and associated design-drainage area for an Action being modeled in SUSTAIN. Cost-benefit optimization is used to determine the collective sizes and/or number of Unit Actions required to achieve a certain pollutant load reduction target. Each Unit Action has an associated cost that is scalable during optimization to estimate total implementation costs.

Unit: Representative footprint of an Action defined so as to be compatible with the SUSTAIN model.

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ATTACHMENT A

Cost Estimates and Life-Cycle Cost Analysis

ATTACHMENT B

Program Cost Benchmarking TM

ATTACHMENT C

Supplemental Analysis for the Program Cost Benchmarking TM

ATTACHMENT D

Evaluation of WQBE Project Cost Sensitivity for SUSTAIN Modeling TM

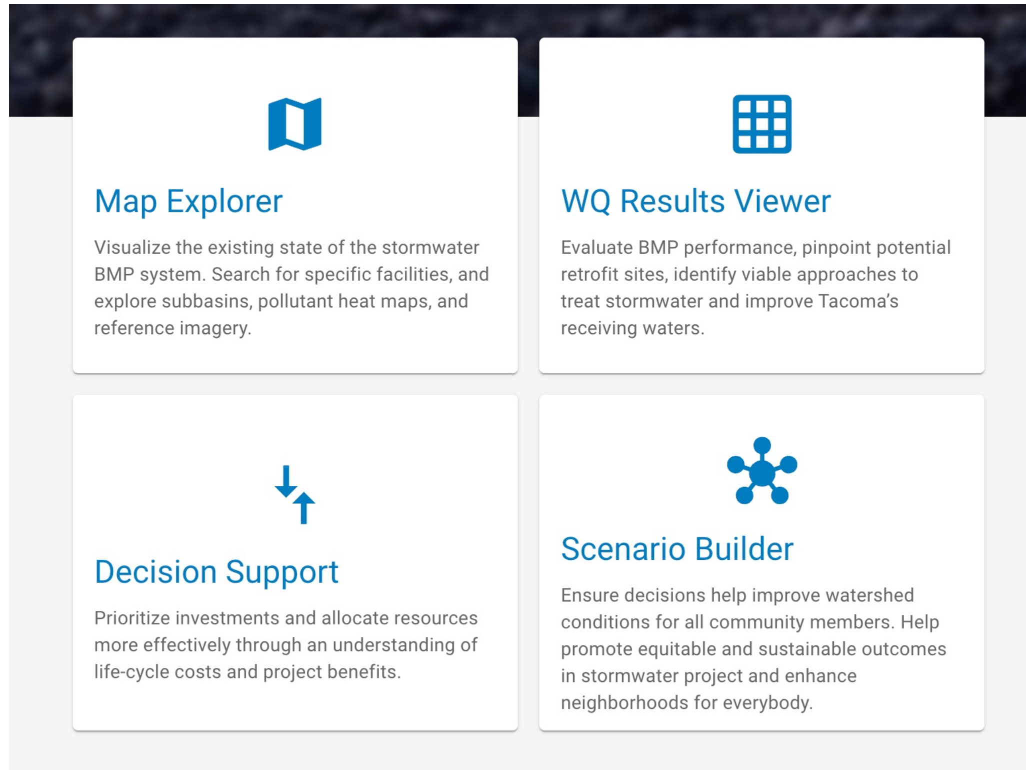
HERRERA

March 2022

13 Appendix C - Workshop Slides

Tacoma Watershed Insights

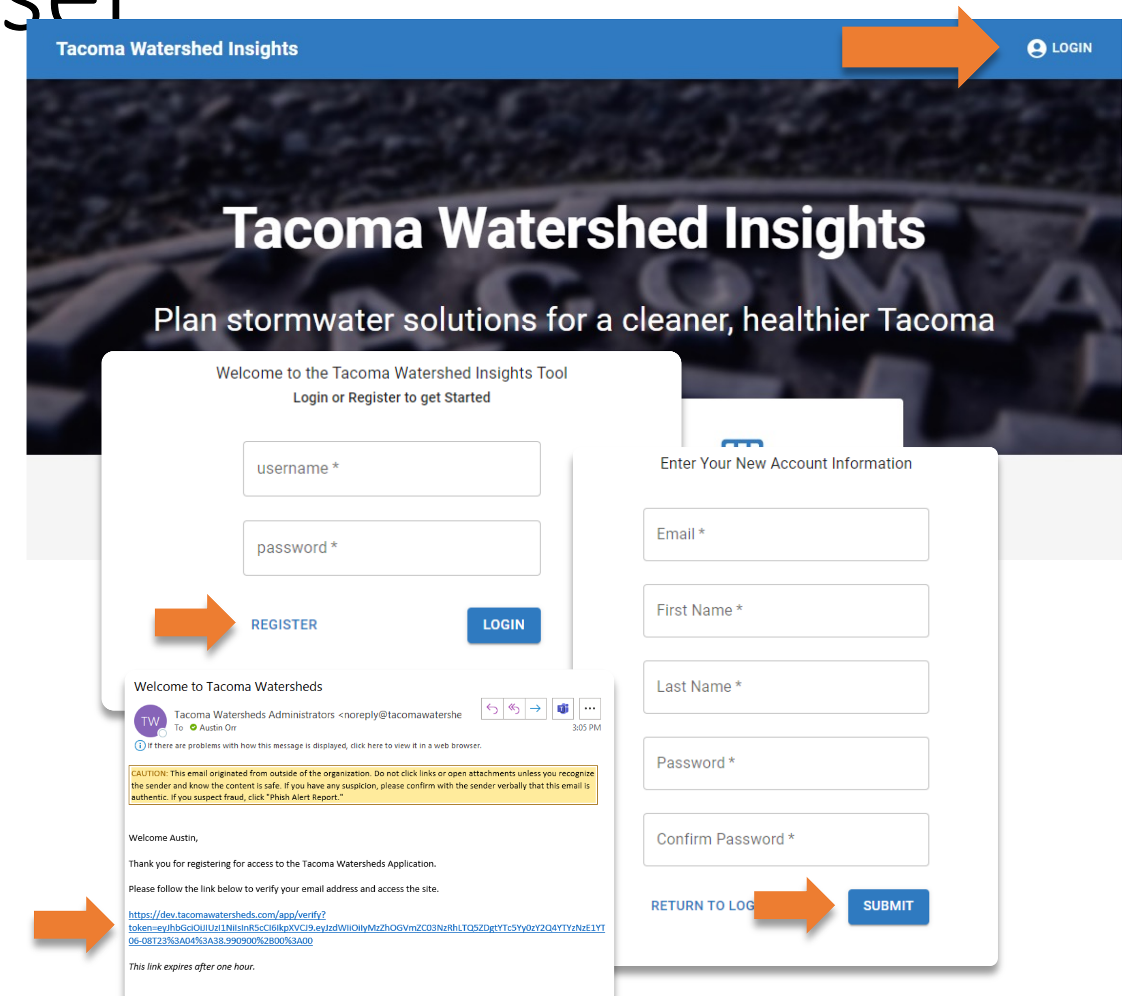
Main Components



System Administration

Enroll New User

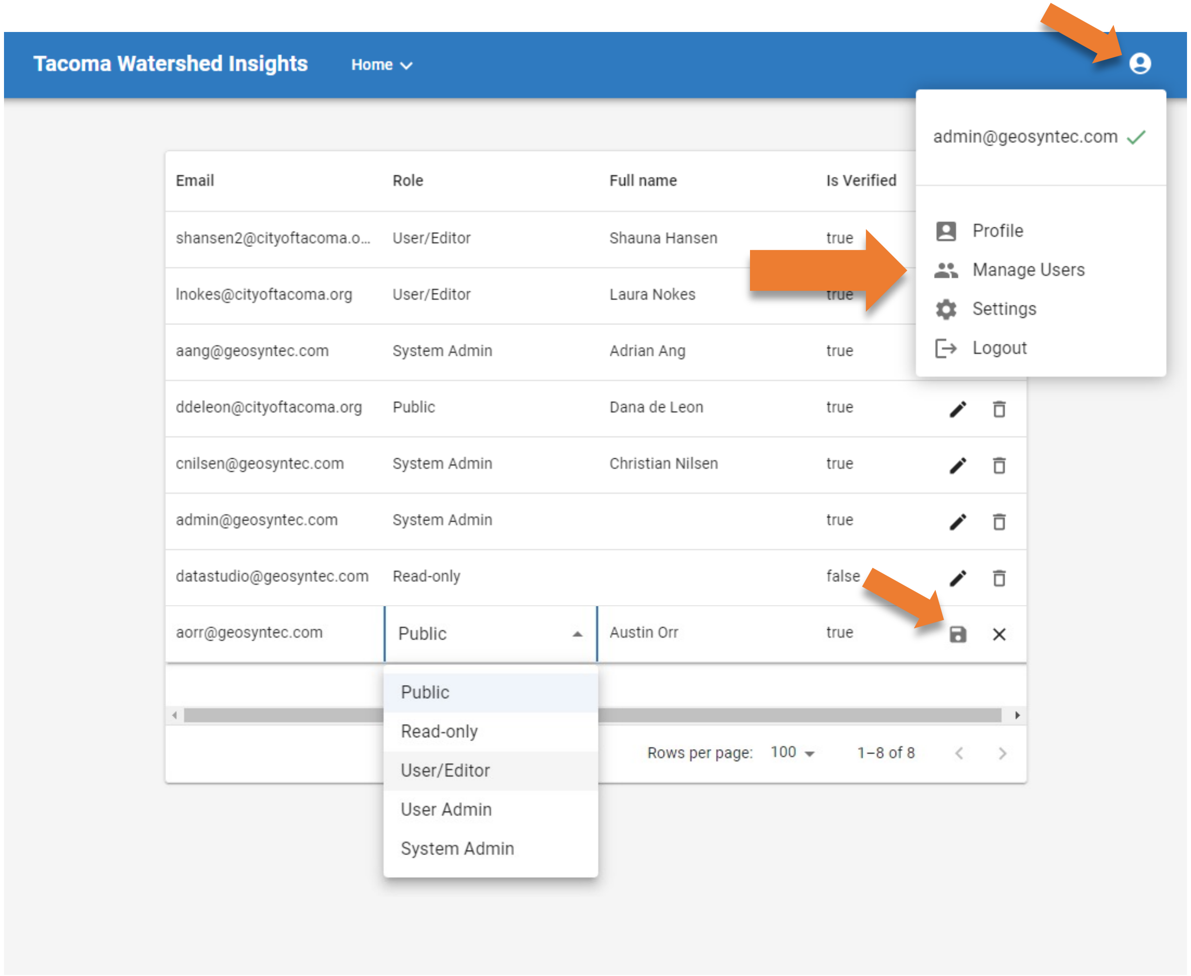
- Navigate to site
- Click Login
- Click Register
- Click Submit
- Check Email & Click through Verification



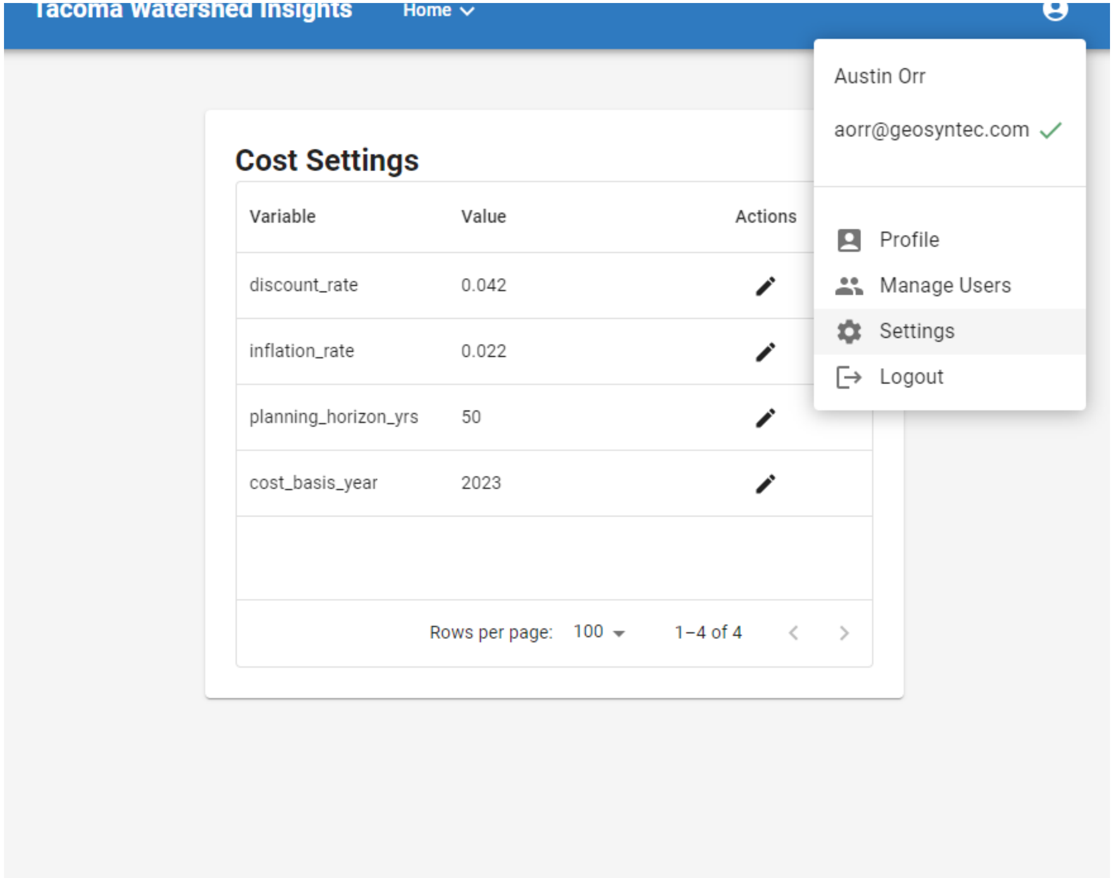
Modify User Roles

Role	Permission
Public	None
Read-only	Read access to data via site and via token
User/Editor	All of the above + access to scenarios and editing data
User Admin	All of the above + access to user manager + access to application settings
System Admin	All of the above + direct api access

- Ask a User Admin to change your role
- Click on Profile
- Click Manage Users
- Click the pen to edit
- Select Role
- Save or cancel



Cost Module Settings

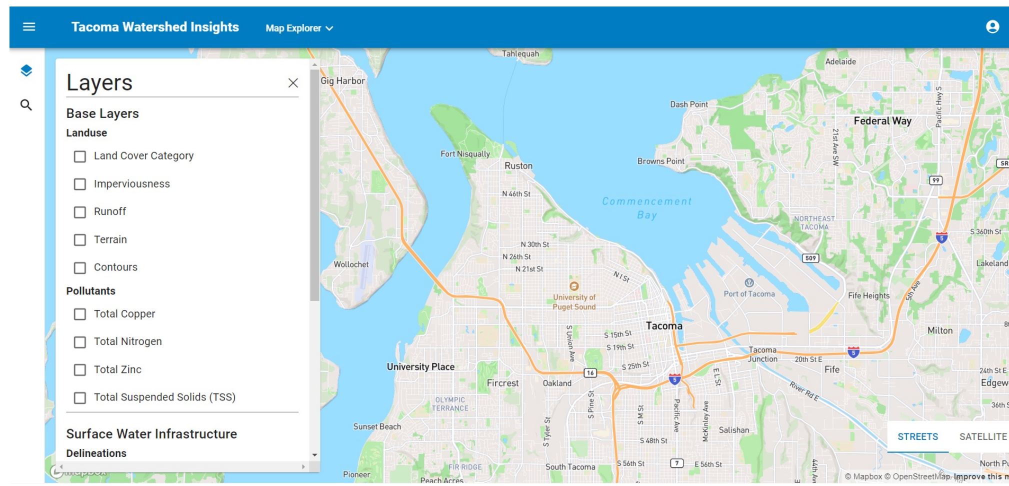


Modify Global Settings

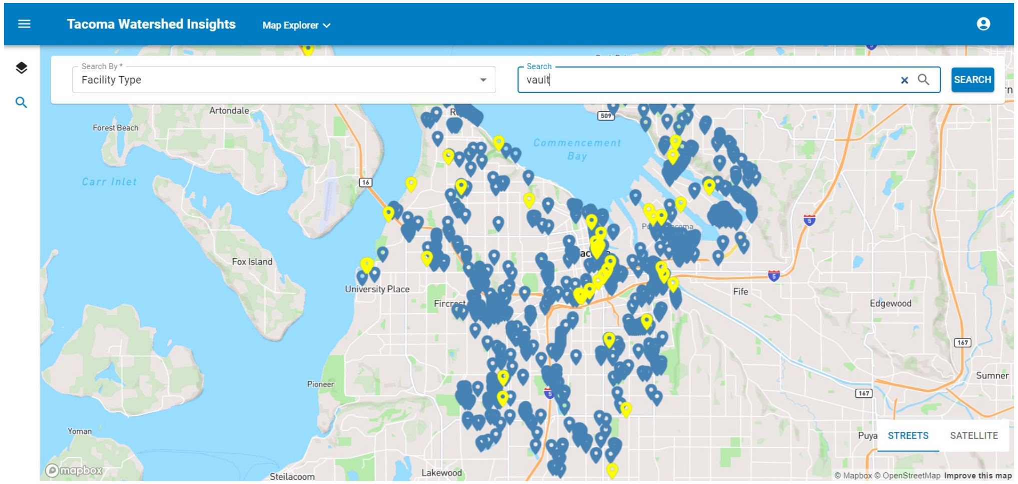
Map Explorer

Visualize Existing Infrastructure and Conditions

- Available Layers:
  - Pollutant heat maps
  - Landuse/Terrain
  - Stormwater subbasins
  - Stormwater BMPs
  - Stormwater pipes

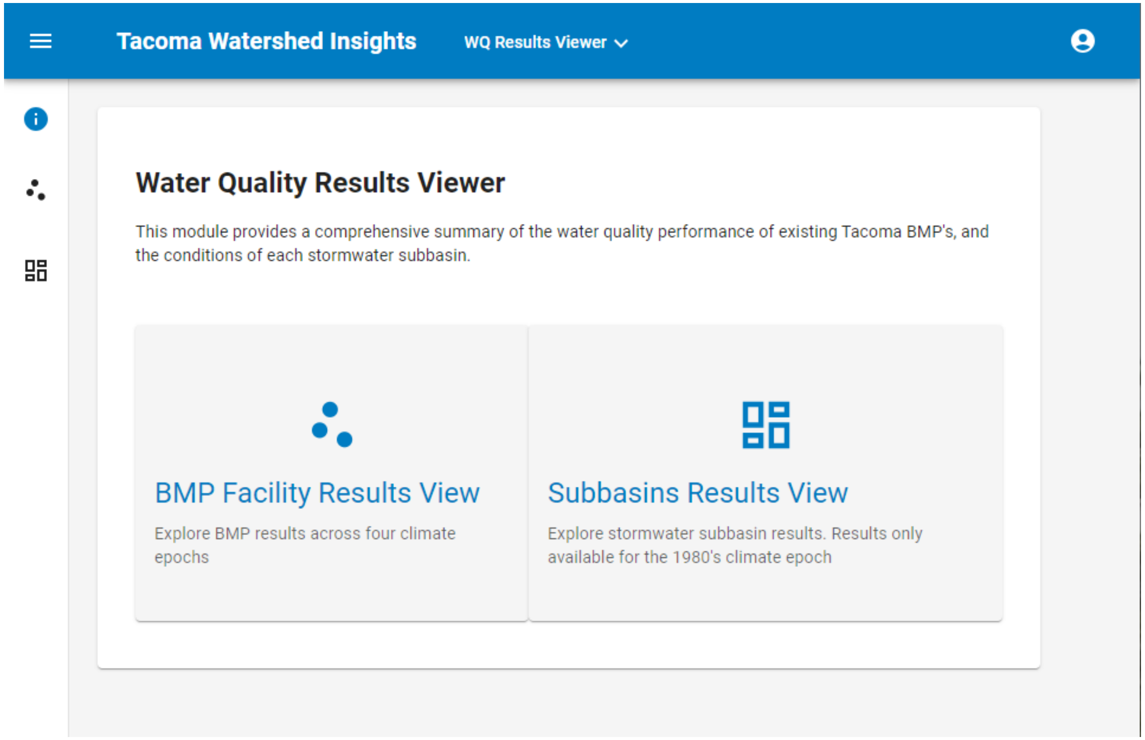


Search by Facility Type



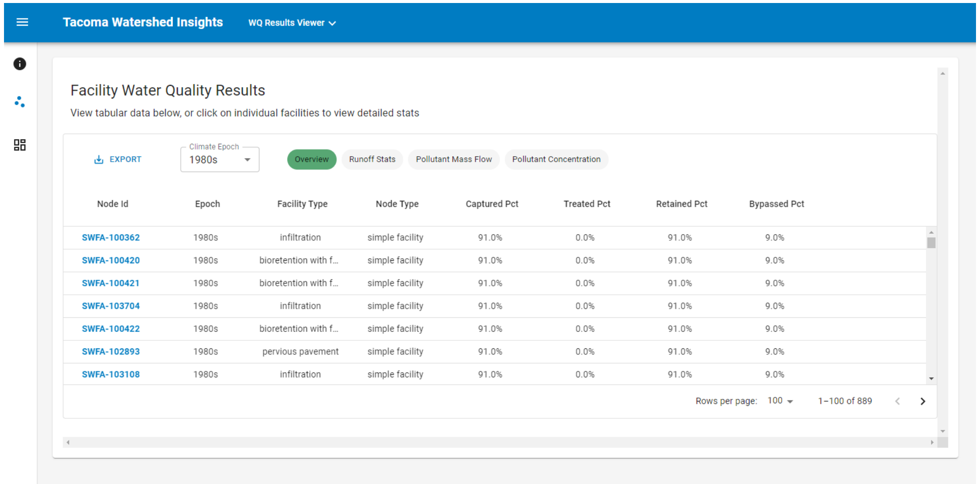
Results Reviewer

Explore WQ Performance at Facilities and Subbasins

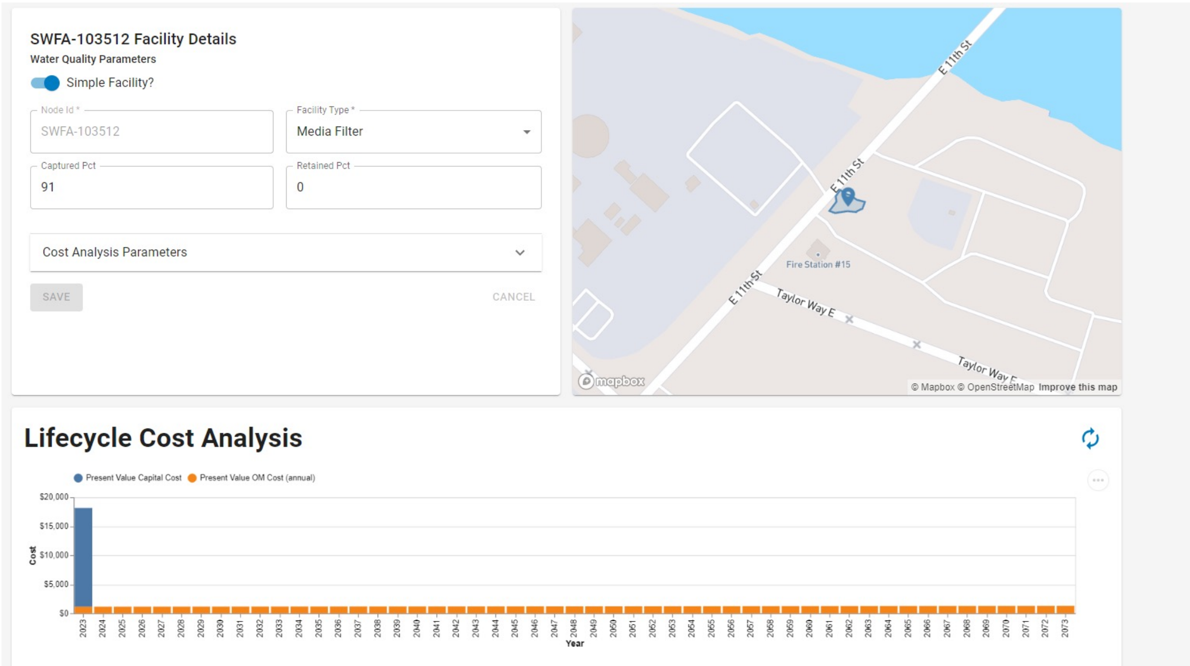


Explore BMP Attributes

- Link to individual facility details
- View stats by climate epoch and type

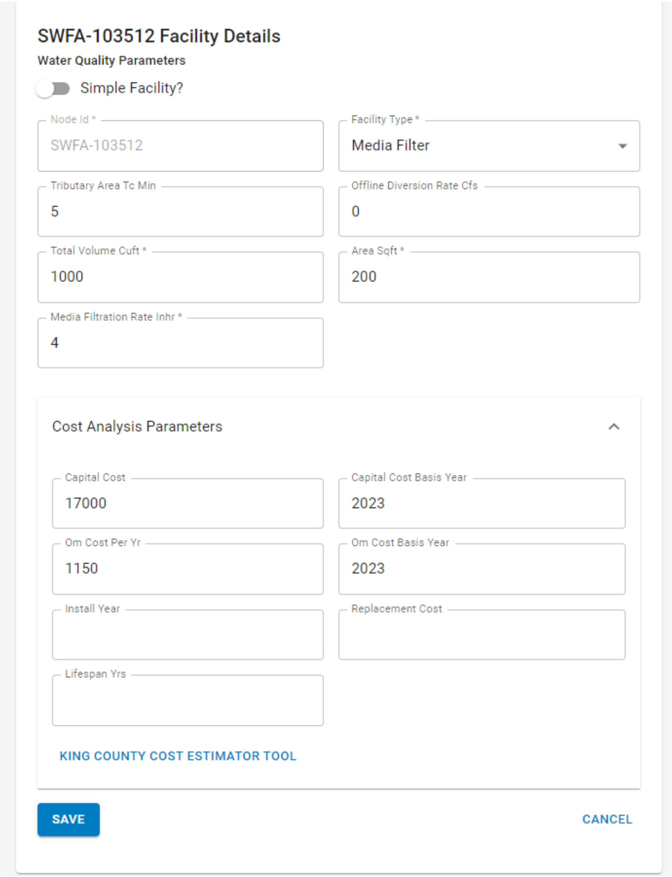


Drill down to individual BMPs



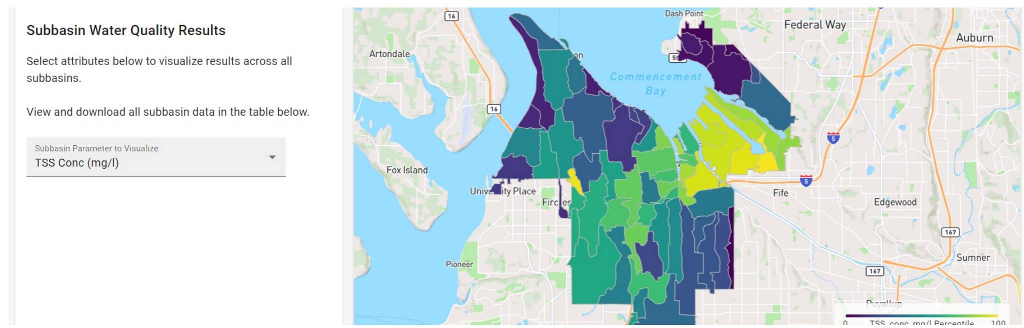
Create BMPs with Detailed Performance and Cost Attributes

- Toggle between ‘simple’ facilities driven by percentage based capture and treatment stats to ones based on physical attributes
- Add cost data that allows for capital and O&M costs to be amortized over the lifespan of the facility



Visualize Subbasin Attributes

- Available Parameters:
- -Land Use/Cover
- -Runoff
- -Treatment Facility Summary
- -Pollutant Concentrations/Reductions



Visualize Subbasin Attributes

- View and download tabular results

EXPORT | Land Use Breakdown | Land Cover Breakdown | Runoff | Treatment Facility Summary | Average Pollutant Washoff Concentration | Annual Load Reductions

Basinname	Subbasin	DEHP Conc (mg/l)	PHE Conc (mg/l)	PYR Conc (mg/l)	TCu Conc (mg/l)	TN Conc (mg/l)	TP Conc (mg/l)	TSS Conc (mg/l)
FLETT CREEK	FL_07	0.000476	0.00000583	0.00000886	0.0121	1.28	0.161	16.8
FLETT CREEK	FL_08	0.00041	0.00000502	0.00000763	0.0114	1.37	0.147	14.5
FLETT CREEK	FL_09	0.00038	0.00000466	0.00000708	0.012	1.05	0.0832	13.4
FLETT CREEK	FL_10	0.000445	0.00000545	0.00000829	0.0117	1.37	0.177	15.7
FOSS WATERWAY	FS_01	0.000445	0.00000545	0.00000829	0.015	1.18	0.137	15.7
FOSS WATERWAY	FS_02	0.000486	0.00000595	0.00000905	0.0136	1.42	0.233	17.1

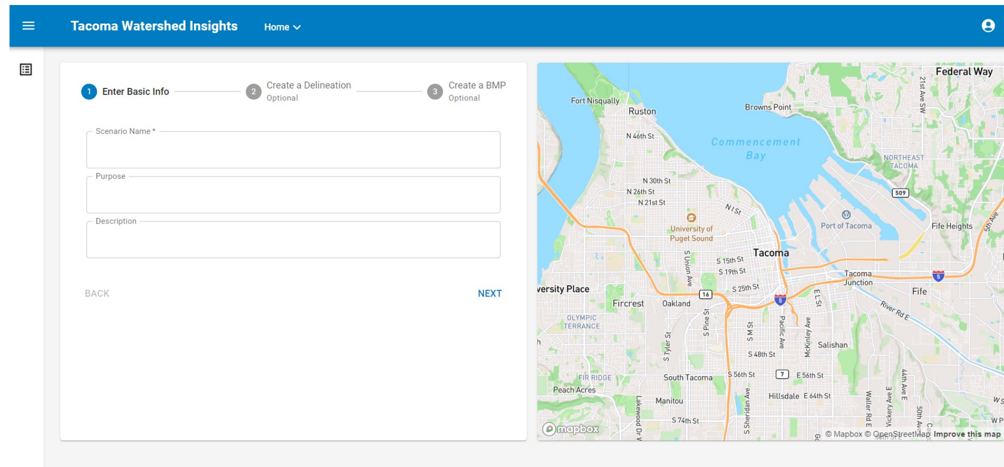
Rows per page: 100 1–67 of 67

Scenario Builder

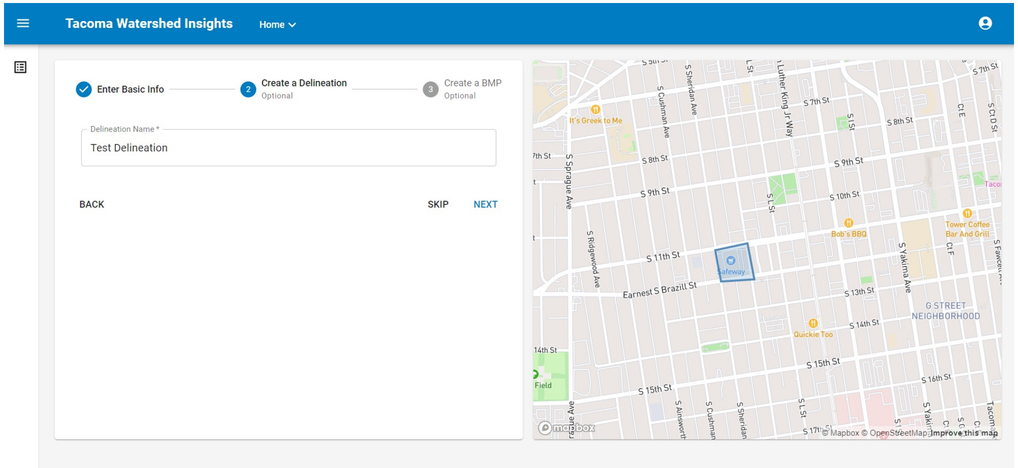
Purpose and Process

- Allows users to model a proposed single BMP facility with an upstream delineation
- Scenarios can be designed incrementally (facility/delineation can be added after creation)
- WQ results can be generated after scenario creation and future edits

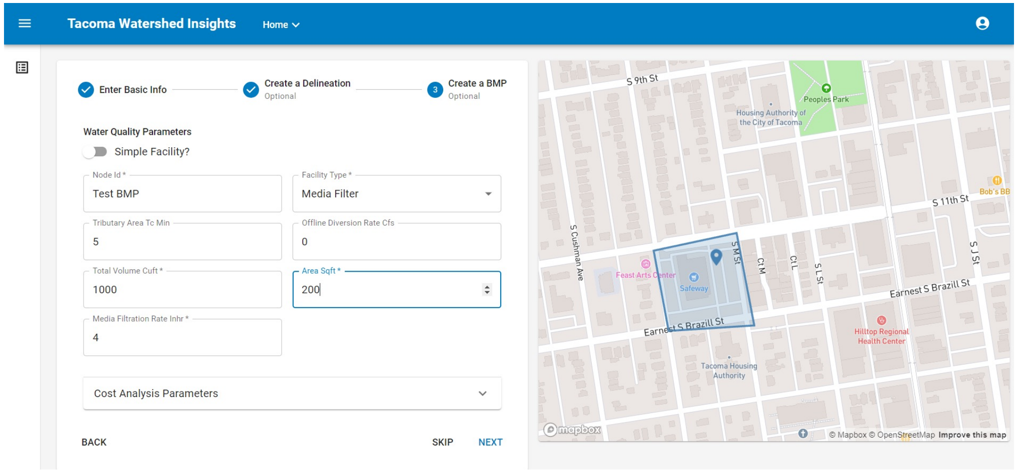
Scenario Design Process



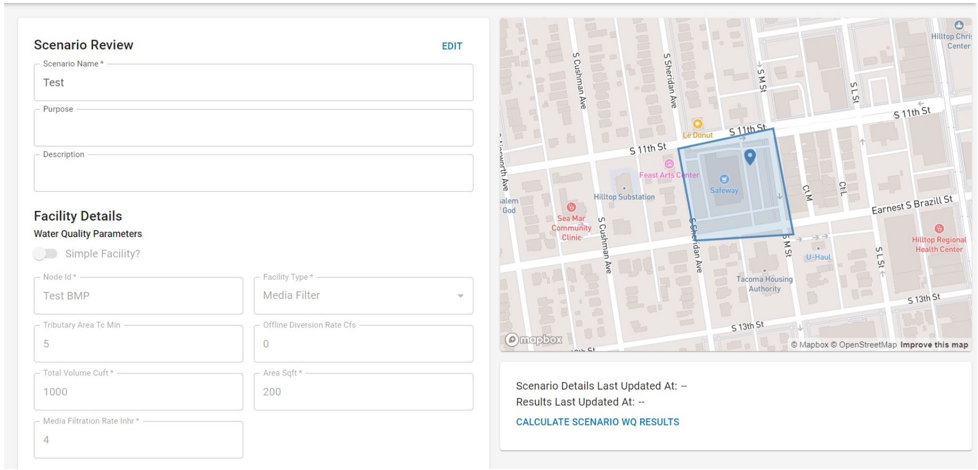
Scenario Design Process



Scenario Design Process



Scenario Design Process



Make edits and calculate results

Purpose and Process

Allows users to prioritize subbasins for stormwater improvements based on a number of goals and subgoals:

- Clean Water Goal
- Resilient Community Goal
- Healthy Ecosystem Goal
- Equity Goal

Subbasins are ranked using a pairwise algorithm - visual/tabular results are produced

Criteria and subbasin ranks can be downloaded for future use

About Subbasin Prioritization

Use this tool to identify regions of the City of Tacoma Watershed that are most in need of stormwater retrofit or preservation projects

Set a project type

Are you prioritizing preservation projects or retrofit projects?

Retrofit

Set Priority Weights

Goal 1: Improve water quality outcomes (Clean Water Goal)

1.1: Prioritize areas based on pollutant concentrations

1

1.2: Improve infrastructure in areas with inadequate stormwater management

0

Goal 2: Increase resilience to climate change impacts (Resilient Community Goal)

2.1: Target areas most vulnerable to and at risk for climate change impacts

0

Goal 3: Preserve and restore critical and sensitive habitat (Healthy Ecosystems)

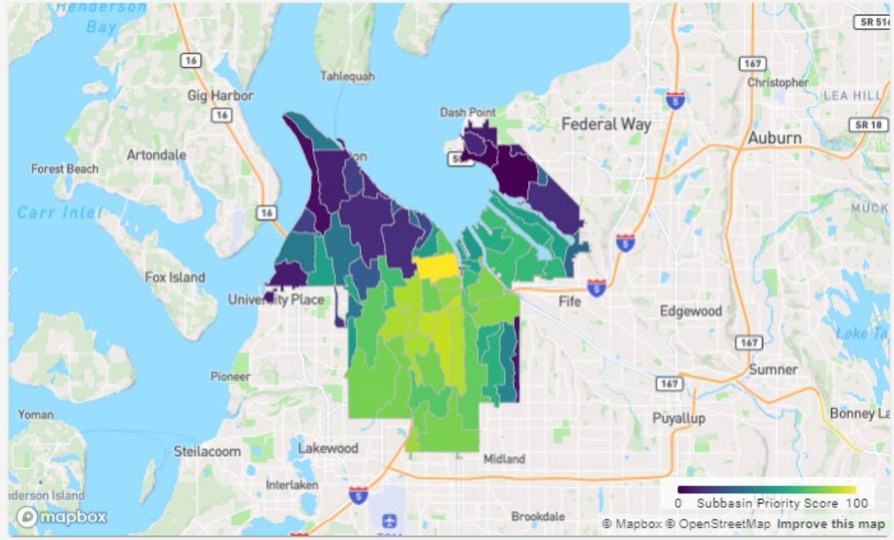
3.1 Preserve and improve Natural Spaces

0

Goal 4: Implement Equity and Social Justice (Healthy neighborhoods; Equity)

4.1: Prioritize areas of overlapping equity needs as identified by other Tacoma programs

2



Subbasin Prioritization Results

Higher priority scores indicate subbasins more favorable for new projects

To view the specific subbasin attributes that determine scores, export the results below

EXPORT

Subbasin ID	Priority Score ↓
FS_05	100
FS_09	91.153
FS_08	90.349
FS_10	88.204
FS_02	87.668
FS_03	87.668
FL_05	86.863

After submitting priorities, subbasins are scored, and results can be visualized and downloaded

Tacoma GIS (refreshed each morning)

- BMP Facilities
- BMP Facility Delineations
- Subbasins (and static subbasin metrics forthcoming)

TNC in Washington Stormwater Heatmap

- POC concentration
- runoff depth (4 climate epochs)

Changeable data

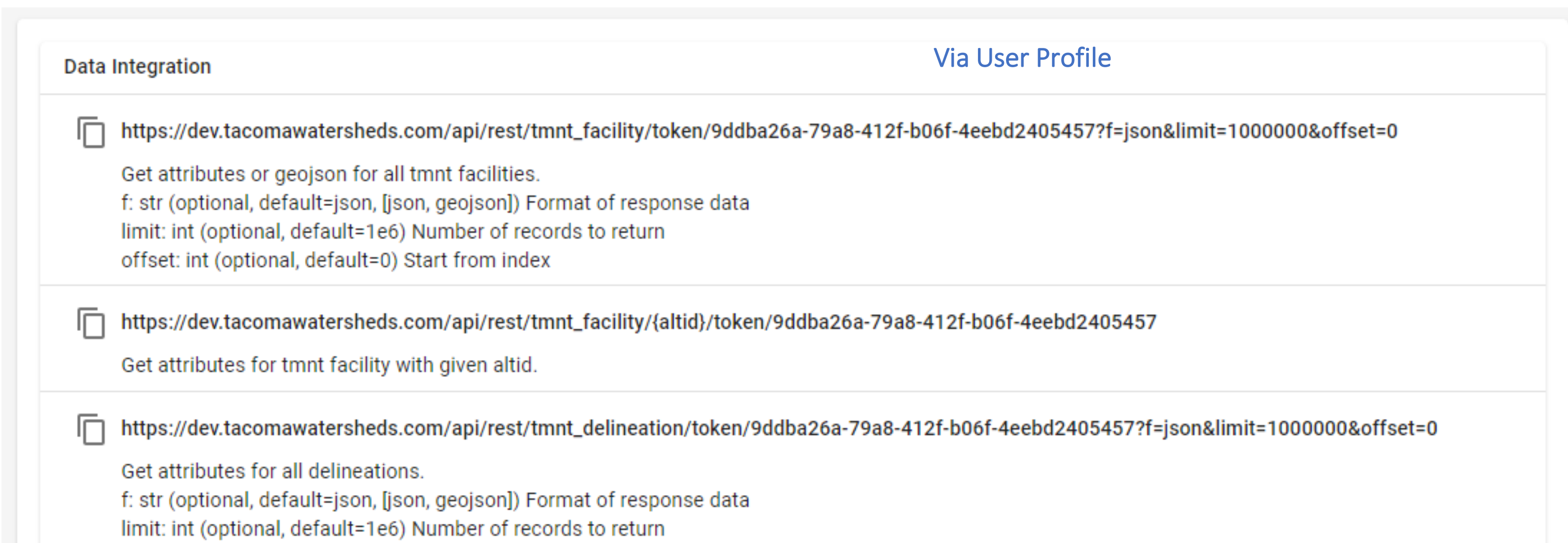
- BMP Facility modeling attributes (e.g. % capture performance, size)
- BMP Facility cost attributes (e.g., capital cost)
- Scenarios
    - Delineations, facility attributes
- Users & Permissions
- Cost Settings (e.g,. Inflation rate)

Calculated data

- BMP Facility volume and load reductions
- BMP Facility cost metrics
- Delineation and Subbasin loading
- Upstream and Downstream source control measures (sweeping and drain line cleaning for Foss Watershed)
- Scenarios
  - Delineations, BMP Facility WQ, BMP Facility Cost

Access via api with token

- TMNT Facilities: https://dev.tacomawatersheds.com/api/rest/tmnt_facility/token/<token>?f=geojson



Data Integration GIS