



ScenCompare with Benefits Module

WMOST Climate Scenario Viewer and Comparison Post Processor

Version 2

ScenCompare with Benefits Module WMOST Climate Scenario Viewer and Comparison Post Processor

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by

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Abstract

An updated version of the Scenario Comparison Tool (ScenCompare) has been developed that incorporates a Benefits Module for EPA's Watershed Management Optimization Support Tool (WMOST). WMOST was developed by the United States Environmental Protection Agency (US EPA) to facilitate integrated water resources management. ScenCompare allows comparison and evaluation of any set of WMOST results to understand the effects of varying climate, land use, and other model inputs on the set of management actions selected by WMOST to meet the specified management goal at the lowest cost. The new Benefits Module for WMOST embedded within ScenCompare v.2 enables stakeholders to calculate the value of additional water quality benefits associated with water resource management as well as additional co-benefits. Water quality benefits (or costs) include both changes in costs of drinking water treatment and total nonmarket benefits (i.e., use and nonuse) of water quality changes. Co-benefits valued include (1) change in housing property value due to improved aesthetic quality of the landscape from increases in green space, (2) air pollution removal and energy savings benefits related to canopy cover, and (3) air pollution removal and energy savings benefits related to green roofs.

Introduction

ScenCompare is a MS-Excel application designed to view and compare scenario results from the Watershed Management Optimization Support Tool (WMOST) v3.01 (Detenbeck et al. 2018 a,b,c). This version of ScenCompare is compatible with MS-Excel (Windows versions 2010, 2013 and 2016) and WMOST v3.01. The tool is specifically intended to allow comparison of WMOST results for different climate scenarios, but ScenCompare more generally allows comparison and evaluation of any set of WMOST results to understand the effects of varying climate, land use, and other model inputs on the set of management actions selected by WMOST to meet the specified management goal at the lowest cost. For example, ScenCompare can assist users interested in applying WMOST as part of Robust Decision Making (RDM) approaches for identifying vulnerabilities, and managing goals and risks, in the face of uncertain future conditions. Under RDM-type approaches, the outcome of a prescribed management strategy, such as a Watershed Implementation Plan (WIP) to meet Total Maximum Daily Load (TMDL) requirements, can be tested against multiple scenarios of future changes in temperature and rainfall and then analyzed within ScenCompare to determine under what conditions the strategy might be expected to fail to meet performance requirements. Robust management solutions are those most effective across a wide range of future conditions (Lempert and Collins 2007). Further, ScenCompare provides WMOST users access to all outputs generated by a WMOST run, thereby expanding on the set of standard outputs visible in the WMOST v3 interface.

These instructions focus on the process for loading WMOST results into ScenCompare, generating summary tables comparing decision variables, and generating time series plots of user-selected variables across scenarios. The results module in WMOST generates a results.csv file during processing of the optimization output text file produced by the optimization program, Bonmin, which is run on NEOS, an online server for optimization programs (<https://neos-server.org/neos/>).

ScenCompare users should already be familiar with WMOST model outputs being processed. Please refer to the WMOST documentation for details on variables and modeled components included in WMOST output files and available for processing with ScenCompare (Detenbeck et al. 2018 b,c). WMOST variables are described in detail in the Appendix C to the theoretical documentation report (Detenbeck et al. 2018c).

1 Workbook Organization

ScenCompare is an Excel workbook that uses customized Visual Basic for Applications (VBA) code to automate key tasks. The initial blank workbook includes:

- Introduction tab: Describes the purpose of ScenCompare and allows the user to navigate to the Controls, Variable Definitions and Loaded Scenarios tabs (the user can also navigate to the tabs by clicking on them at the bottom of the screen).
- Controls tab: Provides access to steps in compiling and analyzing WMOST data.

- Variable Definitions tab: Provides a description of the WMOST variables in the output data.
- Loaded Scenarios tab: Provides the inventory of output files imported by the user
- Model Results tab: Provides the WMOST model results output for each loaded file
- Model Input Data tab: Provides the model input data for each loaded scenario
- Benefits tab: Calculates benefits related to outcomes targeted by a management practice (direct benefits) and benefits that arise from other outcomes of implementing the management practice selected to meet the target (co-benefits). The Benefits Module evaluates benefits and co-benefits for a set of management options from a single optimization scenario. In order to calculate benefits, you will need to load at least one scenario using the Controls tab (Section 2.1) and access the Benefits tab on the Loaded Scenarios tab.

Figure 1: ScenCompare Data Flow

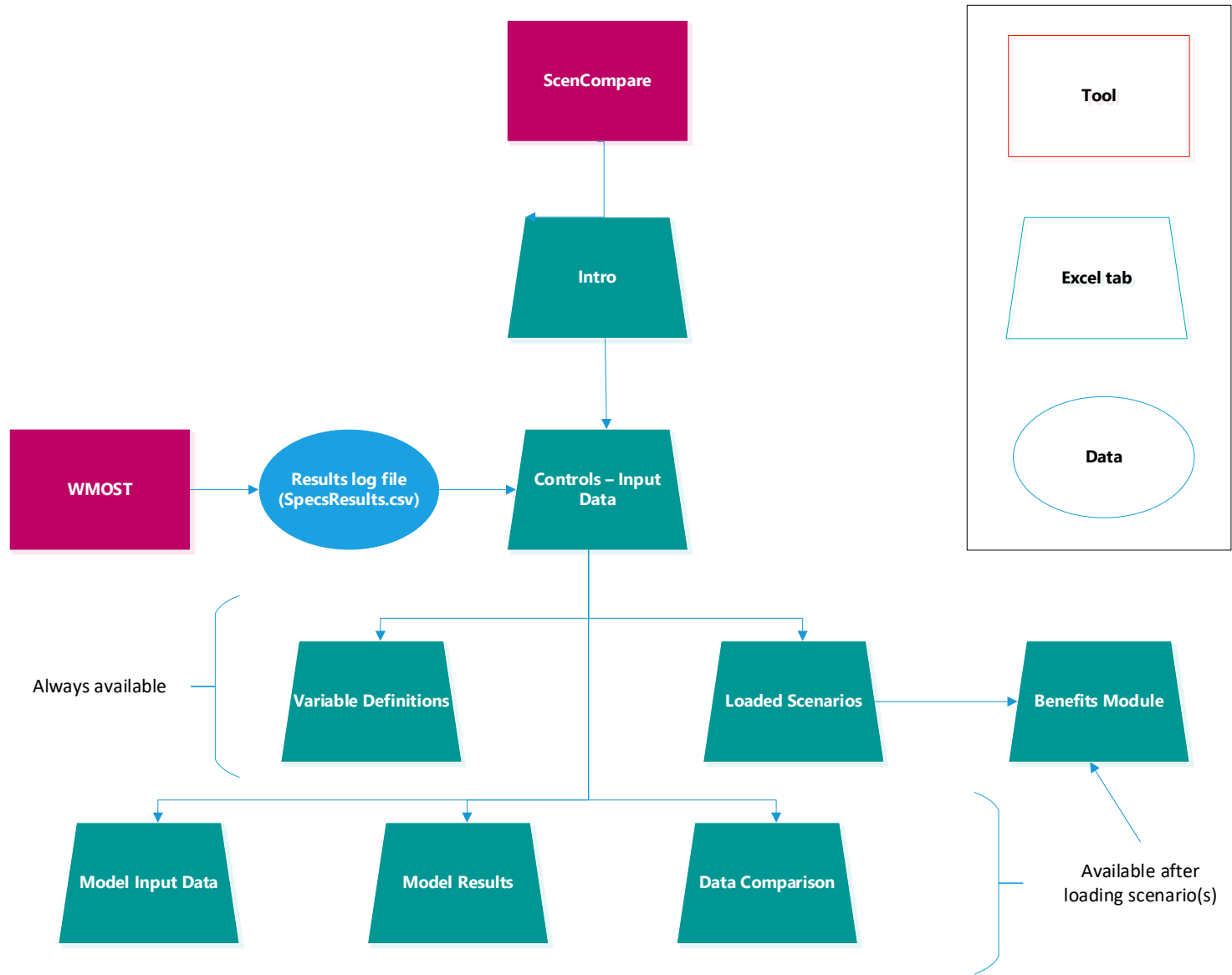


Figure 1 summarizes the data flow from WMOST through ScenCompare, including data flow between tabs.

Section 2 describes the steps involved in compiling and analyzing WMOST data. Note that you can also use all standard Excel functions and capabilities from within ScenCompare to customize graphics or tables, perform calculations, etc.

2 Controls

2.1 Load WMOST Scenario Data

To load WMOST Scenario Input Data and Results into ScenCompare, click on the leftmost button on the Controls tab labeled “Load WMOST Scenario Data”. When prompted, select the model *Specifications and Results* file. Note that the *Specifications and Results* file is a log .csv file generated by WMOST during a model run and saved to the same file folder that contains the WMOST model. The log file contains the model inputs and results for the run. To facilitate comparisons, you may wish to copy the appropriate set of log files to the same directory housing ScenCompare or to a separate subdirectory.

ScenCompare adds the WMOST scenario outputs to the Model Results tab, the WMOST input data to the Model Input Data tab, and the name of the file and other model details to the Loaded Scenarios tab. Repeat these steps to load the data for other WMOST model runs as many times as needed to import the desired data. There is no set limit on the number of scenarios that can be loaded; however, you may experience a slowdown in performance if an excessive number is loaded. Note that you may add results to ScenCompare at any time.

ScenCompare verifies that any data file loaded after the first data file has the same number of land uses, land use sets, water users and time steps. Differences in these variables lead to mismatches in the variable order and incorrect comparisons of data. If a difference is found, ScenCompare gives the option to keep or discard the data that was just loaded. It is recommended that you discard the data and rerun the model with an appropriate setup, if the comparison is still desired.

ScenCompare automatically fills in the average annual precipitation and temperature if you used the hydrology module when developing the WMOST scenarios or used the Hydro-Climate Automation module (HCAM). If you developed the data manually, you can enter precipitation and temperature statistics on the Loaded Scenarios tab. ScenCompare uses this information for some of the graphs (see Section 2.3).

Note that you may also remove scenarios from the Loaded Scenarios tab by selecting the row(s) on this tab and clicking the button on the right side of the tab labeled “Clear Selected Scenarios”.¹ See **Figure 2** below for an example of how to select and delete data for a scenario. To delete Scenario 2, you would

¹ Note that if you have created comparison tables and graphs in Steps 2 and 3 on the Controls tab (see Sections 2.2 and 2.3 for details) and later delete a scenario, you will need to regenerate the data tables and time series to ensure that the tables reflect only the remaining scenarios.

select the row that contains Scenario 2 or the “Data Name” for the second scenario listed, and then click the “Clear Selected Scenarios” button.

Figure 2: Example of selection of scenario for deletion

1	Loaded Files:	Data Name:	Scenario Name	StudyA	Scenario	RunSta	RunEnd	StartDa	EndDat	ModelMode:	
2	H:\ERD\ANCHOR\Assignr	Monponsett_AdjB_ASASR	Monpon AdjB_AS	#####	#####	#####	#####	#####	#####	Hydrology Only	Select row to clear scenario data.
3	H:\ERD\ANCHOR\Assignr	Monponsett_AdjB_wlIBT_100K	Monpon AdjB_wl	#####	#####	#####	#####	#####	#####	Hydrology Only	
4	H:\ERD\ANCHOR\Assignr	Monponsett_AdjB_wlIBT_500K	Monpon AdjB_wl	#####	#####	#####	#####	#####	#####	Hydrology Only	
5	H:\ERD\ANCHOR\Assignr	Monponsett_NoBrockNoBrockton	Monpon NoBrock	#####	#####	#####	#####	#####	#####	Hydrology Only	
6											
7											
8											

Clear Selected Scenarios

TIP: Note that the Model Results and Model Input Data tabs provide the detailed WMOST outputs and inputs, respectively, for each scenario. Because many of the model variables are time series, the data set is extensive (thousands of values). You can use standard Excel filter tools (accessible through the Data menu) to hide/show a subset of variables you are interested in. You can also use standard equations in Excel to quickly identify variables that take on different values across the scenarios. For convenience, ScenCompare provides a pre-calculated column that determines whether differences exist between scenarios.

TIP: You can use the “Data Difference” column on the Model Results and Model Input Data tabs to filter for variables that assume the same or different numerical values across the scenarios, with Data Difference flags of 0 and 1, respectively.

2.2 Compare Decision Variables Across Scenarios

ScenCompare can be used to compare decision variables across scenarios. These are variables representing the least-cost combination of best management practices (BMPs) to meet the management objective (e.g., streamflow minimum threshold). For example, for stormwater BMPs, these are generally expressed as the acres of a given Hydrologic Response Unit (HRU) assigned to treatment by a specific BMP such as a rain garden. See the WMOST theoretical documentation and user guides for more details (Detenbeck et al. 2018 b,c).

To compare all decision variables across scenarios, click on the button on the Controls tab labeled “Compare Scenario Decisions”. This action will create a new tab called Table Comparison containing the values of decision variables from all model runs loaded into ScenCompare. Note that the second column (“Description”) describes each variable and the third column (“Units”) specifies the unit of measure for each variable.

The rightmost column in the sheet (“Data Difference”) contains a flag identifying whether there are differences in variable values across any of the scenarios. A Data Difference value of 1 indicates that at least one of the scenarios differs from the others for that variable.

Figure 3: Example of filter selecting variables that take different values among three scenarios. In this example, the scenarios show differences in total operating costs, management approaches selected (e.g., stormwater BMPs and ASR) and level of implementation, and associated costs.

	A	B	C	D	E	F	G
	Variable	Description	Units	wASR	No Brockton	wIBT	Data Difference
1	objective	Objective cost	\$	18186396.09	466450.5466	1635461.187	1
35	DALu33	Land Area - 0.6" Infiltrat	ac	468.9155099	0	0	1
36	DALu43	Land Area - 0.6" Infiltrat	ac	188.44859	0	0	1
37	DALu53	Land Area - 0.6" Infiltrat	ac	56.29038155	0	52.40900839	1
43	DALu113	Land Area - 0.6" Infiltrat	ac	2.463176949	0	0	1
66	DALu45	Land Area - 1" Infiltratio	ac	133.4065532	0	0	1
67	DALu55	Land Area - 1" Infiltratio	ac	4.51856203	0	0	1
73	DALu115	Land Area - 1" Infiltratio	ac	-3.26569E-16	0	0	1
111	DQAsrAddl	Additional ASR capacity	MGD	186.1776694	0	0	1
125	CluSet3	0.6" Infiltration trench -	\$/yr	160377.4126	0	62698.78515	1
127	CluSet5	1" Infiltration trench - L	\$/yr	70982.79257	0	0	1
135	CWtp	Total cost of potable wa	\$/yr	466450.5466	466450.5466	283139.1895	1
146	CCAsr	Capital cost of aquifer st	\$/yr	16315025.63	0	0	1
147	CAsr	Total cost of aquifer sto	\$/yr	17488585.34	0	0	1
150	CibtW	Total cost of potable int	\$/yr	0	0	183311.3571	1
154	CWMMake	Penalty for water defici	\$/yr	0	0	1106311.856	1
156							

TIP: You can use standard Excel filter tools (accessible through the Data menu) to hide/show a subset of variables you are interested in, or to show only the variables that have Data Difference of 1.

2.3 Compare Overall Costs across Scenarios

Clicking on the “Make Climate Graphs” on the Table Comparison tab (see Section 2.2) creates a new tab called ClimateGraph objective. This tab contains three climate plots:

- 1) a scatterplot that charts the objective cost versus average annual precipitation,
- 2) a scatterplot that charts the objective cost versus average annual temperature, and
- 3) a bubble plot that charts the objective costs versus total annual precipitation and average annual temperature. The area of each bubble is scaled according to the total cost, with the maximum size determined by the maximum cost in the data set

The “objective” value is the total annualized cost of all watershed management actions taken to meet the specified objective (i.e., meeting water demand subject to physical constraints and water quantity and/or quality targets).

As discussed in Section 2.1, if you did not use the hydrology module in WMOST, the model Specifications and Results file does not automatically include statistics for average annual precipitation and average annual temperature. This means that ScenCompare cannot automatically extract the information needed to create the climate graphs. To rectify this issue, you can enter the precipitation and

temperature statistics for each scenario on the [Loaded Scenarios](#) tab before creating the tables and ScenCompare will use those values to create the climate graphs.

2.4 Compare Time Series Variables Across Scenarios

ScenCompare can also be used to compare time series variables such as discharge (Q variables), concentration (X variables), or loads (L variables) across scenarios. These are variables representing time-dependent flows or stocks in the modeled watershed components, listed on the [Controls](#) tab.

To compare time series variables across scenarios, place the cursor in the cell containing the first variable of interest in the list under Step 3 on the [Controls](#) tab, and click on the button labeled “Create Tables and Graphs for Selected Variables”² to the right of the data columns. This action creates a new tab called [Table nn](#) where *nn* is the name of the selected variable. This new tab provides summary statistics for the selected variables for each scenario in ScenCompare (e.g., minimum, maximum, average, and number of observations greater than 0 [as the default threshold]) along with values for each time step.

This action also creates three plots on the time series variable tab:

- 1) a time series plot of the variable over the time period,
- 2) a histogram of the count of time steps (e.g., number of days if WMOST was run using a daily time step) for which the variable takes a value greater than the “Count Threshold” for each scenario, and
- 3) a box-and-whisker plot that shows the minimum, 1st quartile, median, 3rd quartile, and maximum for each scenario.

You can use the button on the right, “Make Climate Graphs”, to create a new tab called [ClimateGraph nn](#) that contains three climate graphs that compare the *average* value over the entire time series across the scenarios. Refer to Section 2.3 for more details on the climate graphs and how they are created.

TIP: You can change the “Count Threshold” from its default value of 0 to any number, and the tab adjusts the count statistics and histogram to reflect the new threshold.

TIP: You can use standard Excel tools to add or modify the formatting of the basic plot generated automatically by ScenCompare.

2.5 Compare Land Management Variables Across Scenarios

ScenCompare can also be used to compare least-cost land management solutions. The variables are described in the second column on the [Table Comparison](#) tab and in the [Variable Definitions](#) tab based on the management option and the HRU. For example, Land Area - 0.6” Infiltration trench, “Medium to low density residential, Sand and Gravel” contains the acres of medium to low density residential land

² Note that you may select multiple variables to be processed at the same time by holding the control key and clicking on all desired variable names before clicking on the button.

on sand and gravel (the HRU represented by the combination of land use and soil type) for which WMOST decided to implement a 0.6" infiltration trench.

Each of the land use management options (HRU sets) has an associated cost variable that contains the cost associated with the decision. The variables are named CLuSet#, where # is the number of the HRU Set. Details on BMP performance and cost calculations are in the WMOST documentation (Detenbeck et al. 2018 b,c).

To compare land use allocation variables, look at each land use management set individually. By convention, the first land use management set represents land conservation decisions. All other sets are related to stormwater management decisions.

- **Land Conservation:** One of the management options available in WMOST is the decision to conserve undeveloped land. The decision essentially reallocates baseline land use to undeveloped land uses, keeping the total land area the same. The final land area allocation is reported through the first set of DALu variables (all DALu variables for HRU set 1). To determine whether land area was conserved, you can first look at the CLUSet1 variable to see if it is greater than \$0 for any of the scenarios, which would indicate that WMOST incurred costs to conserve land.³ To determine how much land area was conserved, look at the DALu variables and compare values to the baseline acres you had specified in your WMOST run.⁴ The resulting difference is the change due to land conservation. A positive difference means more land was conserved, and a negative difference means the land was converted to undeveloped areas or conserved.⁵
- **Stormwater Management:** WMOST may also implement stormwater BMPs on developed HRU areas. The areas managed using stormwater BMPs are reported in the remaining DALu variable sets. The values represent the number of acres receiving the type of stormwater BMP defined by the HRU set, e.g., acres of medium to low density residential on sand and gravel managed using a 0.6" Infiltration trench. The number of acres will be a portion of the HRU area reported in the first management set described above. WMOST may select multiple stormwater BMP types for any given scenario but the total acres managed across the HRU sets cannot exceed the total area, i.e., stormwater BMPs are mutually exclusive and WMOST applies only one type of BMP to any given parcel of land.

TIP: To only view results that relate to land use management, you can use the MS-Excel filter tool to select the relevant variables: DALu## and CLuSet#. The filter should be reset to full display before applying other functions such as graphing, however. The MS-Excel sort function should not be used as it may make comparisons across columns meaningless.

³ This presumes that you specified non-zero costs to acquire land for conservation in your WMOST inputs.

⁴ Note that the baseline HRU acres are reported in the [Model Input Data](#) tab, using the variable ALuBase and HRU number.

⁵ Note that decisions to conserve land will not be flagged as a change in the Data Difference column in [Table Comparison](#) tab unless the allocations differed across scenarios.

Figure 4: Example of selected variables related to land use management decisions. The screen shows differences in the number of acres managed using 0.6” infiltration trenches for several HRUs.

Variable	Description	Unit	wASR	No Brockton	wLBT	Data Difference	
3	DALu11	Land Area - Land Area with Conservation, "Forest, Sand and Gravel"	ac	833.6582144	833.6582144	833.6582144	0
4	DALu21	Land Area - Land Area with Conservation, "Open nonresidential, Sar	ac	74.36874457	74.36874457	74.36874457	0
5	DALu31	Land Area - Land Area with Conservation, "Medium to low density re	ac	597.9906384	597.9906384	597.9906384	0
6	DALu41	Land Area - Land Area with Conservation, "High-density residential,	ac	321.8551432	321.8551432	321.8551432	0
7	DALu51	Land Area - Land Area with Conservation, "Commercial-industrial-tr	ac	60.80894358	60.80894358	60.80894358	0
8	DALu61	Land Area - Land Area with Conservation, "Agriculture, Sand and Gr	ac	10.34096625	10.34096625	10.34096625	0
9	DALu71	Land Area - Land Area with Conservation, "Forest, Till & fine-graine	ac	161.0035535	161.0035535	161.0035535	0
10	DALu81	Land Area - Land Area with Conservation, "Open nonresidential, Till	ac	1.739357974	1.739357974	1.739357974	0
11	DALu91	Land Area - Land Area with Conservation, "Medium to low density re	ac	28.63970334	28.63970334	28.63970334	0
12	DALu101	Land Area - Land Area with Conservation, "High-density residential,	ac	61.81480419	61.81480419	61.81480419	0
13	DALu111	Land Area - Land Area with Conservation, "Commercial-industrial-tr	ac	2.463176949	2.463176949	2.463176949	0
14	DALu121	Land Area - Land Area with Conservation, "Agriculture, Till & fine-gr	ac	12.6231485	12.6231485	12.6231485	0
15	DALu131	Land Area - Land Area with Conservation, "Cranberry bogs, Combin	ac	340	340	340	0
16	DALu141	Land Area - Land Area with Conservation, "Forested wetland, Comb	ac	64.2	64.2	64.2	0
17	DALu151	Land Area - Land Area with Conservation, "Nonforested wetlands, Cc	ac	47.3	47.3	47.3	0
18	DALu12	Land Area - 0.6" Bioretention with UD, "Forest, Sand and Gravel"	ac	0	0	0	0
19	DALu22	Land Area - 0.6" Bioretention with UD, "Open nonresidential, Sand	ac	0	0	0	0
20	DALu32	Land Area - 0.6" Bioretention with UD, "Medium to low density reside	ac	0	0	0	0
21	DALu42	Land Area - 0.6" Bioretention with UD, "High-density residential, San	ac	0	0	0	0
22	DALu52	Land Area - 0.6" Bioretention with UD, "Commercial-industrial-transp	ac	0	0	0	0
23	DALu62	Land Area - 0.6" Bioretention with UD, "Agriculture, Sand and Gravel	ac	0	0	0	0
24	DALu72	Land Area - 0.6" Bioretention with UD, "Forest, Till & fine-grained de	ac	0	0	0	0
25	DALu82	Land Area - 0.6" Bioretention with UD, "Open nonresidential, Till & fi	ac	0	0	0	0
26	DALu92	Land Area - 0.6" Bioretention with UD, "Medium to low density reside	ac	0	0	0	0
27	DALu102	Land Area - 0.6" Bioretention with UD, "High-density residential, Till	ac	0	0	0	0
28	DALu112	Land Area - 0.6" Bioretention with UD, "Commercial-industrial-transp	ac	0	0	0	0
29	DALu122	Land Area - 0.6" Bioretention with UD, "Agriculture, Till & fine-graine	ac	0	0	0	0
30	DALu132	Land Area - 0.6" Bioretention with UD, "Cranberry bogs, Combined"	ac	0	0	0	0
31	DALu142	Land Area - 0.6" Bioretention with UD, "Forested wetland, Combined"	ac	0	0	0	0
32	DALu152	Land Area - 0.6" Bioretention with UD, "Nonforested wetlands, Combi	ac	0	0	0	0
33	DALu13	Land Area - 0.6" Infiltration trench, "Forest, Sand and Gravel"	ac	0	0	0	0
34	DALu23	Land Area - 0.6" Infiltration trench, "Open nonresidential, Sand and l	ac	0	0	0	0
35	DALu33	Land Area - 0.6" Infiltration trench, "Medium to low density residenti	ac	468.9155099	0	0	1
36	DALu43	Land Area - 0.6" Infiltration trench, "High-density residential, Sand a	ac	188.44859	0	0	1
37	DALu53	Land Area - 0.6" Infiltration trench, "Commercial-industrial-transport	ac	56.29038155	0	52.40900839	1
38	DALu63	Land Area - 0.6" Infiltration trench, "Agriculture, Sand and Gravel"	ac	0	0	0	0
39	DALu73	Land Area - 0.6" Infiltration trench, "Forest, Till & fine-grained depos	ac	0	0	0	0
40	DALu83	Land Area - 0.6" Infiltration trench, "Open nonresidential, Till & fine-	ac	0	0	0	0
41	DALu93	Land Area - 0.6" Infiltration trench, "Medium to low density residenti	ac	0	0	0	0
42	DALu103	Land Area - 0.6" Infiltration trench, "High-density residential, Till & fi	ac	0	0	0	0

3 Benefits Module

The WMOST v3/v3.1 optimization model is currently driven by an objective function that seeks to minimize total annual costs. From the various management options input by the user, WMOST helps determine which options would achieve the specified water quantity and quality⁶ targets at the lowest

⁶ At this time, WMOST can only model one constituent at a time. For example, WMOST can optimize the least cost combination of management options related to reducing in-stream phosphorus concentrations.

total annual cost, where the total annual cost includes both annualized capital costs for initial implementation and annual operation and maintenance (O&M) costs.

While WMOST accounts for the effects of management strategies pertaining to the specified targets, some other direct and indirect or ancillary effects (benefits and co-benefits, respectively) of the management strategies are not being considered or reported within WMOST. For example, WMOST considers how land conservation may serve to reduce nitrogen loadings and help meet a nitrogen target, but it does not currently consider how this same practice may also improve overall water quality (other constituents besides nitrogen, including phosphorus and sediment - a benefit) or contribute to carbon sequestration (a co-benefit).

The sections below include instructions on how to use the Benefits Module to calculate potential economic benefits and co-benefits of WMOST-chosen management options. Section 3.1 provides an overview of the benefit and co-benefit categories included in the Benefits Module. Section 3.2 outlines step-by-step instructions for how to use the Benefits Module.

3.1 Benefits and Co-benefits Calculated by the Module

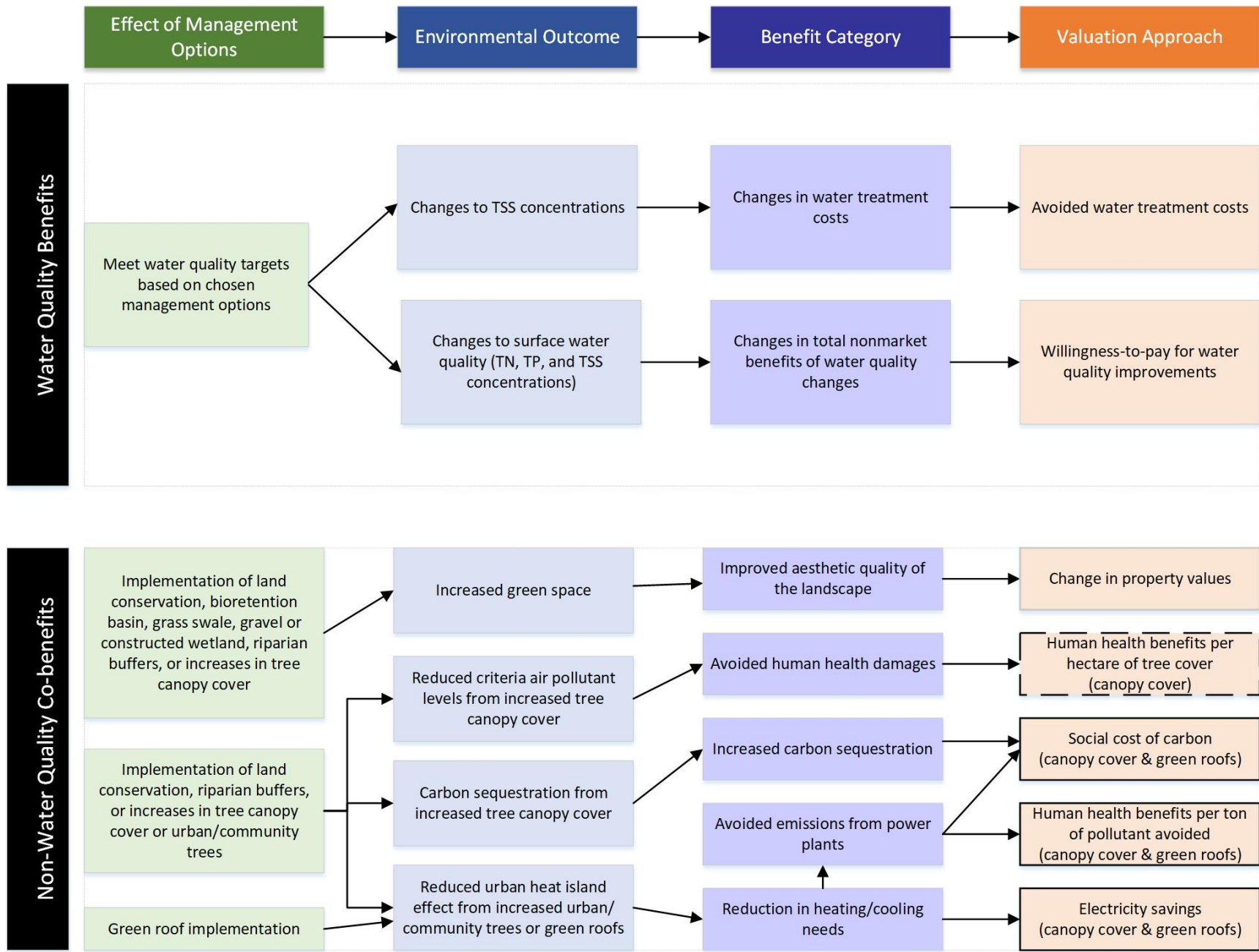
The Benefits Module calculates both benefits and co-benefits. Benefits are water-related outcomes resulting from management options to meet water quality targets. Within the context of WMOST, all benefits within the module are based on water quality changes.⁷ Co-benefits arise from the implementation of the practice(s) selected to meet the target. Within WMOST, all co-benefits are ancillary effects of management options that are not derived from water quality.

Section 3.1.1 describes the two benefit categories available in the Benefits Module. Section 3.1.2 describes the three co-benefit categories available in the Benefits Module. **Figure 5** diagrams the benefits valued within the Benefits Module and the valuation methodology. You will have the option to tailor the categories of benefits and co-benefits that are calculated by the module.

The Benefits Module evaluates benefits and co-benefits for a set of management options from a single optimization scenario. Calculations for certain benefits will require importing data for both baseline conditions and conditions under the set of management options. It is recommended that you evaluate the same watershed and set of management options throughout the module sections in order to accurately evaluate and compare benefits and co-benefits.

⁷ Although none of the Benefits Module benefit or co-benefit categories monetize water quantity changes, WMOST does assess water quantity changes. Comparison of WMOST results on WMOST's Results tab or ScenCompare's Model Results tab can highlight ancillary benefits of achieving water quantity targets. For example, since WMOST allows users to impose limits associated with flood damages, users can compare scenario results to determine the avoided costs associated with flood risk reduction.

Figure 5: Benefit and co-benefit categories and valuation methodologies included in the Benefits Module.



3.1.1 Water Quality Benefits

Water quality benefits are water-related outcomes resulting from management options to meet water quality targets. The Benefits Module includes two benefit categories: (1) change in water treatment costs, and (2) total nonmarket benefits (i.e., use and nonuse) of water quality changes.

Change in water treatment costs: The water treatment cost benefit is based on changes in total suspended solids (TSS) concentrations. Changes in TSS concentrations translate to changes in the amount of chemical coagulant required to reduce turbidity at water treatment plants. The methodology used within the module to calculate the change in water treatment costs is described in detail in the 2009 Environmental Impact and Benefits Assessment for Final Effluent Guidelines and Standards for the Construction and Development Category (U.S. EPA, 2009).

Total nonmarket benefits of water quality changes: Total nonmarket benefits of water quality changes are based on the changes in ecosystem services provided by surface water that are valued by humans, including water-based recreation (e.g., swimming, fishing, wildlife viewing, boating/kayaking), aquatic biodiversity, wildlife support, aesthetic (e.g., water clarity/color), and non-use (e.g., existence and bequest values). The Benefits Module uses a meta-regression model of surface water valuation studies (U.S. EPA, 2015) to estimate the total nonmarket benefits of water quality changes.

3.1.2 Non-Water Quality Co-benefits

Co-benefits are ancillary benefits that arise from the implementation of the practice(s) selected to meet water quality targets. The Benefits Module includes three co-benefit categories: (1) change in housing property value due to improved aesthetic quality of the landscape from increases in green space, (2) air pollution removal and energy savings benefits related to canopy cover, and (3) air pollution removal and energy savings benefits related to green roofs. The three co-benefit categories are also referred to as change in property values, canopy cover benefits, and green roof benefits, respectively, in the Benefits Module and throughout Section 3 of this User Guide. The Theoretical Documentation for the Benefits Module (U.S. EPA, 2020) provides details about how the Benefits Module monetizes these co-benefits.

Change in property values (valuation approach designated with a solid gray line in Figure 5): Increased green space from BMP implementation is often expected to enhance nearby property values by improving the aesthetic quality of the landscape. Potential changes in nearby property value are estimated using a meta-regression model of existing hedonic property valuation studies (Mazzotta et al. 2014). It is not recommended to calculate this benefit if the chosen BMPs will not occur within a certain distance from residential properties. For grass swale, direct reduction tree canopy, and riparian buffer, the appropriate buffer distance is 0-250 meters. For land conservation, bioretention basin, gravel wetland, and riparian buffer, the appropriate buffer distance is 250-500 meters (see Table 1 for detail).

Table 1. WMOST management practice and assumed distance from residences for the change in property values

WMOST management practice	0-250-meter buffer	250-500-meter buffer
Land Conservation		X
Bioretention Basin		X
Grass Swale	X	
Gravel Wetland		X
Direct Reduction Tree Canopy	X	
Riparian Buffer*	X	X

*Riparian buffers are unique in that the assumed distance from residences can be estimated using a riparian contribution lookup table included within ScenCompare. This lookup table was developed by EPA and helps to define what portion of the chosen riparian buffer area falls within each buffer distance of residential homes.

Canopy cover benefits (valuation approaches designated with dashed and solid black lines in Figure 5): Canopy cover benefits are based on increased acres of overall canopy cover and whether this increase includes urban/community trees (see Figure 5). Increased acres of canopy cover results in increased carbon sequestration and increased removal of criteria air pollutants⁸ that cause negative human health impacts (NO₂, SO₂, O₃, PM_{2.5}). Increased acres of urban/community trees also result in energy cost savings for nearby buildings and subsequent reductions in criteria air pollutants (NO_x, SO₂, and PM_{2.5}) and carbon dioxide from avoided power plant emissions.⁹ Table 2 describes the canopy cover benefits in more detail, along with the sources used to quantify and monetize each benefit and the region type of each source (e.g., national, state-level, local).

Table 2. Canopy cover benefits and descriptions of the quantification/monetization sources

Environmental Outcome	Benefit	Source(s)	Region Type
Increased acres of canopy cover	Increased carbon sequestration	Social Cost of Carbon: Global: IWGSCC (2016) Domestic: U.S. EPA (2019a)	National
	Avoided human health damages resulting from tree removal of air pollutants (NO ₂ , SO ₂ , O ₃ , PM _{2.5})	Nowak et al. (2014)	National (regressions); county-level (population density)
Increased acres of urban/community trees	Electricity savings	Nowak et al. (2017); personal communication with authors	State-level
	Avoided human health damages from avoided NO _x , SO ₂ , and PM _{2.5} emissions from power plants	Quantification: Nowak and Greenfield (2012); Nowak et al. (2017) Monetization: U.S. EPA (2018)	Quantification: State-level Monetization: National
	Avoided CO ₂ emissions from power plants	Quantification: Nowak and Greenfield (2012); Nowak et al. (2017) Monetization: IWGSCC (2016), U.S. EPA (2019a)	Quantification: State-level Monetization: National

⁸ EPA has established national ambient air quality standards (NAAQS) for six of the most common air pollutants—carbon monoxide (CO), lead (Pb), ground-level ozone (O₃), particulate matter (PM_{2.5}), nitrogen dioxide (NO₂; NO_x), and sulfur dioxide (SO₂; SO_x) — known as “criteria” air pollutants. The primary NAAQS are set to protect public health.

⁹ Avoided human health damages for acres of tree canopy overall and acres of urban/community trees differ because power plants do not emit ground-level ozone.

Green roof benefits (valuation approaches designated with solid black lines in Figure 5): Green roof benefits are based on energy savings of the affected buildings and subsequent reductions in air pollutants and carbon dioxide from avoided power plant emissions (see Figure 5). You can use Arizona State University’s Green Roof Energy Calculator tool¹⁰ to determine green roof energy savings from the potential green roof(s). The Benefits Module then applies the energy savings estimate to calculate cost savings from changes in cooling and heating needs, human health benefits from avoided emissions of criteria air pollutants, and benefits from avoided carbon dioxide emissions. Table 3 describes the benefits from green roof implementation in more detail, along with the sources used to quantify and monetize each benefit and the region type of each source (national, state-level, local).

Table 3. Green roof benefits and descriptions of the quantification/monetization sources

Benefit	Source(s)	Region Type
Electricity savings	State-level: U.S. EIA (2018)	State-level (you can provide local values)
Avoided human health damages from avoided NO _x , SO ₂ , and PM _{2.5} emissions from power plants	Quantification: U.S. EPA (2019b) Monetization: U.S. EPA (2018)	Quantification: Regional (AVERT regions) Monetization: National
Avoided CO ₂ emissions from power plants	Quantification: U.S. EPA (2019b) Monetization: IWGSCC (2016), U.S. EPA (2019a)	Quantification: Regional (AVERT regions) Monetization: National

3.2 Using the Benefits Module

3.2.1 Navigation

To populate the Benefits Module with the scenario information you loaded into ScenCompare, click the “Calculate Management Option Benefits” button. As mentioned previously, the Benefits Module evaluates benefits and co-benefits for a set of management options from a single optimization scenario. If you end up adding or deleting model runs for the same optimization scenario, navigate through ScenCompare using the various tabs at the bottom of the screen and click the “Update List of Model Runs” button on the Benefits Module tab. If you would like to evaluate a different optimization scenario, navigate through ScenCompare using the “Return to Loaded Scenarios” and “Calculate Management Option Benefits” buttons.

3.2.1.1 Color Key

Data Description and Units
User Inputs
Benefits Module Outputs
Benefit/Co-benefit Totals

The Benefits Module interface is organized by different colored cells (see summary on the left)

- Green cells are typically data descriptions and units,
- blue cells are locations where users should define inputs specific to their scenario,
- yellow cells will be automatically filled in by the Benefits Module as you progress through the module, and
- purple cells summarize the benefit/co-benefit totals as calculated by the module.

¹⁰ <https://sustainability.asu.edu/urban-climate/green-roof-calculator/>

3.2.2 Data Needs

The Benefits Module requires data from multiple sources in addition to WMOST results to calculate benefits and co-benefits. The additional data needs include a mix of user knowledge of the study watershed and data from external data sources. Table A.1 in Appendix A describes specific data needs and any associated data sources and benefit or co-benefit categories.

The following sections describe how users provide the information needed to run the Benefits Module. The Benefits Module is divided into three steps: Study Characteristics (Section 3.2.3), Calculation of Direct Benefits (Section 3.2.4), and Calculation of Co-benefits (Section 3.2.5).

3.2.3 Study Characteristics (Step 1)

3.2.3.1 Step 1A

Step 1A of the Study Characteristics section of the Benefits Module includes data inputs that affect all benefit and co-benefit calculations (Figure 6).

Figure 6: Example of the Study Characteristics Step 1A of the Benefits Module.

1. Study Characteristics		
1A. Specify the year of the analysis.		
2019	Specify the dollar year in which you'd like to evaluate benefits.	
	\$2017	Upload GDP Deflator
Calculate Social Cost of Carbon		
If calculating management option co-benefits (see Section 3), choose if you would like to calculate co-benefits using the global or domestic social cost of carbon.		
Global social cost of carbon		\$/metric ton; delete either the global or domestic cost as appropriate
Domestic social cost of carbon	\$ 6.67	\$/metric ton; delete either the global or domestic cost as appropriate

Under Step 1A, select the year of the analysis and the dollar year. The year of the analysis should correspond with the first year of BMP implementation or the first year you expect benefits to begin accruing. The year of the analysis drop-down includes years 2016 through 2030, which correspond to the first and last years for which Benefit per Ton (BPT) values (U.S. EPA, 2018) are available to value human health benefits of reductions in air pollutants (see Section 3.1.2). The dollar year is also used to standardize all benefit and co-benefit estimates into the same dollar year (e.g., 2019 dollars) using the Gross Domestic Product (GDP) deflator (included as a separate .csv – GDP_PriceDeflators.csv¹¹). The dollar year drop-down includes years 2016 through 2019.¹² The GDP deflator file can be uploaded by pressing the “Upload GDP Deflator” and selecting the GDP deflator file. This file will then be used across the co-benefit and benefit calculations to convert values into the selected dollar year.

To monetize reductions in carbon (carbon sequestration), the Benefits Module can use *either* global (IWGSCC, 2016) or domestic (U.S. EPA, 2019a) social cost of carbon (SC-CO₂) values, depending on your selection. U.S. EPA is currently using interim values of the domestic SC-CO₂ to inform their federal regulatory analyses, but if you are simulating a non-regulatory scenario, you can decide whether domestic or global SC-CO₂ values are appropriate for your analysis. Global social cost of carbon values

¹¹ Keeping the GDP deflator file separate from the background Benefits Module calculations allows for easier updates when the BEA releases annual GDP deflator index values for future years (year 2020 and beyond). GDP updates from the BEA are available here (select modify to show annual values instead of quarterly values): https://apps.bea.gov/iTable/iTable.cfm?reqid=19&step=3&isuri=1&nipa_table_list=13

¹² Future updates of the Benefits Module can incorporate additional dollar years in the drop-down as the Bureau of Economic Analysis (BEA) releases annual GDP deflator index values for future years (year 2020 and beyond).

consider global benefits of reducing CO₂ emissions, or avoided damages worldwide, whereas domestic social cost of carbon values only consider domestic benefits.

To calculate SC-CO₂ values, click the “Calculate Social Cost of Carbon” button *after* selecting the year of the analysis and dollar year. The Benefits Module will calculate both global and domestic SC-CO₂ values. Decide which value is most appropriate for the analysis and then **delete the other value**.

3.2.3.2 Step 1B

Step 1B of the Study Characteristics section of the Benefits Module requires input information about HRUs in the study watershed as well as the proportion of HUC12s located within the study watershed (Figure 7).

Figure 7: Example of the Study Characteristics Step 1B of the Benefits Module.

1B. The Benefits Module uses several databases to calculate management option direct benefits and co-benefits. The databases are based on USGS' fourth level of hydrologic unit classification (HUC12). The Module also requires land use-specific information about the land uses found within your watershed. Select a model below that represents your watershed using the drop-down list.

Model run representing your watershed:

Press the button below to populate the table with the HRU names from your watershed.

Select each data header for more information.

HRU Name	Agricultural land	Residential land	Green space percentage
Turfgrass A/B Montgomery County	0	1	80
Turfgrass C/D Montgomery County	0	1	50
Turfgrass A/B City of Rockville	0	2	70
Turfgrass C/D City of Rockville	0	0	0
Turfgrass A/B MD State Highway	1	0	0
Turfgrass C/D MD State Highway	1	0	0
Turfgrass A/B Other Regulated	0	0	0
Turfgrass C/D Other Regulated	0	0	0
Natural	0	0	0
Water	0	0	0

After setting up the HRU table, enter the number of HUC12s that make up your study area (up to 20).

HUC12 ID	Proportion of HUC12 (percentage)
020700081003	100

Prior to completing the HRU and HUC12 tables, select a model run that represents the study watershed. The drop-down will include all scenario names on the “Loaded Scenarios” tab (see Sections 1 and 2.1). After selecting the model run, select the “Setup HRU Table” button, which will fill the table with HRU names based on the selected model run. Add values for agricultural land by identifying which HRUs can be considered agricultural. Add values for residential land by identifying which HRUs can be considered residential. Add green space percentages for each HRU as appropriate. These designations should all be made based on your knowledge of model land uses. You can also consult external data sources to help determine the appropriate variable values for each HRU, as described in Appendix A. Clicking on the variable headings provides instructions for each variable:

- Agricultural land: 1 if agricultural, 0 otherwise
- Residential land: 1 if low-density, 2 if medium-density, or 3 if high-density residential; 0 otherwise¹³
- Green space percentage: % of residential land use area that is green space (for HRUs with a 1, 2, or 3 in the residential land column); 0 otherwise. You do not need to specify green space percentages for land uses that are not residential.

After completing the HRU table, complete the HUC12 table. First, enter the number of HUC12s that comprise the study watershed.¹⁴ Second, select the “Setup HUC12 Table” button to add more lines to

¹³ See <https://www.mrlc.gov/data/legends/national-land-cover-database-2016-nlcd2016-legend> for more detailed definitions of low-density, medium-density, and high-density residential land use.

¹⁴ HUC12 IDs can have leading zeros so it is recommended to either manually enter the HUC12 ID or Paste As Values to maintain the cell's data type as text.

the HUC12 table, as necessary. Third, enter the HUC12 IDs and the proportion of the HUC12 that falls within the study watershed, based on your knowledge of the study watershed. You can also consult external sources to help determine the appropriate values for the HUC12 table, as described in Appendix A.

3.2.4 Calculate Direct Benefits (Step 2)

The “Calculation of Direct Benefits” section of the Benefits Module includes data inputs necessary to calculate the two direct benefit categories: change in water treatment costs and the total nonmarket value of water quality changes (Figure 8; Section 3.1.1) You have the option to calculate either or both direct benefit categories. If you do not want to calculate values for one or both direct benefit categories,¹⁵ leave the model run choices blank for the non-applicable benefit category or categories.

After completing all of the data inputs, as described in Sections 3.2.4.1 and 3.2.4.2, click the “Calculate Direct Benefits” button (Figure 9), which is located above the data input fields. The benefit estimates will appear in a column along the right-hand side of the Direct Benefits section. If you chose to estimate both direct benefit categories, the Benefits Module will provide separate estimates for “water treatment cost changes” and “annual willingness-to-pay for water quality changes” as well as a total direct benefits value.

Figure 8: Example of the Direct Benefits Step of the Benefits Module.

Choose the appropriate baseline and managed model runs below.

Baseline Model Run TSS_BaselineWTP Managed Model Run TSS_ScenWTP	Fill out the blue input cells to compute the direct benefit value of... Change in water treatment costs <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 40%;">Estimated ratio of turbidity to TSS</td> <td style="width: 20%; text-align: center;">1.5</td> <td style="width: 40%;">1.5 by default</td> </tr> <tr> <td>Cost of alum</td> <td style="text-align: center;">\$ 440.00</td> <td>\$/ton</td> </tr> <tr> <td></td> <td style="text-align: center;">2018</td> <td>Dollar year</td> </tr> </table>	Estimated ratio of turbidity to TSS	1.5	1.5 by default	Cost of alum	\$ 440.00	\$/ton		2018	Dollar year
Estimated ratio of turbidity to TSS	1.5	1.5 by default								
Cost of alum	\$ 440.00	\$/ton								
	2018	Dollar year								

Indicate below if your case study falls into any of the three defined US regions. If your case study does not fall into any of the three, leave all values as zero.

Northeast	0	1 if located in the Northeast (ME, NH, VT, MA, RI, CT, and NY); 0 otherwise
Central	0	1 if located in the Central US (OH, MI, IN, IL, WI, MN, IA, MO, ND, SD, NE, KS, MT, WY, UT, and CO); 0 otherwise
South	0	1 if located in the South (NC, SC, GA, FL, KY, TN, MS, AL, AR, LA, OK, TX, and NM);

Specify the dollar year of the income data.
2018

Specify the data frequency of BOD, DO, and FC data
Monthly

Figure 9: Button for calculating direct benefits in the Benefits Module.

2. Calculation of Direct Benefits

Once input values have been entered below, use this button to calculate the value of direct benefits.

If any of the direct benefit calculations are inappropriate for your study area, leave the model run choices blank under step 2A.

¹⁵ You may not want to calculate values for a benefit category for various reasons: (1) you are not interested in the category for your analysis, (2) you do not have the inputs required to run the analysis, or (3) you believe the benefit category is inappropriate for your study area/analysis (e.g., change in drinking water treatment costs likely isn’t appropriate since all BMPs will occur downstream from any drinking water treatment intakes).

3.2.4.1 *Change in Water Treatment Costs*

Calculations for the change in water treatment costs will require importing data for both baseline conditions and conditions under the set of management options. To calculate the change in water treatment costs, select baseline and managed model runs from the drop-down menus on the left-hand side that are aligned with the “Change in water treatment costs” variable box. The model run drop-downs contain all scenario names on the “Loaded Scenarios” tab (see Sections 1 and 2.1). Since the benefit is related to change in water treatment costs for treating TSS/turbidity, it is recommended that you only select TSS model runs.

You will also need to provide values for two additional variables: (1) the estimated ratio of turbidity to TSS and (2) the cost of aluminum sulfate (alum) used to reduce turbidity.

- (1) Calculating changes in water treatment costs requires converting TSS results from WMOST model runs into turbidity using an equation provided in U.S. EPA (2009). The regulatory analysis used ratio values of 0.8, 1.5, and 2.2 for high, midpoint, and low treatment cost estimates, respectively. The benefits module uses 1.5 as the default ratio value but you can adjust the value in the interface. As the value of the ratio decreases, a given level of TSS generates more turbidity, requiring higher doses of chemical coagulants for treatment.
- (2) Aluminum sulfate is the primary coagulant used to treat turbidity. If available, you can enter alum cost values based on actual per-ton expenditures at drinking water treatment plants within your study area. If you do not have actual alum expenditure information, U.S. EPA (2005) provides alum values for dry stock (\$300/ton) and liquid stock alum (\$230/ton) in 1998\$. It is recommended that you select the value based on the type of alum used at the drinking water treatment plant(s) with water intakes within the study watershed. You also need to provide the dollar year of the alum cost estimate. If the estimate is based on current site-specific alum costs, specify the latest available dollar year (currently year 2019).

3.2.4.2 *Total Nonmarket Benefits of Water Quality Changes*

To calculate total nonmarket benefits of water quality changes, you will need to run WMOST for each combination of the pollutant (total nitrogen [TN], total phosphorus [TP], and TSS) and analytic scenario (i.e., baseline and managed conditions), for a total of six separate runs.

- For the baseline TN, TP, and TSS runs, you will need to run WMOST in simulation mode (see Section 2.1 of WMOST User Guide) to obtain time series representative of baseline conditions for each constituent.
- For the managed condition runs, you will first run WMOST in optimization mode for a parameter of interest (e.g., TN) to determine cost-effective BMPs that help to meet your desired water quality target(s). Then, you will need to run WMOST in simulation mode two additional times to determine how the selected BMPs will affect the two other parameters (e.g., TP and TSS).

Once those models have been loaded into ScenCompare as listed on the “Loaded Scenarios” tab within the Benefits Module, select baseline and managed model runs from the drop-down menus on the left-hand side that are aligned with the “Total nonmarket benefits of water quality changes” variable box.

The model run drop-downs contain all scenario names on the “Loaded Scenarios” tab (see Sections 1 and 2.1). If you are calculating both changes in water treatment cost benefits and total nonmarket benefits of water quality changes, select the same TSS baseline and scenario models for both benefit categories.

In addition to selecting model results for TN, TP, and TSS, you will need to: (1) provide values for regional variables, (2) upload income and population data, and (3) upload data for three other water quality metrics (biochemical oxygen demand [BOD], dissolved oxygen [DO], and fecal coliform [FC]).

(1) The regional variables are dummy variables based on the state(s) in which the study watershed falls. If the study watershed is within one of the states described for each regional variable, set the variable to 1 (and to 0 otherwise). If the study watershed does not fall within any of the states described for the three regional variables, set all the regional variables to 0. The three regions are defined as follows:

- **Northeast:** Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont
- **Central:** Colorado, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Montana, Nebraska, North Dakota, Ohio, South Dakota, Utah, Wisconsin, and Wyoming
- **South:** North Carolina, South Carolina, Georgia, Florida, Kentucky, Tennessee, Mississippi, Alabama, Arkansas, Louisiana, Oklahoma, Texas, and New Mexico

(2) Estimation of the total nonmarket benefits of water quality changes also requires mean income and number of households for the counties that intersect the study watershed. Data for mean income and number of households should correspond with the year of the analysis. If the year of the analysis is a future year for which mean income and number of households is not yet available, use data for the closest available year (e.g., 2018 data for year 2021). If more than one county intersects the study watershed, average the mean income and sum the total number of households in the affected counties.¹⁶ The American Community Survey (ACS) 5-year estimates provide both values in one table: mean income in the past 12 months and the number of households (TableID: S1901).¹⁷ Compile the income and household data using the same format as the “Population_Income_Template.csv” template included with the ScenCompare

¹⁶ Averaging the mean income across intersecting counties enables the calculation of one household willingness-to-pay (WTP) value for the study watershed instead of county-specific WTP values. The Benefits Module then applies the household WTP value to affected households, or the number of households residing in counties intersecting the study watershed. Applying the WTP value to only households in intersecting counties is a conservative application since households beyond the intersecting counties may also have a WTP for the water quality changes.

¹⁷ To obtain the ACS mean income and number of households data, go to <https://data.census.gov/cedsci/advanced> and type “S1901” into the Table ID data field. Under “Browse Filters,” select the appropriate geography and years for your study area and analysis. For instance, if you need data for Apache County, Arizona, click the Geography filter and then select County > Arizona > Apache County, Arizona. You can select more than one county from more than one state, if needed. To select the year of the data, select the year filter and then the desired year. Table S1901 is available for years 2010 to 2018. After adding the table ID number and the geography/year filters, select “Search” in the bottom right-hand corner. Select the table in the search results to view in full-screen. Underneath the table title, select the 5-year estimates from the “Product” drop-down. 5-year estimates are based on the largest sample size and are the most reliable. You can download the data by clicking the “Download” button in the upper left-hand corner of the screen, checking the box next to the table, and clicking “Download Selected.” A box will appear that provides the option to download 1-year or 5-year estimates (or both) in either CSV or PDF format. Select 5-year estimates in CSV format to most easily match the “Population_Income_Template.csv” format. Select “Download” in the bottom right-hand corner and then “Download Now” once the file is ready. In the data CSV file (file name contains “data_with_overlays”), each selected geographic region will appear as a row. Use the column names to find the total number of households and mean income estimates.

download and upload the dataset by selecting the “Upload Income and Population Data” button. You will also need to provide the dollar year for the income data. For ACS data, the dollar year is based on the last year included in the estimates (e.g., 2013-2017 ACS 5-Year Estimates are reported in 2017\$).

- (3) Three additional water quality parameters—BOD, DO, and FC—are needed to calculate the Water Quality Index (WQI). As described above, the Benefits Module uses a meta-regression model of surface water valuation studies (U.S. EPA, 2015) to estimate benefits of water quality changes measured on the 100-point WQI. You can download BOD (mg/L), DO (mg/L), and FC (cfu/100 mL) data for your study watershed from the water quality portal.¹⁸ The BOD, DO, and FC data should match the time frame of your model run. If water quality portal data for your study watershed are unavailable or you are unsure of which data to use, reference the spreadsheet included with the ScenCompare download (BOD_DO_FC_ByHUCs.xlsx).¹⁹ Compile the BOD, DO, FC data using the same format as the “BOD_DO_FC_Template.csv” template, which is included with the ScenCompare download, and upload the dataset by selecting the “Upload BOD, DO, and FC Data” button. Since BOD, DO, and FC data are available at different frequencies (e.g., monthly, daily), use the drop-down below the “Upload BOD, DO, and FC Data” button to indicate the frequency of the uploaded data. If using the provided default data, the data frequency should be set to “Annually”.

3.2.5 Calculate Co-benefits (Step 3)

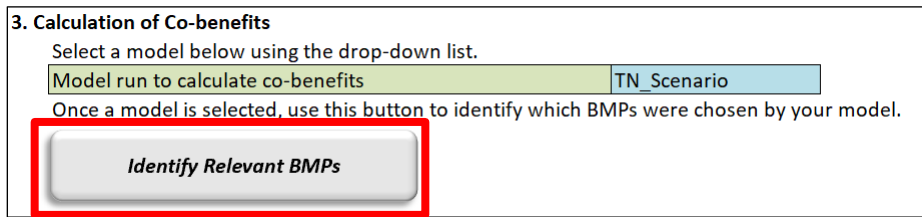
To calculate co-benefits, first select a model run from the drop-down in Step 3 of the Benefits Module, which will include all scenario names on the “Loaded Scenarios” tab (see Sections 1 and 2.1; **Figure 10**). Select a model run that includes the management option(s) that you want to evaluate. After selecting the model run, select the “Identify Relevant BMPs” button to identify the BMPs chosen by the model. The selected BMPs will appear in bold along the left-hand side of the Co-benefits section (see red box in **Figure 11**). The WMOST results (yellow cells in Figure 11) for each benefit category will also auto-populate upon clicking the “Identify Relevant BMPs” button. If you do not want to calculate values for one or several of the co-benefit categories,²⁰ unbold (i.e., highlight, go to Home menu, and select bold format) the associated BMP(s) under Step 3. You cannot bold any BMPs not identified by the “Identify Relevant BMPs” button because it indicates that that BMP was not chosen during the least-cost optimization and, therefore, would be inaccurate to include in the benefits analysis.

¹⁸ <https://www.waterqualitydata.us/portal/>

¹⁹ This spreadsheet summarizes annual average BOD, DO, and FC data from the National Water Information System over various geographies (HUC8, HUC6, and HUC4) from 2007 to 2018. You should select data that corresponds with your watershed. For example, if your watershed corresponds with HUC 020700081003, look for data for all three parameters in either 02070008, 020700, or 0207.

²⁰ You may not want to calculate values for a co-benefit category for various reasons: (1) you are not interested in the category for your analysis, (2) you do not have the inputs required to run the analysis, or (3) you believe the benefit category is inappropriate for your study area/analysis (e.g., none of the BMPs are anticipated to be implemented within the specified distances from residential properties that would lead to changes in property values).

Figure 10: Button for identifying relevant BMPs for co-benefit calculations within the Benefits Module.



After identifying relevant BMPs chosen by your model and determining which co-benefit categories to estimate, you will need to provide the required inputs for calculating the associated benefits in Step 3 of the “Calculation of Co-benefits” section (**Figure 11**). Step includes data inputs necessary to calculate the three co-benefit categories: (1) change in housing property value due to improved aesthetic quality of the landscape from increases in green space (change in property values), (2) air pollution removal, energy savings, and air emission reduction benefits related to canopy cover (canopy cover benefits), and (3) energy savings and air emission reduction benefits related to green roofs (green roof benefits; see Section 3.1.2).

After completing all of the data inputs, as described in Sections 3.2.5.1, 3.2.5.2, and 3.2.5.3, click the “Calculate Co-benefits” button, which is located above the data input fields (**Figure 12**). If you leave the “Price of electricity for residential customers” field blank (see Section 3.2.5.3), the Benefits Module will also prompt to you to select the “ElectricityPrice_byState.csv” file. The co-benefit estimates will then appear in a column along the right-hand side of the Co-benefits section. The Benefits Module will provide separate values for each co-benefit category that you elect to estimate (change in property values, canopy cover benefits, and green roof benefits) as well as a total co-benefits value. If you unbold any BMPs, the WMOST results (yellow cells: acres of increased green space, acres of increased canopy cover, acres of green roof) will also update to reflect acreage from the bold BMPs upon selecting the “Calculate Co-benefits” button.

Note: Estimates of canopy cover benefits, green roof benefits, and total co-benefits have lower and upper bound values. The range of values results from using BPT values for the Electricity Generating Units sector (U.S. EPA, 2018) to estimate human health benefits resulting from reductions in air pollutants due to avoided power plant emissions. Estimates vary based on the epidemiology study used as the basis for premature mortality estimates, with the lower bound estimates based on Krewski et al. (2009) and the higher bound estimates based on Lepeule et al. (2012). If human health benefits resulting from reductions in air pollutants due to avoided power plant emissions are not calculated within the module, the lower and upper bound values will be the same.

Figure 11: Example of the co-benefits Step of the Benefits Module.

BMPs chosen by your model are in bold below.

Fill out the blue input cells to compute the co-benefit value of...

Change in housing property value due to improved aesthetic quality of the landscape from increases in green space

Land Conservation	Acres of increased green space	59	WMOST results
Bioretention Basin	Wetland	1	1 if wetland area is expected to increase; 0 otherwise
Grass Swale	Recreational	1	1 if recreational amenities are included in development; 0 otherwise
Gravel Wetland			
Direct Reduction Tree Canopy			
Riparian Buffer			

Import Default Values - Percent Tree Cover

Air pollution removal and energy savings benefits related to canopy cover

Land Conservation	Acres of increased canopy cover	59.16	WMOST results
Direct Reduction Tree Canopy	Population density	2,115	people/square mile
Riparian Buffer			

Air pollution removal and energy savings benefits related to green roofs

Green Roof	Acres of green roof	0	WMOST results
	Direct energy savings		kWh/year
	Location		AVERT region
	Source of energy savings		AVERT emission factor category
			\$/MWh
	Price of electricity for residential customers		Dollar/year

Figure 12: Button for calculating co-benefits in Step 3 of the Benefits Module.

3. Calculation of Co-benefits

Select a model below using the drop-down list.

Model run to calculate co-benefits TN_Scenario

Once a model is selected, use this button to identify which BMPs were chosen by your model.

Identify Relevant BMPs

If any of the co-benefit calculations are inappropriate for your study area, unbold the associated BMP under Step 3A. Once input values have been entered below, use this button to calculate the value of co-benefits.

Calculate Co-benefits

3.2.5.1 Change in Housing Property Value Due to Improved Aesthetic Quality of the Landscape from Increases in Green Space (Change in Property Values)

To calculate the change in property values, you will need to provide values for two variables, one indicating whether wetland area is expected to increase and the other indicating whether recreational amenities (e.g., park, greenway, trail, path) are included in the implementation of the WMOST-chosen BMPs. This should be based on your knowledge of potential BMP implementation. You can also consult external data sources to help determine the appropriate values for these two variables, as described in Appendix A.

You will also need to import values for the percentage of new green space that is tree cover. Selecting the “Import Default Values – Percent Tree Cover” button adds percent tree cover input rows applicable to the identified BMPs and adds default values for bioretention basin, grass swale, gravel wetland, and riparian buffer BMPs (as described in Appendix B). If WMOST identified land conservation as a cost-effective BMP, you will need to manually enter tree cover percentages for each of the watershed HRUs based on your knowledge of the study watershed. You can also consult external data sources to help determine the appropriate values for tree cover percentages, as described in Appendix A.

3.2.5.2 *Air Pollution Removal and Energy Savings Benefits Related to Canopy Cover (Canopy Cover Benefits)*

To calculate canopy cover benefits, you need to provide population density (people/square mile) for the county(s) that intersects your study watershed. You can calculate population density using the following two resources: 1) the most recent ACS 5-year population estimates²¹ and 2) the most recent Census land area values in square miles.²² If you know that county boundaries have changed since the most recent Census, you can use alternative sources, such as GIS shapefiles or state-level estimates, to determine the appropriate land area values for intersecting counties. To account for multiple intersecting counties, average the population density values. If you have information about the proportion of the study watershed that falls within each county, you can calculate a weighted average population density using the intersection proportions as weights or use the population density associated with the county that intersects with the majority of your study watershed. If you do not have information about the intersection proportions, you can either use the population density for the county that accounts for the majority of the watershed or use a standard average population density value.

3.2.5.3 *Air Pollution Removal and Energy Savings Benefits Related to Green Roofs (Green Roof Benefits)*

To calculate green roof benefits, first determine green roof energy savings by inputting information about potential green roofs into Arizona State University's Green Roof Energy Calculator tool.²³ The calculator tool requires green roof characteristics and location (select the closest available city to your study watershed).

To quantify reductions in criteria air pollutants (SO₂, NO_x, PM_{2.5}) and carbon dioxide (CO₂) from reduced energy consumption due to the installation of green roofs, the Benefits Module applies regional AVERT²⁴ emission rates (U.S. EPA, 2019b) to convert energy savings into avoided emission of criteria air pollutants (in lbs of SO₂, NO_x, and PM_{2.5}) and carbon dioxide (in tons of CO₂). The contiguous United States is divided into ten AVERT regions (Figure 13). Four different types of regional AVERT emission rates are available: wind, utility-scale photovoltaic, portfolio energy efficiency, and uniform energy efficiency. Use the uniform energy efficiency values, which represent consistent energy savings throughout the year, unless you have reason to believe that one of the other types is more appropriate for your study area.²⁵ Consult U.S. EPA (2019b) for additional details about the four types of AVERT emission rates.

²¹ <https://data.census.gov/cedsci/all?t=Populations%20and%20People&y=2018&tid=ACSST1Y2018.S0101&hidePreview=false>

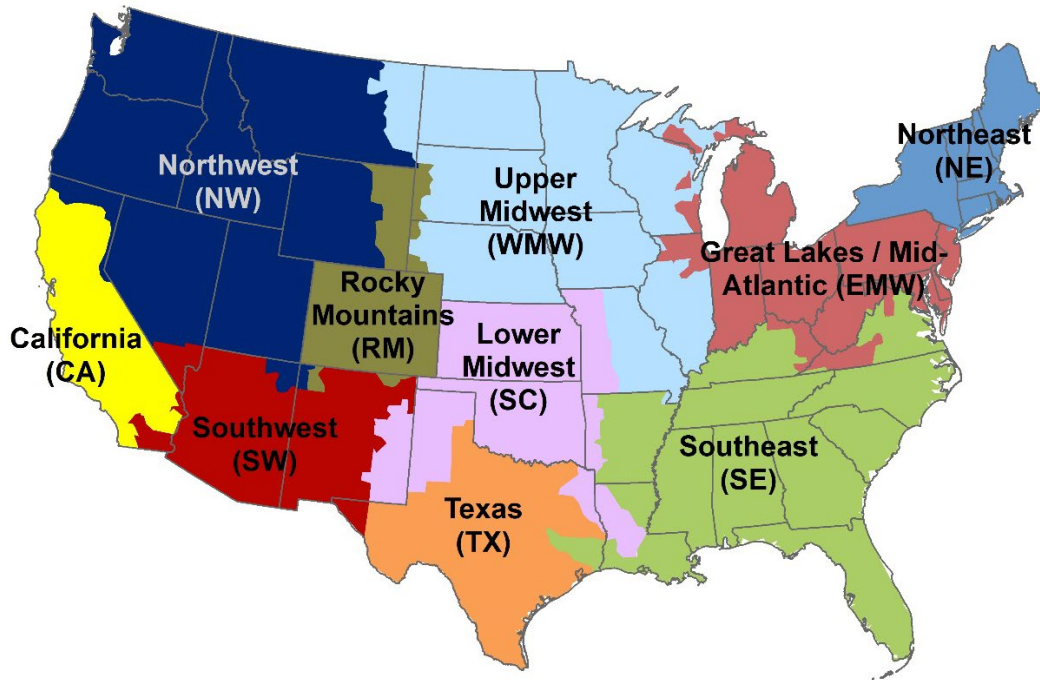
²² <https://www.census.gov/quickfacts/fact/table/US/PST045219>

²³ <https://sustainability.asu.edu/urban-climate/green-roof-calculator/>

²⁴ AVoided Emissions and geneRation Tool

²⁵ Portfolio energy efficiency rates are most appropriate for assessing energy savings from a wide range of energy efficiency programs. Uniform energy efficiency rates are most appropriate if energy savings are consistent throughout the year. Wind and utility-scale photovoltaic are most appropriate if the savings can be attributed to the associated renewable energy technology type.

Figure 13: Map of the ten AVERT regions in the contiguous United States.



Lastly, you need to provide the price of a megawatt hour of residential electricity (\$/MWh) and the dollar year of the provided value. You can use local values for the price of a megawatt hour of residential electricity if available. However, if you leave the cell blank, you can load state-level average prices for residential electricity from the U.S. Energy Information Administration (2018; “ElectricityPrice_byState.csv” file included with the ScenCompare download. The Benefits Module will prompt you to upload the state-level average prices for residential electricity after selecting the “Calculate Co-benefits” button (see Section 1.1.1.1).

4 Example Application of ScenCompare for Wading-Threemile Watershed

Below is an example of an application of ScenCompare using a WMOST case study on the Wading-Threemile River Watershed in the Taunton Basin in Massachusetts. The example provides a guide for setting up and loading scenario runs in ScenCompare (Section 4.1), using the tool’s functions and evaluating the scenario data (Section 4.2), and analyzing the various land use management decisions in WMOST (Section 4.3).

4.1 Getting Started

The primary purpose of ScenCompare is to provide users with an interface and tool for comparing WMOST results for different future climate scenarios. Therefore, this example details the differences in WMOST least-cost management decision solutions between the baseline and future climate scenarios.

However, in general, the functions of this tool can be used to evaluate any set of WMOST results and help you to understand the effects of model inputs on the management actions selected by the WMOST optimization model, which meets specified management goals at the lowest cost. The following section discusses the development of the WMOST scenarios for the Wading-Threemile River Watershed, and how those scenarios are loaded into ScenCompare to prepare the tool for analysis.

4.1.1 Run WMOST Scenarios

Data for this example come from the Wading-Threemile subwatershed in the upper Taunton River basin in Massachusetts (<https://www.mass.gov/service-details/taunton-river-watershed>). The Taunton River watershed is the second largest watershed in Massachusetts and the largest freshwater contributor to Narragansett Bay. The Taunton River is the longest undammed tidal river in New England, supporting the largest herring run in the state. In 2009 it was designated as a Partnership Wild and Scenic River by the National Park Service. In these Partnership Wild and Scenic Rivers, communities protect their own outstanding rivers and river-related resources through a collaborative approach. Challenges faced by communities in the Taunton include protection of outstanding natural resource areas, flooding, sea level rise and storm surges, water body impairments related to eutrophication, water supply constraints, and the need to protect the downstream Mount Hope Bay ([RTI 2014](#)). This case study was developed in cooperation with a consortium of regional development agencies (Southeast Regional Planning and Development District, SERPDD and the Metropolitan Area Planning Council, MAPC) and nongovernmental organizations (Manomet, the Nature Conservancy, and Mass Audubon) which had received funding from EPA Region 1 from the [Healthy Communities Grant Program](#) to assess the benefits of green infrastructure within the watershed and to educate the public about those benefits.

The EPA ORD team has applied WMOST v3 to the two subwatersheds within the upper Taunton. A two-stage objective was established: first, to minimize costs (capitol plus operations and maintenance) for near term planning, and second, to minimize future costs under projected growth and climate scenarios. Goals and constraints considered in Stage 1 included ecoregional targets for total phosphorus in lakes and flowing waters, a reduction in total nitrogen loads to the Mt Hope Bay, and maintenance of minimum low flows for a stable water supply and to support fish populations. Management options under consideration include land conservation, stormwater best management practices (BMPs, including green infrastructure), forested riparian buffer restoration, repair of water infrastructure leaks, upgrades in wastewater treatment, water conservation, and aquifer storage and recharge. A comparison of different traditional (“gray”) and nature-based (“green) stormwater BMPs showed that infiltration basins were the most cost-effective option to meet water quality goals. Initial results were shared with the Resilient Taunton Watershed Network (RTWN).

In this case, we apply WMOST v3.01 to future growth and climate scenarios to identify the most cost-effective management actions. Future projections of mean annual temperature and mean annual precipitation were obtained from the general circulation models (GCMs) included in the 5th Coupled Model Intercomparison Project (CMIP5) for two of the representative concentration pathways (rcp-4.5 and rcp-8.5) adopted by the Intergovernmental Panel on Climate Change (IPCC) in its 5th Assessment Report (IPCC 2014). The pathways in this report correspond to changes in radiative forcing relative to pre-industrial values (i.e. +2.6, +4.5, +6.0, +8.5 W/m²) that are possible in year 2100 based on

projections of greenhouse gas emissions (IPCC 2014). These data were corrected for bias and statistically downscaled to a regional scale (Brekke et al. 2013). Four combinations of changes in temperature and precipitation (ΔT , ΔP) were selected for this study to roughly bound the extremes of ΔT and ΔP reflected by the collection of GCMs, thereby representing a range of possible future climate scenarios, and an average of these scenarios was also calculated. Bounding scenarios were identified using the US EPA LASSO tool (Morefield 2016), focusing on 21 of the models that had been shown to perform well for New England in hindcasting exercises (Sheffield et al. 2015). The average projection was $\Delta T = +4.4^\circ\text{F}/\Delta P = +10.1\%$. The bounding scenarios were based on the FGOALS-s2, realization 3 (GCM $\Delta T = +6.2^\circ\text{F}/\Delta P = +19.4\%$), IPSL-CM5A_LR, realization 1 (GCM $\Delta T = +5.0^\circ\text{F}/\Delta P = -1.7\%$), MPI-ESM-LR realization 2 (GCM $\Delta T = 3.7^\circ\text{F}/\Delta P = -2.2\%$), and CSIRO-Mk3-6-0 realization 1 (GCM $\Delta T = +3.3^\circ\text{F}/\Delta P = +19.5\%$) model runs²⁶.

A new set of input hourly temperature and precipitation data was generated for each scenario by uniformly adjusting the baseline temperature and precipitation records by the corresponding ΔT (absolute) and ΔP (percentage) values, respectively. Using the adjusted temperature and precipitation data, hourly runoff rates were generated for input to WMOST for each scenario using SWMM. Similarly, the temperature, precipitation, and runoff data were used in SWMM to generate four new sets of hourly nitrogen and phosphorus loading rates for input to WMOST. In the following, climate change scenarios are labeled as General Circulation Model (GCM) ΔT ($^\circ\text{F}$)/ ΔP (%).

One of the objectives of the WMOST Wading-Three mile case study is to analyze the robustness of WMOST management decisions over these future climate scenarios. To do this, we created a series of WMOST runs based on a historical dry year (2002) and each of the five climate scenarios described above (one median projection and four bounding scenarios).

We ran the historical climate and five future climate scenarios (four bounding and one median) for three types of comparisons:

1. Baseline (baseline land use with no land management options);
2. Optimal stormwater BMP implementation for 2002 (fixed set of optimal stormwater land use BMPs for climate scenario runs); and
3. Optimal riparian zone implementation for 2002 (selection of 10 potential riparian buffer land conversions from developed land to forest).

The TN loading target (1,156 lbs N) was turned off for the baseline run (for the historical scenarios and the climate scenarios), as well as in the climate scenarios for the stormwater BMP and riparian zone runs to see if the future scenarios would meet the target given optimal BMPs selected for 2002. This set of runs was designed to test how robust the original solution was to a range of plausible, future climate conditions.

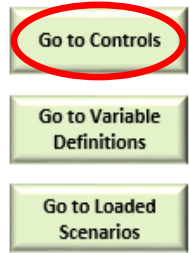
In addition to the three comparisons listed above, we also compared the differences in decisions between the historical baseline and two climate scenarios (the median and extreme) with the TN

²⁶ CSIRO-Mk3-6-0 is from the Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence; FGOALS-s2 is from the LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences; IPSL-CM5A-LR is from Institut Pierre-Simon Laplace; MPI-ESM-LR is from Max Planck Institute for Meteorology (MPI-M).

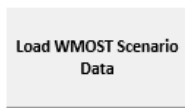
loading target turned on and a stormwater BMP set available (Section 4.3.2). This set of comparisons evaluated whether optimal management practices would change given climate change scenarios.

4.1.2 Load WMOST Data to ScenCompare

The following instructions describe how you would use the example result log files generated for WMOST scenarios as described above to assess differences in scenario results using ScenCompare. Once you have completed your scenario runs and prepared the Scenario Log Files in WMOST (see WMOST v3 User Guide²⁷ for more details), open the ScenCompare application. From the Introduction tab, navigate to the Controls tab. You can also use the Introduction tab to navigate to the Variable Definitions tab and the Loaded Scenarios tab.

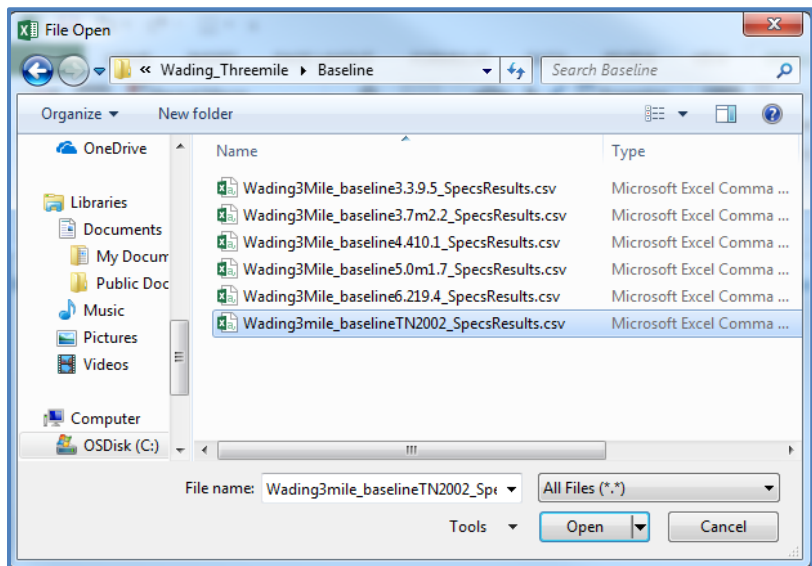
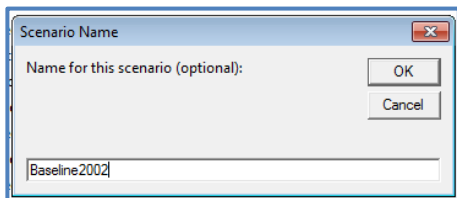


Step 1: Load data from selected WMOST log files



On the Controls tab, click the “Load WMOST Scenario Data” button to open a file selection dialog box. In the dialog box, select the Scenario Log File you created for your baseline run and click “Open”.

After opening your file, another dialog box will pop up, prompting you to name this scenario. Enter a name in the text box that will help you quickly identify the scenario, if you would like one (this step is optional). Then, click “OK” to load the scenario.



Once the data is loaded, you can view the summary information for the scenario on the Loaded Scenarios tab, which includes the average annual precipitation and average temperature statistics for the model run. If these columns have “NA” for the statistics, enter the average annual precipitation and average temperature statistics for the scenario in their given columns. This tab also includes information, including the file path of the data file, study area name, scenario name, and start and end dates.

²⁷ Available from <https://www.epa.gov/ceam/wmost-30-download-page>

Loaded Scenarios tab

	A	B	C	D	E	F	G	H	I	J	K
1	Loaded Files:	Data Name:	Scenario Name (edit here):	StudyAreaName:	ScenarioName:	RunStartTime:	StartDate:	EndDate:	ModelMode:	Avg Annual Precip	Avg Temperature
2	\\camfile01.corp.abtas	Wading3mile_TF	Baseline2002	Wading3mile	TN2002baselin	7/1/2018 12:35	1/1/2002	12/31/2002	Hydrology & Loa	42.05	52.697
3											

You can view the input data and results in the Model Input Data and Model Results tabs, respectively, for the scenario you just loaded.

Repeat the steps above to load as many scenarios as you would like. You can use the “Return to Controls” button on the Loaded Scenarios tab to easily return to the Controls tab to load additional scenario data files. If you want to remove a scenario, select the row of that scenario and click the “Clear Selected Scenarios” button. A message box will pop up asking you if you are sure you want to delete the data for that scenario.

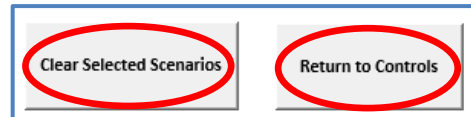
Model Input Data tab

	A	B	C	D	E	F
1	Wadit -	Wadit -	Wadit -	Wadit -	mile_TN2002baseline	
2	Variable	Identifie	Value	Units		
3	AvgAnnu	None	42.05	total inches per year		
4	AvgTemp	None	52.697	deg F		
5	NDateHy	None	365	time steps in model		
6	Dt	None	1	days in time step		
7	Nlu	None	16	# HRUS		
8	NluName	1	forest sa			
9	NluName	2	open nor			
10	NluName	3	MLD res			
11	NluName	4	MHHD re			
12	NluName	5	comindtr			
13	NluName	6	ag sand			
14	NluName	7	forest til			
15	NluName	8	open nor			
16	NluName	9	MLD res			
17	NluName	10	MHHD re			
18	NluName	11	comindtr			
19	NluName	12	ag till			
20	NluName	13	cranberry			
21	NluName	14	forested			
22	NluName	15	nonfores			
23	NluName	16	water			
24	AluBase	1	13647	acre		
25	AluBase	2	2296.36	acre		
26	AluBase	3	5948.68	acre		
27	AluBase	4	973.221	acre		
28	AluBase	5	2536.94	acre		
29	AluBase	6	694.234	acre		
30	AluBase	7	12553.5	acre		
31	AluBase	8	1082.57	acre		
32	AluBase	9	2821.25	acre		

Model Results tab

	A	B	C	D	E	F
1	Wadit -	Wadit -	Wadit -	Wadit -	mile_T -	002baseline
2	Variable	Identifie	Value	Units		
3	objective	None	2261.31	S/yr		
4	DALu11	None	13647	ac		
5	DALu21	None	2296.36	ac		
6	DALu31	None	5948.68	ac		
7	DALu41	None	973.221	ac		
8	DALu51	None	2536.94	ac		
9	DALu61	None	694.234	ac		
10	DALu71	None	12553.5	ac		
11	DALu81	None	1082.57	ac		
12	DALu91	None	2821.25	ac		
13	DALu101	None	448.338	ac		
14	DALu111	None	1104.44	ac		
15	DALu121	None	240.572	ac		
16	DALu131	None	98.4156	ac		
17	DALu141	None	6473.56	ac		
18	DALu151	None	2132.34	ac		
19	DALu161	None	1330.48	ac		
20	DQSwExt	1	131.162	MGD		
21	DQSwExt	2	99.0065	MGD		
22	DQSwExt	3	105.615	MGD		
23	DQSwExt	4	99.6948	MGD		
24	DQSwExt	5	93.6522	MGD		
25	DQSwExt	6	93.4212	MGD		
26	DQSwExt	7	128.981	MGD		
27	DQSwExt	8	96.3411	MGD		
28	DQSwExt	9	97.379	MGD		
29	DQSwExt	10	99.5948	MGD		
30	DQSwExt	11	119.877	MGD		
31	DQSwExt	12	100.46	MGD		

In the example below, there are five climate scenarios loaded in addition to the baseline run. The precipitation change and temperature change columns calculate the difference between the average annual precipitation and average temperature of the climate scenario and the baseline run. For example, if the average temperature change is positive, then the climate scenario has a greater average temperature than the baseline run for the time period.



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Loaded Files:	Data Name:	Scenario Name (edit here):	StudyAreaName:	ScenarioName:	RunStartTime:	StartDate:	EndDate:	ModelMode:	Avg Annual Precip	Avg Temperature	Precipitation Change	Temperature Change
2	H:\ERD\ANCHOR\Assj	Wading3mile_TF	Baseline2002	Wading3Mile	TN2002baselin	7/1/2018 12:35	1/1/2002	12/31/2002	Hydrology & Loa	42.05	52.697		
3	H:\ERD\ANCHOR\Assj	Wading3M	Baseline3.3	Wading3Mile	baseline3.3.5	6/29/2018 13:25	1/1/2002	12/31/2002	Hydrology & Loa	50.32	55.997	8.27	3.3
4	H:\ERD\ANCHOR\Assj	Wading3M_2	Baseline3.7	Wading3Mile	baseline3.7m2	6/29/2018 13:35	1/1/2002	12/31/2002	Hydrology & Loa	41.182	56.397	-0.868	3.7
5	H:\ERD\ANCHOR\Assj	Wading3M_3	Baseline4.4	Wading3Mile	baseline4.410	6/29/2018 13:42	1/1/2002	12/31/2002	Hydrology & Loa	46.258	57.097	4.208	4.4
6	H:\ERD\ANCHOR\Assj	Wading3M_4	Baseline5.0	Wading3Mile	baseline5.0m1	6/30/2018 15:32	1/1/2002	12/31/2002	Hydrology & Loa	41.348	57.697	-0.702	5
7	H:\ERD\ANCHOR\Assj	Wading3M_5	Baseline6.2	Wading3Mile	baseline6.219	6/29/2018 14:05	1/1/2002	12/31/2002	Hydrology & Loa	50.287	58.897	8.237	6.2

In this example, the precipitation difference between the climate scenarios and the baseline run varies, with less annual precipitation in the GCM $\Delta T = +3.7^\circ\text{F}/\Delta P = -2.2\%$ and $\Delta T = +5.0^\circ\text{F}/\Delta P = -1.7\%$ climate scenarios (-0.868 and -0.702 in/year, respectively) and more precipitation in all the other climate scenarios compared to 2002 (up to from +4.208 and +8.237 in/year). The average temperature in the future climate scenarios is always greater than the baseline year of 2002, varying from +3.3°F to +6.2°F.

4.2 Comparing Results Across Baseline and Climate Scenarios

In this section, we detail how to use the functions in ScenCompare to compare model input data (e.g., baseline hydrology and loading time series) and model results across scenarios. Function buttons can be found under Step 2 and Step 3 on the Controls tab to facilitate the creation of tables and graphs, and all Excel functionality can be used with the Model Input Data and Model Results tabs to facilitate data value comparisons.

4.2.1 Compare Model Input Data

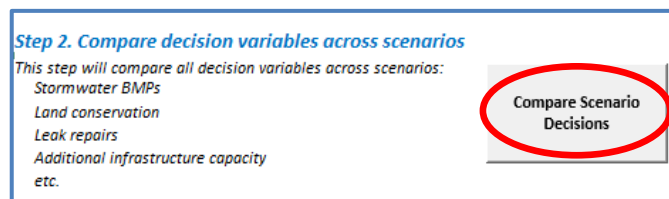
First, we look at the model input data. As an example, we will consider the first comparison type in our list: the baseline historical run versus the future climate scenarios with no management targets or land use decisions. In this run, the only varying model input data is the hydrology data inputs (runoff, recharge, runoff loadings, and recharge loadings). To see this, we navigate to the Model Results tab and filter the “Data Difference” column to show only values of “1”. Values of “1” indicate that the input data values are different in at least one scenario. Values of “0” indicate that the input data values are all the same.

	U	V	W	X	Y	
Wading3M_5	-	Wadir	-	Wading3M_5	-	Data Difference
AvgAnnualPrecip	None	50.287	total inches per year			1
AvgTemp	None	58.897	deg F			1
QRuT	1;1	8.9818	in/acre/month			1
QRuT	2;1	5.95246	in/acre/month			1
QRuT	3;1	15.0658	in/acre/month			1
QRuT	4;1	10.6832	in/acre/month			1
QRuT	5;1	17.6976	in/acre/month			1
QRuT	6;1	11.9563	in/acre/month			1
QRuT	7;1	0.95592	in/acre/month			1
QRuT	8;1	6.34416	in/acre/month			1
QRuT	9;1	19.1135	in/acre/month			1
QRuT	10;1	12.068	in/acre/month			1
QRuT	11;1	18.4752	in/acre/month			1
QRuT	12;1	16.9107	in/acre/month			1
QReT	1;1	37.0396	in/acre/month			1
QReT	2;1	21.9068	in/acre/month			1
QReT	3;1	58.6548	in/acre/month			1
QReT	4;1	28.8215	in/acre/month			1
QReT	5;1	47.4223	in/acre/month			1
QReT	6;1	19.4081	in/acre/month			1
QReT	9;1	26.7919	in/acre/month			1
QReT	10;1	34.0932	in/acre/month			1
QReT	11;1	78.5421	in/acre/month			1
QReT	12;1	75.2742	in/acre/month			1
LRuT	1;1;1	2.38654	lbs/acre/month			1
LRuT	2;1;1	1.90926	lbs/acre/month			1

After filtering the “Data Difference” column for values of “1”, we see that only the climate statistics (AvgAnnualPrecip and AvgTemp) and the monthly runoff and recharge hydrology and loadings statistics²⁸ (QRuT, QReT, LRuT, and LReT [not shown in above image]) differ between the scenarios.

4.2.2 Compare Cost and Decision Variables Across Scenarios

Next, we look at the difference in decision variables across the scenario results. To do this, go to the Controls tab and select the “Compare Scenario Decisions” button under Step 2.



This button will generate the **Table Comparison** tab, which displays all the cost and decision variables from the model results. Cost variables begin with a “C” and decision variables begin with a “D”.

This table first shows the objective cost across scenarios, followed by the specific cost and decision variables. The image below shows the objective cost (total annual cost for watershed management) and the 16 HRU land use decisions for the baseline land area set. To the right of the scenario comparison,

²⁸ The statistics represent the monthly sum of runoff or recharge per acre for all land area for each managed set.

there is a “Data Difference” column, which can be used to filter varying values, and buttons to navigate back to the Controls tab or generate graphs that compare the objective cost to the climate statistics.

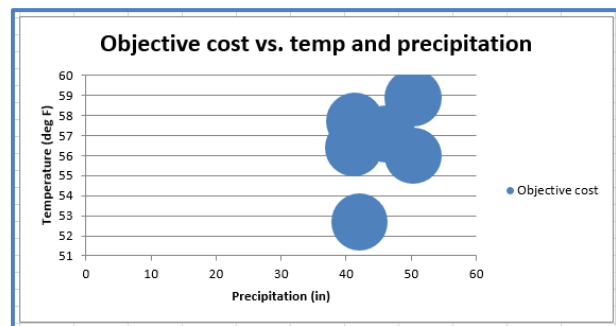
Variable	Description	Units	Baseline2002	Baseline_GCM-3.3	Baseline_GCM-3.7	Baseline_GCM-4.4	Baseline_GCM-5.0	Baseline_GCM-6.2	Data Difference
objective	Objective cost	S/yr	4524.5	4524.5	4524.5	4524.5	4524.5	4524.5	0
DALu11	Land Area - Land Area w/ Conservation, forest sand	ac	13647.0	13647.0	13647.0	13647.0	13647.0	13647.0	0
DALu21	Land Area - Land Area w/ Conservation, open nonres sand	ac	2296.4	2296.4	2296.4	2296.4	2296.4	2296.4	0
DALu31	Land Area - Land Area w/ Conservation, MLD res sand	ac	5948.7	5948.7	5948.7	5948.7	5948.7	5948.7	0
DALu41	Land Area - Land Area w/ Conservation, MHHD resid sand	ac	973.2	973.2	973.2	973.2	973.2	973.2	0
DALu51	Land Area - Land Area w/ Conservation, comindtr sand	ac	2536.9	2536.9	2536.9	2536.9	2536.9	2536.9	0
DALu61	Land Area - Land Area w/ Conservation, ag sand	ac	634.2	634.2	634.2	634.2	634.2	634.2	0
DALu71	Land Area - Land Area w/ Conservation, forest till	ac	12553.5	12553.5	12553.5	12553.5	12553.5	12553.5	0
DALu81	Land Area - Land Area w/ Conservation, open nonres till	ac	1082.6	1082.6	1082.6	1082.6	1082.6	1082.6	0
DALu91	Land Area - Land Area w/ Conservation, MLD res till	ac	2821.2	2821.2	2821.2	2821.2	2821.2	2821.2	0
DALu101	Land Area - Land Area w/ Conservation, MHHD resid till	ac	448.3	448.3	448.3	448.3	448.3	448.3	0
DALu111	Land Area - Land Area w/ Conservation, comindtr till	ac	1104.4	1104.4	1104.4	1104.4	1104.4	1104.4	0
DALu121	Land Area - Land Area w/ Conservation, ag till	ac	240.6	240.6	240.6	240.6	240.6	240.6	0
DALu131	Land Area - Land Area w/ Conservation, cranberry bog	ac	98.4	98.4	98.4	98.4	98.4	98.4	0
DALu141	Land Area - Land Area w/ Conservation, forested wetland	ac	6473.6	6473.6	6473.6	6473.6	6473.6	6473.6	0
DALu151	Land Area - Land Area w/ Conservation, nonforested wetland	ac	2132.3	2132.3	2132.3	2132.3	2132.3	2132.3	0
DALu161	Land Area - Land Area w/ Conservation, water	ac	1330.5	1330.5	1330.5	1330.5	1330.5	1330.5	0

For this table, when we try to filter the “Data Difference” column for varying values, we find that there are no differences across the scenarios for the objective cost and all of the other variables. This result is not surprising because there were no management targets (flow or loadings) set for any of the scenarios in the baseline run. We used the baseline run to determine the flows and costs associated with the watershed and model time period, and checked whether we could achieve the same targets under future climate scenarios.

Next, using the “Make Climate Graphs” button, we generated three climate graphs to compare the objective costs across the scenarios. This button produces a new tab titled **ClimateGraph_objective**, which has a table of the climate statistics and the objective cost for all scenarios, and three graphs: 1) Objective cost vs. precipitation, 2) Objective Cost vs. temperature, and 3) Objective cost vs. temperature and precipitation.



The Objective cost vs. temperature and precipitation graph shows a bubble plot of the objective cost, where the area of the bubble is related to the magnitude of the objective cost and graphed with the temperature statistics on the y-axis and the precipitation statistic on the x-axis, to show how costs vary by climate. In this example, the objective cost bubbles are uniform because the objective costs do not vary by scenario.



4.2.3 Compare Time Series Variables Across Scenarios

Finally, we look at the comparisons available for the results time series variables such as the discharge from the watershed. Under Step 3, on the Controls tab, you can select one or more variables you would like to compare on their own tab. Select the variables of interest in the “Series Variables” column, and click the “Create Tables and Graphs from Selected Variables” button to generate a new tab for each variable. In this case, we selected DQSwExt, the flow time series of surface water flowing outside the watershed. The flow regime from surface water to the external watershed is an indicator of watershed health because it represents the volume of water available to the stream and downstream watersheds after the water is used for human demand.

Step 3. Compare time series across scenarios.

Series Variables (select below)	Category	Description
ComAsr	O&M Costs	Aquifer storage and recovery (ASR)
ComESep	O&M Costs	Enhanced septic treatment
ComGwPump	O&M Costs	Groundwater pumping
ComIbtW	O&M Costs	Interbasin transfer (IBT) potable water
ComIbtWw	O&M Costs	IBT wastewater
ComNpdist	O&M Costs	Nonpotable distribution system
ComOS	O&M Costs	Operation cost of offline storage use
ComRes	O&M Costs	Reservoir management
ComSwPump	O&M Costs	Surface water pumping
ComWrf	O&M Costs	Water reuse facility (WRF)
ComWtp	O&M Costs	Water treatment
ComWwtp	O&M Costs	Wastewater treatment
DQCSOS	Flow	Combined sewer to offline storage
DQGWExt	Flow	Groundwater to external
DQGWMake	Flow	Groundwater deficits
DQGWwtp	Flow	Groundwater to water treatment plant
DQIbtWUseNp	Flow	IBT potable water to nonpotable water use
DQIbtWUseP	Flow	IBT potable water to potable water use
DQOSWwtp	Flow	Offline storage to wastewater treatment plant
DQResAsr	Flow	Reservoir to ASR
DQResWtp	Flow	Reservoir to water treatment plant
DQSwAsr	Flow	Surface water to ASR
DQSwExt	Flow	Surface water to external
DQSwWtp	Flow	Surface water to water treatment plant

Create Tables and Graphs from Selected Variables

Clear Tables and Graphs

After selecting the button, a new tab is created entitled **Table DQSwExt**. On the left side of this tab, there is a table of the time series for all scenarios, as well as the minimum, average, and maximum statistics for the time series, and a time step count threshold. The count threshold defaults to zero, but it can be edited to calculate the count of time steps above a certain value. In the example below, we can see that the flow out of the watershed exceeds zero for all days in the time period.

Surface water to external	Baseline2002	Baseline_GCM-3.3	Baseline_GCM-3.7	Baseline_GCM-4.4	Baseline_GCM-5.0	Baseline_GCM-6.2		
MIN	4.91604281	4.923838995	4.923838995	4.852392972	4.629905929	4.890133854		
AVERAGE	113.7807581	140.0302234	140.0302234	124.4070025	105.762474	136.9017693		
MAX	394.1073415	486.2379146	486.2379146	439.6757833	382.8236989	483.7298046		
COUNT > 0	365	365	365	365	365	365	Count Threshold (edit):	0
1/1/2002	131.4222063	131.1075806	131.1075806	131.3151699	131.2154625	131.1097389		
1/2/2002	98.65000245	98.94297298	98.94297298	98.70411448	98.82435458	98.80215908		
1/3/2002	105.5583947	105.3437909	105.3437909	105.1340121	105.0347991	105.0600119		
1/4/2002	99.60279215	99.29465405	99.29465405	98.97426677	98.91342454	98.89097536		
1/5/2002	93.50104626	93.18199199	93.18199199	92.67792243	92.67217684	92.67959862		
1/6/2002	92.91998335	93.10734564	93.10734564	92.24913241	92.28638843	92.52314579		
1/7/2002	129.9370666	141.3680892	141.3680892	134.5667786	126.534404	140.5475422		

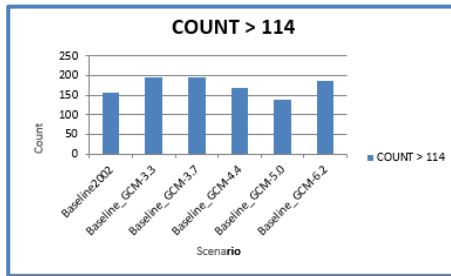
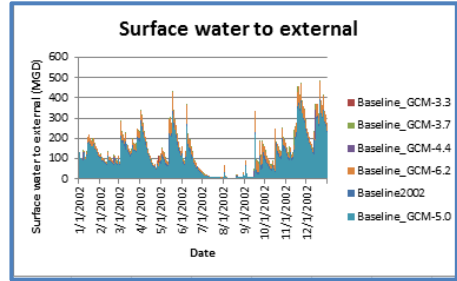
As an example, we changed the count threshold to 114 MGD (the average flow of the baseline scenario) and found that most of the scenarios had more time steps with flow out of the watershed exceeding the baseline average compared to the baseline. However, the GCM 5.0 to -1.7 scenario did not follow this trend, with fewer time steps exceeding the baseline average compared to the baseline scenario.

Surface water to external	Baseline2002	Baseline_GCM-3.3	Baseline_GCM-3.7	Baseline_GCM-4.4	Baseline_GCM-5.0	Baseline_GCM-6.2		
MIN	4.91604281	4.923838995	4.923838995	4.852392972	4.629905929	4.890133854		
AVERAGE	113.7807581	140.0302234	140.0302234	124.4070025	105.762474	136.9017693		
MAX	394.1073415	486.2379146	486.2379146	439.6757833	382.8236989	483.7298046		
COUNT > 114	155	196	196	168	137	186	Count Threshold (edit):	114

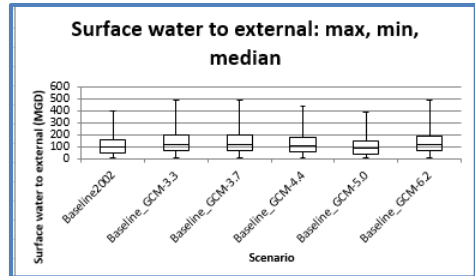
4.2.3.1 Time Series Graphs

The time series comparison tab also has graphing functions available. On the right side of this tab, there are three graphs: 1) a time series graph, 2) a count threshold histogram, and 3) a box plots graph.

The time series graph (right) shows the flow or loadings time series for the model period and all scenarios. Depending on the number of scenarios, you may need to change the order of the time series to better see the comparison between flows. In this example, we brought the baseline and GCM 5.0/-1.7 to the forefront to see the magnitude of the flows in comparison to scenarios with larger flows, like GCM 6.2/19.4.



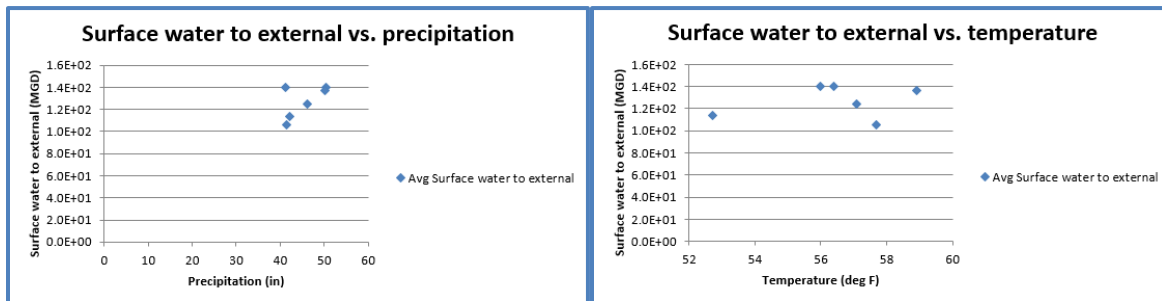
The count threshold histogram (left) shows a column chart of the number of threshold exceedances for each scenario. The histogram changes whenever the count threshold is edited. The box plots graph (right) shows box plots displaying the minimum, first quartile, median, third quartile, and maximum flows for each scenario.



It shows how the distribution of flow magnitudes vary by scenario. We see that the GCM 3.3/19.5 scenario has the largest spread, though it is similar to other scenarios.

4.2.3.2 Climate Graphs

The time series comparison tab also has climate graphing functionality. On the right side of the tab, you can use the “Make Climate Graph” button, to create a new tab titled **ClimateGraph DQSwExt**. This tab creates a similar tab as seen in Section 4.2.2, with three climate graphs showing the average time series value for all scenarios versus the climate statistics (average annual precipitation and average temperature).



The images above show the average flow out of the watershed compared to precipitation and temperature. In the precipitation graph, we see a trend with increasing annual precipitation and larger flows, although the GCM $\Delta T = +3.7^\circ\text{F}/\Delta P = -2.2\%$ appears to be an outlier. We see no clear trend between temperature and flows, which indicates that annual precipitation likely has a larger effect on stream flows.

4.3 Land Use Optimization Scenarios

In this section, we discuss the two land use optimization scenarios developed for the Wading-Threemile watershed, the optimal stormwater BMP and the optimal riparian zone implementation, as well as how to compare and analyze land management variables within ScenCompare.

4.3.1 Compare Robustness of Land Management Variables Decisions Across Climate Scenarios

The second and third comparison types for this case study, the optimal stormwater BMP and optimal riparian zone implementation, were developed to test the robustness of the WMOST land use management decisions in future climate scenarios, i.e., whether the optimal set would change in the future. We show how the model decisions varied by climate scenario for each run in the following sections.

4.3.1.1 Stormwater BMP Optimization Scenarios

For the stormwater BMP comparison, we modeled a fixed set of stormwater land use BMPs optimized for the historical baseline run with a user-specified stream loadings target, and modeled the five future climate scenarios with the stormwater land use BMPs fixed at the 2002 solution and with no stream loadings target. For the future climate scenarios, although WMOST had no decision variables with respect to BMP implementation, there were still decision variables related to meeting water demand. The optimal stormwater BMP selected was 1,088 acres of infiltration basins with a 0.6” design depth on Commercial/Industrial/Transportation land use on a till and fine-grained deposits soil type. Using this stormwater BMP set, we found that the optimization models for the future climate scenarios determined a least-cost objective value of about \$6,414/year, which is slightly lower than the historical baseline scenario objective value of \$6,430/year.

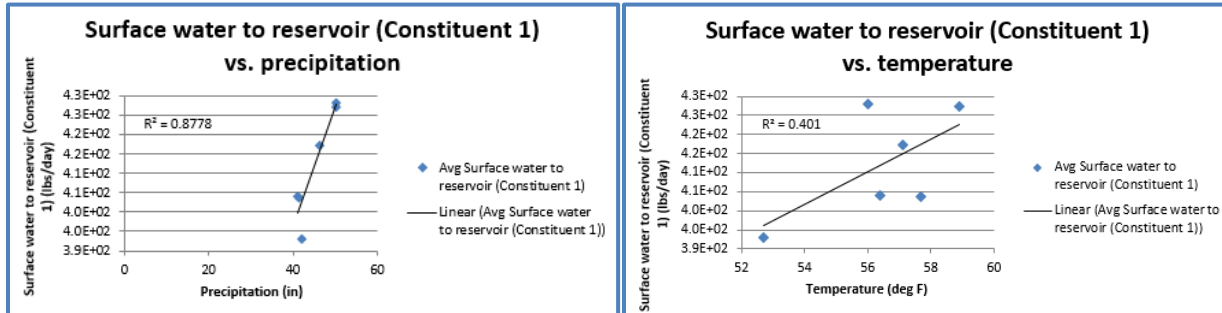
Variable	Description	Units	OptBMPs_Baseline	OptBMPs_GCM-3.7	OptBMPs_GCM-4.4	OptBMPs_GCM-5.0	OptBMPs_GCM-6.2	optbmps3.99.5	Data Difference
Objective	Objective cost	\$/yr	6430.9395	6414.6307	6414.6307	6414.6307	6414.6307	6414.6307	1
CGWPump	Total cost of groundwater pumping	\$/yr	490.0586873	291.19066	291.19066	291.19066	291.19066	291.19066	1
CSWPump	Total cost of surface water pumping	\$/yr	117.8049938	124.0212959	124.0212959	124.0212959	124.0212959	124.0212959	1
CbtW	Total cost of IBT potable water	\$/yr	362.3837596	538.7266703	538.7266703	538.7266703	538.7266703	538.7266703	1

The cost difference between the baseline and climate scenarios occur in the model’s usage of groundwater pumping, surface water pumping, and interbasin transfer of potable water.

We used the “Create Tables and Graphs from Selected Variables” button to tabulate and graph the loadings time series LSwRes, which is the loadings flow from the stream to the reservoir, and the flow upon which the stream loadings target is based. By changing the Count Threshold to 1,156 lbs (the baseline stream loading target), we found that the stream loadings for two of the five future climate scenarios achieved the baseline loadings target. The other three scenarios exceeded the loadings target on only one time step in the model period.

Surface water to reser	OptBMPs_Baseline	OptBMPs_GCM-3.3	OptBMPs_GCM-3.7	OptBMPs_GCM-4.4	OptBMPs_GCM-5.0	OptBMPs_GCM-6.2		
MIN	42.59782234	138.3093323	131.7356999	134.8816899	131.3388132	138.0435979		
AVERAGE	392.9978659	428.0723073	404.0083285	417.1245325	403.8378292	427.2204664		
MAX	1147.533395	1188.52981	1150.731899	1172.097451	1151.979989	1189.114321		
COUNT > 1156	0	1	0	1	0	1	Count Threshold (edit):	1156

When comparing the loadings in the surface water to the climate statistics, we found that, in general, the average surface water loadings increased with increasing precipitation and increasing temperature. As shown in the images below, the linear relationship between stream loadings and precipitation is stronger than the relationship between stream loadings and temperature, with an r^2 value of 0.8778 for precipitation versus an r^2 value of 0.401 for temperature.



4.3.1.2 Riparian Buffer Optimization Scenarios

For the riparian buffer run, we modeled a selection of 10 potential riparian buffer land conversions from developed land to forest with the same climate scenarios and stream loadings targets as the stormwater BMP run (i.e., with a loading target for the historical baseline run and no loadings target for the future climate scenarios). The optimization model selected the optimal riparian buffer land use conversion with the least cost.

We found that the model selected all of the same riparian conversion sets, except the baseline run did not select the conversion from HRU 4 (medium/high-density residential on sand-and-gravel soil type) to HRU 1 (forest on sand-and-gravel soil type) for loads group three, as indicated by the zero value for CRipSet133, which resulted in a lower total riparian conversion cost (CRipTotal).

Variable	Description	Unit	OptRip1	OptRip2	OptRip3	OptRip4	OptRip5	OptRip6	Data Difference
objective	Objective cost	\$/yr	574.0	5533.1	5533.1	5533.1	5533.1	5533.1	1
CRipSet111	LU Conv. From HRU2 To HRU1 - Cost of riparian buffer land use conversion set for loads group 1	\$/yr	3.6	3.6	3.6	3.6	3.6	3.6	0
CRipSet112	LU Conv. From HRU2 To HRU1 - Cost of riparian buffer land use conversion set for loads group 2	\$/yr	62.0	62.0	62.0	62.0	62.0	62.0	0
CRipSet113	LU Conv. From HRU2 To HRU1 - Cost of riparian buffer land use conversion set for loads group 3	\$/yr	0.0	0.0	0.0	0.0	0.0	0.0	0
CRipSet121	LU Conv. From HRU3 To HRU1 - Cost of riparian buffer land use conversion set for loads group 1	\$/yr	3.6	3.6	3.6	3.6	3.6	3.6	0
CRipSet122	LU Conv. From HRU3 To HRU1 - Cost of riparian buffer land use conversion set for loads group 2	\$/yr	210.0	210.0	210.0	210.0	210.0	210.0	0
CRipSet123	LU Conv. From HRU3 To HRU1 - Cost of riparian buffer land use conversion set for loads group 3	\$/yr	0.0	0.0	0.0	0.0	0.0	0.0	0
CRipSet132	LU Conv. From HRU4 To HRU1 - Cost of riparian buffer land use conversion set for loads group 2	\$/yr	79.5	79.5	79.5	79.5	79.5	79.5	0
CRipSet133	LU Conv. From HRU4 To HRU1 - Cost of riparian buffer land use conversion set for loads group 3	\$/yr	0.0	48.0	48.0	48.0	48.0	48.0	1
CRipSet141	LU Conv. From HRU5 To HRU1 - Cost of riparian buffer land use conversion set for loads group 1	\$/yr	1.1	1.1	1.1	1.1	1.1	1.1	0
CRipSet142	LU Conv. From HRU5 To HRU1 - Cost of riparian buffer land use conversion set for loads group 2	\$/yr	184.0	184.0	184.0	184.0	184.0	184.0	0
CRipSet143	LU Conv. From HRU5 To HRU1 - Cost of riparian buffer land use conversion set for loads group 3	\$/yr	0.0	0.0	0.0	0.0	0.0	0.0	0
CRipSet152	LU Conv. From HRU6 To HRU1 - Cost of riparian buffer land use conversion set for loads group 2	\$/yr	12.5	12.5	12.5	12.5	12.5	12.5	0
CRipSet153	LU Conv. From HRU6 To HRU1 - Cost of riparian buffer land use conversion set for loads group 3	\$/yr	44.7	44.7	44.7	44.7	44.7	44.7	0
CRipSet161	LU Conv. From HRU8 To HRU7 - Cost of riparian buffer land use conversion set for loads group 1	\$/yr	4.1	4.1	4.1	4.1	4.1	4.1	0
CRipSet162	LU Conv. From HRU8 To HRU7 - Cost of riparian buffer land use conversion set for loads group 2	\$/yr	62.0	62.0	62.0	62.0	62.0	62.0	0
CRipSet163	LU Conv. From HRU8 To HRU7 - Cost of riparian buffer land use conversion set for loads group 3	\$/yr	0.0	0.0	0.0	0.0	0.0	0.0	0
CRipSet171	LU Conv. From HRU9 To HRU7 - Cost of riparian buffer land use conversion set for loads group 1	\$/yr	12.9	12.9	12.9	12.9	12.9	12.9	0
CRipSet172	LU Conv. From HRU9 To HRU7 - Cost of riparian buffer land use conversion set for loads group 2	\$/yr	122.3	122.3	122.3	122.3	122.3	122.3	0
CRipSet173	LU Conv. From HRU9 To HRU7 - Cost of riparian buffer land use conversion set for loads group 3	\$/yr	0.0	0.0	0.0	0.0	0.0	0.0	0
CRipSet181	LU Conv. From HRU10 To HRU7 - Cost of riparian buffer land use conversion set for loads group 1	\$/yr	1.9	1.9	1.9	1.9	1.9	1.9	0
CRipSet182	LU Conv. From HRU10 To HRU7 - Cost of riparian buffer land use conversion set for loads group 2	\$/yr	45.8	45.8	45.8	45.8	45.8	45.8	0
CRipSet183	LU Conv. From HRU10 To HRU7 - Cost of riparian buffer land use conversion set for loads group 3	\$/yr	0.0	0.0	0.0	0.0	0.0	0.0	0
CRipSet191	LU Conv. From HRU11 To HRU7 - Cost of riparian buffer land use conversion set for loads group 1	\$/yr	1.6	1.6	1.6	1.6	1.6	1.6	0
CRipSet192	LU Conv. From HRU11 To HRU7 - Cost of riparian buffer land use conversion set for loads group 2	\$/yr	103.4	103.4	103.4	103.4	103.4	103.4	0
CRipSet193	LU Conv. From HRU11 To HRU7 - Cost of riparian buffer land use conversion set for loads group 3	\$/yr	0.0	0.0	0.0	0.0	0.0	0.0	0
CRipSet1102	LU Conv. From HRU12 To HRU7 - Cost of riparian buffer land use conversion set for loads group 2	\$/yr	5.5	5.5	5.5	5.5	5.5	5.5	0
CRipSet1103	LU Conv. From HRU12 To HRU7 - Cost of riparian buffer land use conversion set for loads group 3	\$/yr	0.0	0.0	0.0	0.0	0.0	0.0	0
CRipTotal	Total cost of applying riparian buffer land management sets	\$/yr	960.6	1008.5	1008.5	1008.5	1008.5	1008.5	1

4.3.2 Compare Land Management Variables Across Scenarios

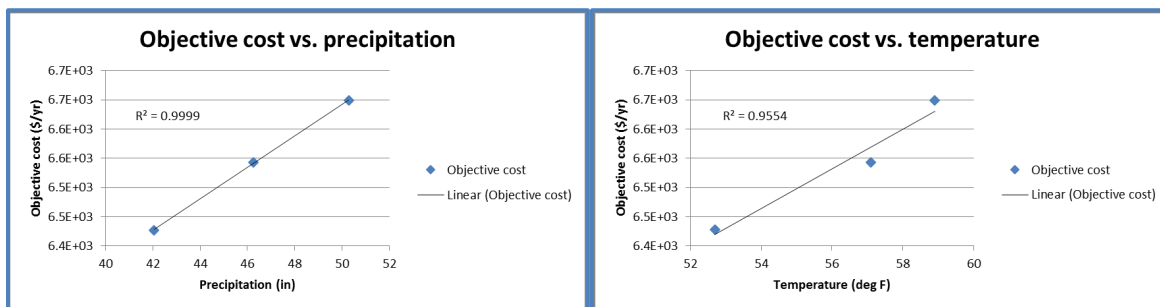
In this section, we provide an example of how to compare the least-cost type and magnitude of application of stormwater BMPs identified by WMOST to meet the user-specified loading target under the historical baseline and two future climate scenarios (GCM 4.4/10.1 [the median scenario] and GCM 6.2/19.4 [an extreme bounding scenario]). In these cases, the optimization model is allowed to decide how much land area to allocate to a stormwater BMP. In this run, the stream loadings target for TN was applied for all scenarios.

We viewed the different stormwater BMP decisions made by using the “Compare Scenario Decisions” button to create the **Table Comparison** tab. After filtering the “Data Difference” column for values of “1”, we found that, for all scenario runs, to meet the loading target at least cost, the model selected an Infiltration Basin with a design depth of 0.6” to be implemented on the Commercial/Industrial/Transportation land use on the sand-and-gravel soil type and till-and-fine-grained deposits soil type (DALu52 and DALu112, respectively).

Variable	Description	Units	BMPs_Baseline2002	BMPs_GCM-4.4	BMPs_GCM-6.2	Data Difference
objective	Objective cost	\$/yr	6427.4676	6543.0085	6649.0394	1
DALu52	Land Area - 0.6" Infiltr ac		0.0000174	53.16350656	114.7482124	1
DALu112	Land Area - 0.6" Infiltr ac		1090.555717	1104.442104	1104.442104	1
CLuSet2	0.6" Infiltration Basin	\$/yr	1894.536918	2010.916898	2117.786745	1
CGwPump	Total cost of groundv	\$/yr	479.1857416	483.2004344	489.1591315	1
CSwPump	Total cost of surface	\$/yr	120.8216609	121.1416244	121.4615879	1
ClbtW	Total cost of IBT pote	\$/yr	362.3282006	357.1545276	350.0369083	1

The land use allocation for this BMP changed across all three climate scenarios. The baseline scenario selected the BMP only on the till and fine-grained deposits soil type (the value for DALu52 is negligible), and the future climate scenarios selected the BMP for both the sand-and-gravel and till-and-fine-grained deposits soil types, with a larger allocation of overall land area for the BMP in the extreme climate scenario (GCM 6.2/19.4).

We also see that the objective cost increased from the baseline scenario to the future climate scenarios, with the highest objective cost occurring in the extreme climate scenario. The climate comparison graphs show an extremely close linear relationship between objective cost and increasing precipitation and temperature with r^2 values of 0.9999 and 0.9554, respectively.



5 References

- Brekke, L., B.L. Thrasher, E.P. Maurer, and T. Pruitt. (2013). Downscaled CMIP3 and CMIP5 Climate Projections: Release of Downscaled CMIP5 Climate Projections, Comparison with Preceding Information, and Summary of User Needs. Avail. At: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/.
- Detenbeck, N., A. Piscopo, M. ten Brink, C. Weaver, A. Morrison, T. Stagnitta, R. Abele, J. LeClair, T. Garrigan, V. Zoltay, A. Brown, A. Le, J. Stein, and I. Morin. (2018a). Watershed Management Optimization Support Tool v3. U.S. Environmental Protection Agency, Washington, DC, EPA/600/C-18/001.
- Detenbeck, N., A. Piscopo, M. ten Brink, C. Weaver, A. Morrison, T. Stagnitta, R. Abele, J. LeClair, T. Garrigan, V. Zoltay, A. Brown, A. Le, J. Stein, and I. Morin. (2018b). Watershed Management Optimization Support Tool (WMOST) v3: User Guide. US EPA Office of Research and Development, Washington, DC, EPA/600/R-17/255.
- Detenbeck, N., M. ten Brink, A. Piscopo, A. Morrison, T. Stagnitta, R. Abele, J. LeClair, T. Garrigan, V. Zoltay, A. Brown, A. Le, J. Stein, and I. Morin. (2018c). Watershed Management Optimization Support Tool (WMOST) v3: Theoretical Documentation. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-17/220.
- Interagency Working Group on Social Cost of Carbon (IWGSCC), United States Government. (2016). Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866. Revised August 2016.
- Intergovernmental Panel on Climate Change (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151.
- Krewski D., M. Jerrett, R.T. Burnett, R. Ma, E. Hughes, and Y. Shi, et al. (2009). Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. Research report. Health Effects Institute, 2009, 5-114 (discussion 115–36).
- Lempert, Robert J., and Myles Collins. (2007). Managing the Risk of Uncertain Threshold Responses: Comparison of Robust, Optimum, and Precautionary Approaches, *Risk Analysis* 27(4):1009 –1026.
- Lepeule, J., F. Laden, D. Dockery, and J. Schwartz. (2012). Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities study from 1974 to 2009. *Environmental Health Perspectives* 120(7), 965-70.
- Mazzotta, M.J, E. Besedin, and A.E. Speers. (2014). A Meta-Analysis of Hedonic Studies to Assess the Property Value Effects of Low Impact Development. *Resources*, 3(1), 31-61.
- Morefield, P. (2016). Locating and Selecting Scenarios On-line (LASSO). Presentation to the STAC Climate Change Scenarios Workshop, March 7-8, 2016. Avail. at: http://www.chesapeake.org/stac/presentations/258_Morefield_climate_tool_STAC_scenarios%20workshop_v2.pdf

Nowak, D. J., and E. J. Greenfield. (2012). Tree and impervious cover in the United States. *Landscape and Urban Planning*, 107(1), 21-30.

Nowak, D.J., S. Hirabayashi, A. Bodine, and E. Greenfield. (2014). Tree and forest effects on air quality and human health in the United States. *Environmental Pollution*, 193, 119-129.

Nowak, D.J., N. Appleton, A. Ellis, and E. Greenfield. (2017). Residential building energy conservation and avoided power plant emissions by urban and community trees in the United States. *Urban Forestry & Urban Greening*, 21, 158-165.

RTI. 2014. Strengthening the Resilience of the Taunton River Watershed: A Tool to Prioritize Local Action. Prepared by RTI International for the U.S. Environmental Protection Agency. Available at: <https://www.epa.gov/sites/production/files/2015-11/documents/hwptauntonriver.pdf>.

Sheffield, J. et al. (2015). North American Climate in CMIP5 Experiments. Part I: Evaluation of Historical Simulations of Continental and Regional Climatology. *Journal of Climate* 26: 9209-9245.

United States Energy Information Administration (U.S. EIA). (2018). Average retail price of electricity (cent per kilowatthour). Retrieved from: <https://www.eia.gov/electricity/data/browser/#/topic/7?agg=1,0&geo=vvvvvvvvvvvo&endsec=8&freq=A&start=2001&end=2018&ctype=linechart<ype=pin&rtype=s&matype=0&rse=0&pin=>

United States Environmental Protection Agency (U.S. EPA). (2005). Technologies and Costs Document for the Final Long Term 2 Enhanced Surface Water Treatment Rule and Final Stage 2 Disinfectants and Disinfection Byproducts Rule. EPA 815-R-05-013. U.S. EPA, Office of Water, Washington, DC. December 2005.

United States Environmental Protection Agency (U.S. EPA). (2009). Environmental Impact and Benefits Assessment for Final Effluent Guidelines and Standards for the Construction and Development Category (EPA Document 821-R-09-012). Washington, D.C.: U.S. EPA Office of Water.

United States Environmental Protection Agency (U.S. EPA). (2015). Benefit and Cost Analysis for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category (EPA Document 821-R-15-005). Washington, D.C.: U.S. EPA Office of Water.

United States Environmental Protection Agency (U.S. EPA). (2018). Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors. Technical Support Document. February 2018.

United States Environmental Protection Agency (U.S. EPA). (2019a). Regulatory Impact Analysis for Repeal of the Clean Power Plan; Emission Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units; Revisions to Emission Guidelines Implementing Regulations. EPA-452/R-19-003. June 2019

United States Environmental Protection Agency (U.S. EPA). (2019b). AVERT Avoided Emission Factors 2007-2018. Retrieved from: https://www.epa.gov/sites/production/files/2019-05/documents/avert_emission_factors_05-30-19_508.pdf

United States Environmental Protection Agency (U.S. EPA). (2020 – in review). WMOST ScenCompare Tool with Benefits Module: Theoretical Documentation. EPA/600/R-20/244.

Appendix A. Data needs for the Benefits Module

Table A.1 describes the Benefits Module data requirements to calculate all available benefit and co-benefit categories. If you do not plan to calculate all possible benefit and co-benefit categories, use the “Associated Benefit” column to determine which data needs are required for your selected benefit and co-benefit categories.

Table A.1 Data needs for the Benefits Module

Data Inputs	Data Source	Associated Benefit
Analysis Year	Based on the management option implementation year. User chooses the analysis year in the Benefits Module.	All
Dollar Year	User chooses the dollar year in the Benefits Module.	All
Agricultural land designation	Based on your knowledge of model land uses. You can intersect WBD watersheds (https://www.usgs.gov/core-science-systems/ngp/national-hydrography/access-national-hydrography-products) and NLCD data (https://www.mrlc.gov/data) or reference StreamCat (https://www.epa.gov/national-aquatic-resource-surveys/streamcat).	Total nonmarket benefits of water quality changes
Residential land designation	Based on your knowledge of model land uses. You can intersect WBD watersheds (https://www.usgs.gov/core-science-systems/ngp/national-hydrography/access-national-hydrography-products) and NLCD data (https://www.mrlc.gov/data) or reference StreamCat (https://www.epa.gov/national-aquatic-resource-surveys/streamcat).	Change in housing property value due to improved aesthetic quality of the landscape from increases in green space
Green space percentage	Based on your knowledge of model land uses. You can reference EnviroAtlas (https://www.epa.gov/enviroatlas) for percent green space by census block group.	Change in housing property value due to improved aesthetic quality of the landscape from increases in green space
Number of HUC12s; HUC12 ID; Proportion of HUC12	Based on your knowledge of model study area. You can use the “Science in Your Watershed” resource (https://water.usgs.gov/wsc/map_index.html) to narrow down to the HUC8.	Change in housing property value due to improved aesthetic quality of the landscape from increases in green space; Air pollution removal and energy savings benefits related to canopy cover and green roofs

Table A.1 (Continued)

Data Inputs	Data Source	Associated Benefit
Estimated ratio of turbidity to TSS	U.S. EPA (2009)	Change in water treatment costs
Cost of alum, including dollar year	Based on your knowledge of the water treatment system. You can use EPA values (U.S. EPA, 2005).	Change in water treatment costs
Northeast; Central; South	Based on your knowledge of model study area. You can intersect WBD watersheds (https://www.usgs.gov/core-science-systems/ngp/national-hydrography/access-national-hydrography-products) and state boundaries (https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html).	Total nonmarket benefits of water quality changes
Income and population data	U.S. Census (https://www.census.gov/data.html)	Total nonmarket benefits of water quality changes
BOD, DO, and FC data	Water quality portal (https://www.waterqualitydata.us/portal/) or using the spreadsheet downloaded with ScenCompare (BOD_DO_FC_ByHUCs.xlsx)	Total nonmarket benefits of water quality changes
Wetland	Based on your knowledge of BMP implementation. You can reference the National Wetland Inventory (https://www.fws.gov/wetlands/nwi/Overview.html) or hydrologic model land use definitions to understand if BMP implementation will expand existing wetlands within the study area	Change in housing property value due to improved aesthetic quality of the landscape from increases in green space
Recreational	Based on your knowledge of BMP implementation. You can reference resources from your local natural resources or environmental management department.	Change in housing property value due to improved aesthetic quality of the landscape from increases in green space
Percent tree cover	Hard coded for bioretention basin, grass swale, gravel wetland, and riparian buffer. If WMOST identified land conservation as a cost-effective BMP, you will need to manually enter tree cover percentages for each of the watershed HRUs based on your knowledge of model land uses and informed by Appendix B.	Change in housing property value due to improved aesthetic quality of the landscape from increases in green space

Table A.1 (Continued)

Data Inputs	Data Source	Associated Benefit
Population density	U.S. Census (https://www.census.gov/data.html)	Air pollution removal and energy savings benefits related to canopy cover
Direct energy savings	Green roof calculator: https://sustainability.asu.edu/urban-climate/green-roof-calculator/	Air pollution removal and energy savings benefits related to green space
Location	Based on your knowledge of model study area (see Figure 13).	Air pollution removal and energy savings benefits related to green space
Source of energy savings	Based on your knowledge of energy source for green roof building	Air pollution removal and energy savings benefits related to green space
Price of electricity for residential customers	Based on your knowledge of model population or using the spreadsheet downloaded with ScenCompare (ElectricityPrice_byState.csv)	Air pollution removal and energy savings benefits related to green space

Appendix B. Default tree canopy values

Table B.1 Default percent tree canopy values for each vegetated NLCD land cover class²⁹

Land Cover Class	Land Cover Description	Percent Tree Canopy
11	Open Water – areas of open water	0%
12	Perennial Ice/Snow – areas characterized by a perennial cover of ice and/or snow	0%
31	Barren Land – areas of desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material.	0%
41	Deciduous Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.	100%
42	Evergreen Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.	100%
43	Mixed Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.	100%
51	Dwarf Scrub - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.	0%
52	Shrub/Scrub - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.	30%
71	Grassland/Herbaceous - areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.	0%
72	Sedge/Herbaceous - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.	0%

²⁹ We did not report default percent tree canopy values for developed land cover types as they are unlikely to be conserved within WMOST.

Table B.1 (Continued)

	Land Cover Description	Percent Tree Canopy
73	Lichens - Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.	0%
74	Moss - Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.	0%
81	Pasture/Hay - areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.	0%
82	Cultivated Crops - areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.	0%
90	Woody Wetlands - areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	100%
95	Emergent Herbaceous Wetlands - areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	0%