

# WATERSHED MANAGEMENT OPTIMIZATION SUPPORT TOOL (WMOST) v3

## User Guide







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## Notice

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Although a reasonable effort has been made to assure that the results obtained are correct, the computer programs described in this manual are experimental. Therefore, the author and the U.S. Environmental Protection Agency are not responsible and assume no liability whatsoever for any results or any use made of the results obtained from these programs, nor for any damages or litigation that result from the use of these programs for any purpose.

## Abstract

The Watershed Management Optimization Support Tool (WMOST) is a decision support tool that facilitates integrated water management at the local or small watershed scale. WMOST models the environmental effects and costs of management decisions in a watershed context that is, accounting for the direct and indirect effects of decisions. The model considers water flows and water quality. It is spatially lumped with options for a daily or monthly modeling time step. In this version (v3), management option cost optimization occurs through nonlinear programming. As a screening tool, WMOST contributes to an integrated watershed management process such as that described in EPA's watershed planning handbook (EPA 2008). WMOST serves as a public-domain, efficient, and user-friendly tool for local water resources managers and planners to screen a wide range of potential water resources management options across their jurisdiction for cost-effectiveness and environmental and economic sustainability (Zoltay et al., 2010). WMOST includes functions to evaluate various management practices, including projects related to stormwater (including green infrastructure [GI] and combined sewer overflow ([CSO] systems), stream restoration, water supply, wastewater and land resources such as low-impact development (LID) and land conservation. WMOST can aid in evaluating LID and green infrastructure as alternative or complementary management options in projects proposed for grant funding. In WMOST v3, the Baseline Hydrology and Loadings and Stormwater Hydrology and Loadings Modules assist users with input data acquisition and pre-processing. The Combined Sewer Overflow (CSO) Module allows for the evaluation of management options to minimize the number of CSO events. The Flood Module allows the consideration of flood damages and their reduction in assessing the cost-effectiveness of management practices. The target user group for WMOST consists of local water resources managers, including municipal water works superintendents and their consultants.

Keywords: Integrated watershed management, water resources, decision support, optimization, green infrastructure

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## Preface

Integrated Water Resources Management (IWRM) has been endorsed for use at multiple scales. The Global Water Partnership defines IWRM as “a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems” (UNEP-DHI, 2009). IWRM has been promoted as an integral part of the “Water Utility of the Future” (NACWA, 2013) in the United States. The American Water Resources Association (AWRA) has issued a position statement, calling for implementation of IWRM across the United States and committed the AWRA to help strengthen and refine IWRM concepts.<sup>1</sup>

Several states and river basin commissions have started to implement IWRM (AWRA, 2012). For example, in the arid West, both Oregon and California have incorporated integrated water resources management into their planning strategies.<sup>2</sup> Even in EPA Region 1 where water is relatively plentiful, states face the challenge of developing balanced approaches for equitable and predictable distribution of water resources to meet both human and aquatic life needs during seasonal low flow periods and droughts. The state of Massachusetts recently spearheaded the Sustainable Water Management Initiative (SWMI) process to allocate water among competing human and aquatic life uses in a consistent and sustainable fashion (MA EAA, 2012). WMOST has been applied in pilot projects funded by the state of Massachusetts to apply IWRM in the permit planning process.<sup>3</sup>

Stormwater and land use management are two aspects of IWRM which include practices such as green infrastructure (GI, both natural GI and structural stormwater best management practices [BMPs]), low-impact development (LID) and land conservation. In a few notable cases, local managers have evaluated the relative cost and benefit of preserving green infrastructure compared to traditional approaches. In those cases, the managers have championed the use of green infrastructure as part of a sustainable solution for IWRM, but these examples are rare.<sup>4</sup>

In order to assist communities in the evaluation of GI, LID, and land conservation practices as part of an IWRM approach, EPA’s Office of Research and Development, in partnership with EPA’s Region 1, supported the development of several versions of the Watershed Management Optimization Support Tool (WMOST). Table 0-1 below summarizes the supporting organizations and development of WMOST.

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<sup>1</sup> <http://www.awra.org/policy/policy-statements-IWRM.html>, January 22, 2011.

<sup>2</sup> [http://www.oregon.gov/owrd/pages/law/integrated\\_water\\_supply\\_strategy.aspx](http://www.oregon.gov/owrd/pages/law/integrated_water_supply_strategy.aspx), <http://www.water.ca.gov/irwm/>, accessed June 2017.

<sup>3</sup> See examples at <http://www.abtassociates.com/wma>.

<sup>4</sup> <http://www.crwa.org/blue.html>

**Table 0-1. Summary of Development of WMOST and Supporting Organizations**

Version	Year Released	Supporting Organization(s)	Model Enhancements
Version 1 (v1)	2013	EPA Office of Research and Development (ORD), EPA Region 1	
Version 2 (v2)	2016	RARE grant to EPA Region1 and ORD collaborators, US EPA ORD’s Green Infrastructure Initiative research program	Baseline Hydrology and Stormwater Hydrology Modules
			Flood Damage Module
Version 3 (v3)	2017	US EPA ORD’s Green Infrastructure Initiative research program	Baseline Hydrology and Loadings and Stormwater Hydrology and Loadings Modules
			Water Quality Module
			CSO Module
			Calibration Module

WMOST is based on a prior integrated watershed management optimization model that was created to allow water resources managers to evaluate a broad range of technical, economic, and policy management options within an urban or mixed-use watershed (Zoltay, V. I., 2007; Zoltay et al., 2010). This model includes evaluation of conservation options for source water protection and infiltration of stormwater on forest lands, green infrastructure stormwater BMPs to increase infiltration, and other water quantity and quality related management options.

Development of each version of the WMOST tool was overseen by an EPA Planning Team. Priorities for update and refinement of the original model (Zoltay, V. I., 2007; Zoltay et al., 2010) were established following review by a Technical Advisory Group (TAG) comprised of water resource managers and modelers. Case studies for two communities (Upper Ipswich River, and Danvers/Middleton, MA) were developed to illustrate the application of IWRM using WMOST. These case studies are available from the WMOST website<sup>5</sup>. WMOST was presented to stakeholders in a workshop held at the EPA Region 1 Laboratory in Chelmsford, MA, in April 2013, with a follow-up webinar on the Danvers/Middleton case study in May 2013. Feedback from the Technical Advisory Group and workshop participants has been incorporated into the user guide and theoretical documentation for WMOST.

The development of the Baseline Hydrology, Stormwater Hydrology and Flood Damage Modules in WMOST v2 was assisted by a TAG with expertise in one or more of these topics. Prior to development of WMOST v2, US EPA Region 1 solicited communities in the Taunton River watershed for interest in testing and applying WMOST to solve their problems, and Halifax, MA, was

<sup>5</sup> <https://www.epa.gov/exposure-assessment-models/wmost>



identified as an interested collaborator. Multiple meetings with stakeholders in the Monponsett Pond watershed (Halifax, MA) were held to engage the community in a case study application of WMOST v2. Input from the TAG and community members were incorporated in the final methodology for WMOST v2 and the modeling case study.

WMOST v2.1 corrected for known errors in WMOST v2, but did not include significant model changes. The corrections addressed the following issues:

- Aquifer storage and recharge (ASR) facility constraint and cost equations were using incorrect variable names
- Limits on interbasin transfer volumes
  - limit exclusions were not functioning properly
  - potential additional interbasin transfer volumes were not being correctly multiplied by the number of days in the month when modeling with a monthly time step
- Recharge from pervious and disconnected impervious areas was not blended when calculating total recharge for a hydrologic response unit (HRU)
- WMOST v2 equations inaccurately modeled a time step delay in groundwater discharges from the ASR facility and the septic system
- Cost equation for insufficient water penalty (make-up water) did not include an annualization factor
- Calculation of the annualization factor over the modeling period did not take into account leap years

Two training workshops for WMOST v2.1 were held in summer 2016, the first with joint sessions at EPA Region 1 in Boston, MA, and at the University of RI – Kingston, RI, in June and the second during the International LID conference in Portland, Maine, in August. Presentations from the June workshop were recorded and are available on the WMOST website<sup>5</sup>.

Development of Version 3 of WMOST was informed by input from stakeholders involved in three case study applications of WMOST. The first case study, focused on the upper Taunton River watershed in Massachusetts (Wading, Mill, and Threemile River subwatersheds), was coordinated with a consortium (Manomet, Audubon, Nature Conservancy, and the Southeastern Regional Development Commission), which had received a grant from EPA Region 1 to evaluate the potential uses for and to educate municipalities in the Taunton River watershed about the value of natural and constructed green infrastructure under both current and future climate and growth scenarios. The second case study, focused on the Cabin John Creek watershed in Montgomery County, MD, was designed for the Maryland Department of the Environment (MDE) to evaluate costs and benefits of different stormwater BMPs while meeting local targets for a sediment total maximum daily load (TMDL) as well as downstream loading targets for total suspended solids, total nitrogen, and total phosphorus for the Chesapeake Bay TMDL. The third case study, focused on subwatersheds of the Middle Kansas River, Kansas, was designed with EPA Region 7 and Kansas Department of Health

<sup>5</sup> <https://www.epa.gov/exposure-assessment-models/wmost>

and Environment (KDHE) to evaluate BMPs (including agricultural BMPs) in a mixed land-use watershed to meet waters quality targets for local TMDLs. Results of these case studies will be made available on the WMOST website when complete.

Two ancillary utilities are being developed in conjunction with WMOST v3: a preprocessor (the HydroProcessor) and a Scenario Comparison Tool (ScenCompare), both funded with support from EPA's Safe and Sustainable Waters and from EPA's Air, Climate, and Energy research program. The HydroProcessor facilitates import and formatting of model outputs from hydrological models such as HSPF and SWAT to provide runoff, recharge, and loading inputs to WMOST. The ScenCompare tool facilitates comparison of outputs from multiple WMOST runs, e.g., to evaluate the implications of different climate change scenarios on optimal management actions

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<sup>6</sup> Versions 1 through 3

<sup>7</sup> Versions 1 through 3

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## 1. Background

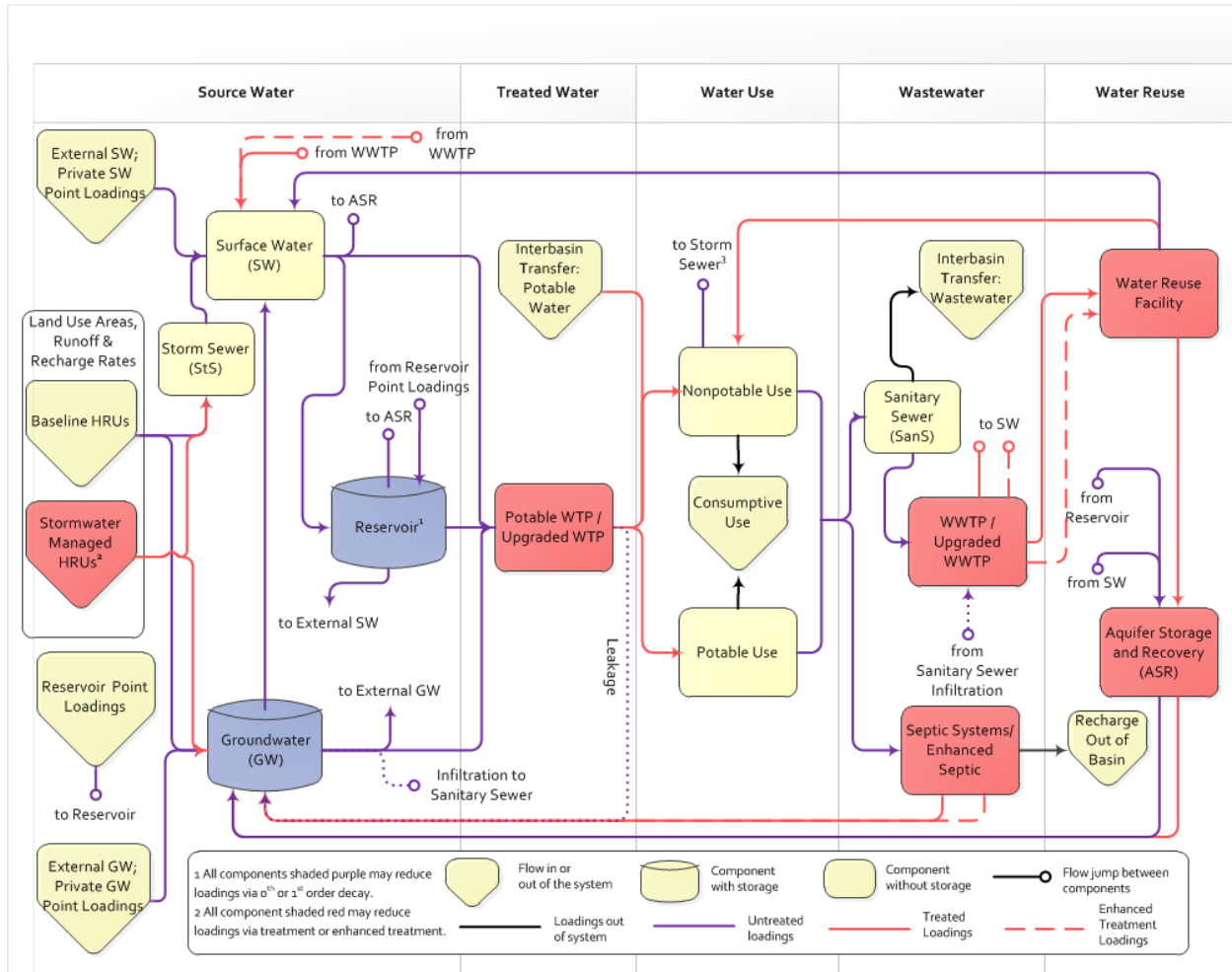
### 1.1 Objective of the Tool

The Watershed Management Optimization Support Tool (WMOST) is a public-domain enhancement to Microsoft Office Excel 2010, 2013 and 2016 designed to aid decision making in integrated water resources management. WMOST is intended to serve as an efficient and user-friendly tool for water resources managers and planners to screen a wide-range of strategies and management practices for cost-effectiveness and environmental sustainability in meeting watershed or jurisdiction management goals (Zoltay et al. 2010).

Overall, WMOST is intended to be used as a screening tool as *part* of an integrated watershed management process such as that described in EPA's watershed planning handbook (EPA 2008), to identify the strategies and practices that seem most promising for more detailed evaluation. WMOST identifies the least-cost combination of management practices to meet the user specified management goals. Management goals may include reducing damages associated with flooding and meeting projected water supply demand, minimum and maximum in-stream flow targets, and in-stream and reservoir water quality targets. The tool considers a range of management practices related to water supply and quality, wastewater, nonpotable water reuse, aquifer storage and recharge, sewer and CSO systems, stormwater, low-impact development (LID) and land conservation, accounting for both the cost and performance of each practice. In addition, WMOST may be run for a range of values for management goals to perform a cost-benefit analysis and obtain a Pareto frontier or trade-off curve. For example, running the model for a range of minimum in-stream flow standards provides data to create a trade-off curve between increasing in-stream flow and total annual management cost.

### 1.2 Overview

WMOST combines an optimization framework with water resources modeling to evaluate the effects of management decisions within a watershed context. The watershed system modeled in WMOST v3 is shown in Figure 1-1. Figure 1-1 shows the *possible* watershed system components and *potential* water loadings among the watershed components, including the use of upgraded WTP, WWTP, and septic systems for additional loadings reductions. Figure 1-2 shows the *possible* watershed component interactions when CSO events are modeled. This figure only provides a diagram of the components that have different possible flows when modeling these events (sewer, wastewater treatment, and surface water components).



**Figure 1-1. Schematic of Possible Loadings Flows and Possible Watershed Components in WMOST.**

SW = surface water, GW = groundwater, HRU = hydrologic response unit, WTP = water treatment plant, WWTP = wastewater treatment plant, ASR = aquifer storage and recharge

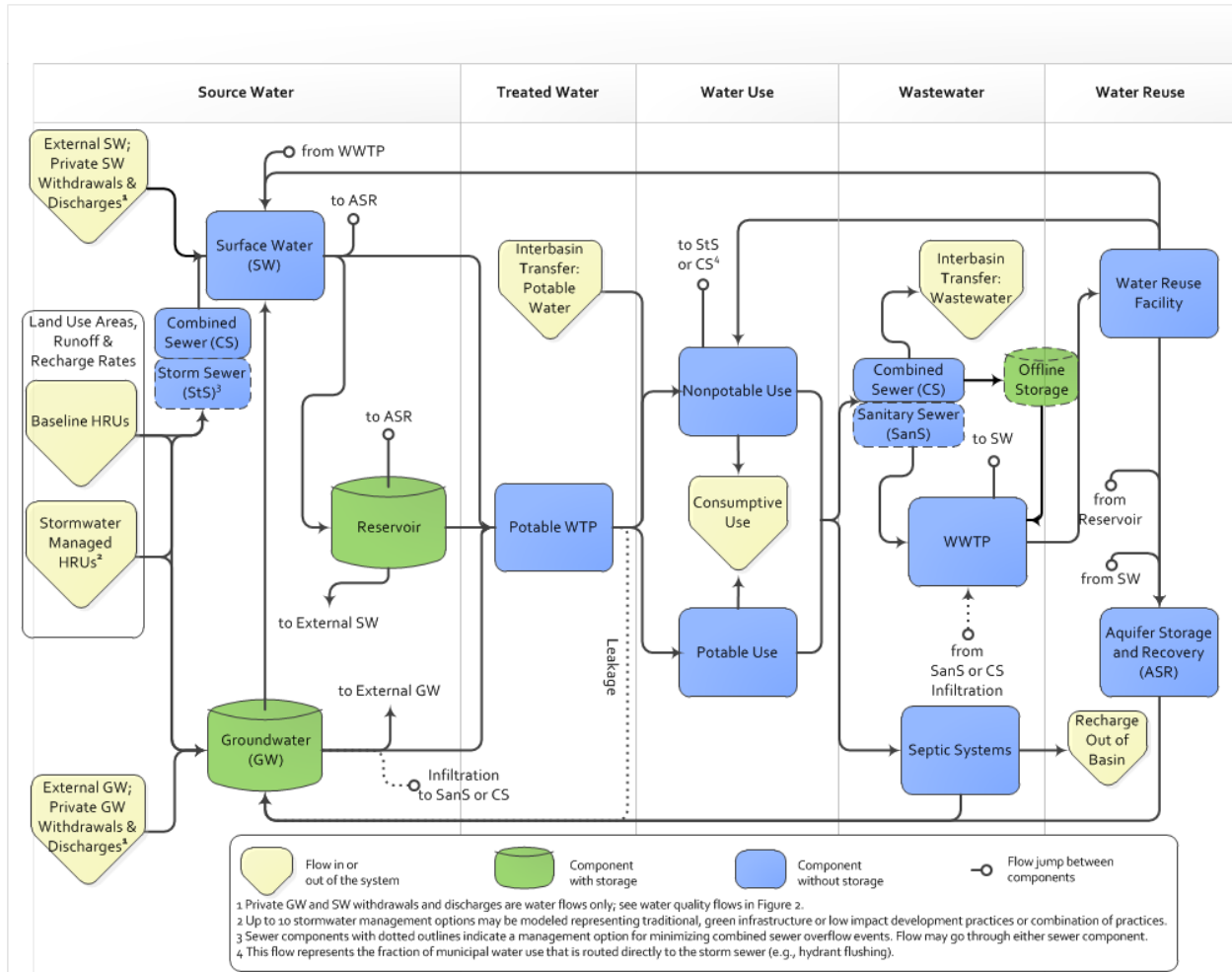


Figure 1-2. Schematic of Potential Combined Sewer Flows in the WMOST.

SW = surface water, StS = storm sewer, HRU = hydrologic response unit,  
 SanS = sanitary sewer treatment plant, CS = combined sewer,  
 WWTP = wastewater treatment plant

The principal characteristics of WMOST include:

- Implementation in Microsoft® Excel 2010, 2013, and 2016® that is linked seamlessly with Visual Basic for Applications (VBA) and NEOS (Czyzyk et al. 1997; Dolan 2001; Gropp and More 1997), a free, online optimizer, eliminating the need for specialized software and using the familiar Excel platform for the user interface;
- User-specified inputs for characterizing the watershed, management practices, and management goals and generating a customized optimization model (see Table 1-1 for a list of available management practices and goals);
- Use of BONMIN (Bonami et al. 2008), a mixed integer nonlinear programming (MINLP) optimization solver (freely available through NEOS), to determine the least-cost combination of practices that achieves the user-specified management goals (See Section 3-1 in the Theoretical Documentation report for WMOST for details on BONMIN, MINLP optimization, and the software configuration);
- Spatially lumped calculations modeling one basin and one reach but with flexibility in the number of HRUs,<sup>11</sup> each with an individual runoff and recharge rate;
- Modeling time step of a day or month without a limit on the length of the modeling period;<sup>12</sup>
- Solutions that account for both the direct and indirect effects of management practices (e.g., since optimization is performed within the watershed system context, the model will account for the fact 1) that implementing water conservation will reduce water revenue, wastewater flow and wastewater revenue if wastewater revenue is calculated based on water flow or 2) that implementing infiltration-based stormwater management practices will increase aquifer recharge and baseflow for the stream reach which can help meet minimum in-stream flow requirements during low precipitation periods, maximum in-stream flow requirements during intense precipitation seasons, and water supply demand from increased groundwater supply);
- Ability to specify up to ten stormwater management options, including traditional (detention basins), green infrastructure, LID, or agricultural runoff control practices;
- Enforcement of physical constraints, such as the conservation of mass (i.e., water and loadings), within the watershed; and
- Consideration of both water quantity and quality.

The rest of this document is organized as follows. Section 2 provides considerations for model definition and setup and directions for computer and software preparation. Section 3 leads the user through model setup with screenshots. Section 4 provides directions for initiating an optimization run, and processing and analyzing optimization results. Section 5 provides directions for performing flood damage modeling to derive input data for the Flood Damage Module. Section 6 summarizes tips for the user in performing model runs and analyzing results, including methodology for conducting sensitivity analyses and trade-off analyses.

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<sup>11</sup> Land cover, land use, soil, slope and other land characteristics affect the fraction of precipitation that will runoff, recharge and evapotranspire. Areas with similar land characteristics that respond similarly to precipitation are termed hydrologic response units.

<sup>12</sup> While the number of HRUs and modeling period are not limited, solution times are significantly affected by these model specifications. It is recommended to model a maximum of 32 HRUs and five years at a daily time step.



A separate Theoretical Documentation report provides a detailed description of WMOST that includes a mathematical description and internal configuration of the software applications that constitute the model. Case study examples are presented in individual documents and are provided with the WMOST files. These example applications may be used as a source of default data, especially for similar watersheds in Region 1 and similar sized water and wastewater systems. Case study examples for WMOST v3 will be added in the near future.

**Table 1-1. Summary of Management Goals and Management Practices<sup>13</sup>.**

MGD = million gallons per day

Management Practice	Action <sup>14</sup>	Model Component Affected	Impact
Land conservation	Increase area of land use type specified as 'conservable'	Land area allocation	Preserve runoff and recharge quantity and quality
Stormwater management via traditional, agricultural, green infrastructure or low impact development practices	Increase area of land use type treated by specified management practice	Land area allocation	Reduce runoff; increase recharge and treatment
Agricultural stormwater runoff management via traditional and green infrastructure	Increase area of land use type treated by specified management practice	Land area allocation	Reduce runoff; increase recharge; increase treatment
Stormwater quality management via street sweeping, tree canopy over impervious/turf, urban nutrient management, or other direct reduction runoff loadings BMPs	Percent reduction of runoff loadings	Runoff loadings	Reduce runoff loadings to meet in-stream or reservoir loading targets
Riparian buffer land use management	Increase area of land use type in the riparian zone	Land area allocation and runoff loadings	Reduce runoff; reduce loadings to stream to help meet in-stream or reservoir loadings targets
Surface water storage capacity	Increase maximum storage volume	Reservoir/Surface Storage	Increase storage; reduce demand from other sources
Surface water pumping capacity	Increase maximum pumping capacity	Potable water treatment plant	Reduce quantity and/or timing of demand from other sources
Groundwater pumping capacity	Increase maximum pumping capacity	Potable water treatment plant	Reduce quantity and/or timing of demand from other sources

<sup>13</sup> The user may specify which practices are available for their study area and are to be included in the optimization. Directions for this are provided with each practice in the User Manual and WMOST interface.

<sup>14</sup> Please refer to the separate Theoretical Documentation for the specific effect of each management practice.

<b>Table 1-1 (continued)</b>			
<b>Management Practice</b>	<b>Action<sup>14</sup></b>	<b>Model Component Affected</b>	<b>Impact</b>
Change in quantity of surface versus groundwater pumping	Change in pumping time series for surface and groundwater sources	Potable water treatment plant	Change the timing of withdrawal impact on water source(s)
Potable water treatment capacity	Increase MGD	Potable water treatment plant	Meet potable human demand; meet water quality treatment standards
Potable water treatment upgrade	Increase treatment	Potable water treatment plant	Further reduce loadings from potable water treatment
Leak repair in potable distribution system	Decrease % of leaks	Potable water treatment plant	Reduce demand for water quantity
Convert septic to sewer areas	Increase MGD, reduce % customers on septic	Wastewater treatment plant, septic discharge	Maintain or improve water quality of receiving water
Wastewater treatment capacity	Increase MGD	Wastewater treatment plant	Maintain or improve water quality of receiving water
Wastewater treatment upgrade	Increase treatment	Wastewater treatment plant	Further reduction of loadings from wastewater treatment
Infiltration repair in wastewater collection system	Decrease % of leaks	Wastewater treatment plant	Reduce demand for wastewater treatment capacity
Water reuse facility (advanced treatment) capacity	Increase MGD	Water reuse facility	Produce water for nonpotable demand, ASR, and/or improve water quality of receiving water
Nonpotable distribution system	Increase MGD	Nonpotable water use	Reduce demand for potable water
Aquifer storage & recharge (ASR) facility capacity	Increase MGD	ASR facility	Increase recharge, treatment, and/or supply
Demand management by price increase	Increase % of price	Potable and nonpotable water and wastewater	Reduce demand
Direct demand management	Percent decrease in MGD	Potable and nonpotable water and wastewater	Reduce demand
Interbasin transfer – potable water import capacity	Increase or decrease MGD	Interbasin transfer – potable water import	Increase potable water supply or reduce reliance on out of basin sources
Interbasin transfer – wastewater export capacity	Increase or decrease MGD	Interbasin transfer – wastewater export	Reduce need for wastewater treatment plant capacity or reduce reliance on out of basin services

<sup>14</sup> Please refer to the separate Theoretical Documentation for the specific effect of each management practice.

Table 1-1 (continued)

Management Practice	Action <sup>14</sup>	Model Component Affected	Impact
Enhanced septic treatment	Decrease septic average effluent concentration	Septic	Use upgraded treatment within the septic system
Sewer separation	Decrease flows through the combined sewer	Storm, sanitary, and combined sewers	Minimize combined sewer overflow events
Offline storage	Delay flows to the wastewater treatment facility through the sewer system	Combined sewer	Minimize combined sewer overflow events
Streambank restoration or stabilization	Apply a loadings credit to the loadings target in the stream or reservoir	Surface water or reservoir	Meet in-stream or reservoir loading targets
Outfall enhancement or stabilization	Apply a loadings credit to the loadings target in the stream or reservoir	Surface water or reservoir	Reduce loadings to stream or reservoir to meet in-stream or reservoir loading targets
Minimum human water demand	MGD	Groundwater and surface water pumping and/or interbasin transfer	Meet human water needs
Minimum in-stream flow	ft <sup>3</sup> /sec	Surface water	Meet in-stream flow standards; improve ecosystem health and services; improve recreational opportunities
Maximum in-stream flow	ft <sup>3</sup> /sec	Surface water	Meet in-stream flow standards; improve ecosystem health and services by reducing scouring, channel and habitat degradation; decrease loss of public and private assets due to flooding
Target concentration or loadings	mg/L or lbs	Surface water or reservoir	Meet in-stream or reservoir TMDL targets; improve ecosystem health and services; improve recreational opportunities

<sup>14</sup> Please refer to the separate Theoretical Documentation for the specific effect of each management practice.

## 2. Getting Started

WMOST is a screening tool for watershed management and planning. One specific application of WMOST is determining the least cost combination of management options to meet management goals for a town or watershed's planning horizon. For example, the water works portion of a town's master plan may ask, "What stormwater practices must be installed, demand management programs created and/or infrastructure capacity constructed to meet projected human demand for the next 20 years while meeting minimum and maximum in-stream flow targets and in-stream/reservoir water quality targets to preserve stream health?" To address such a planning question, all input data must correspond to the conditions projected to occur by the end of a 20-year planning period. For example, human demand would need to be projected 20 years from the planning year. Most of the User Guide is written from the perspective of a user who is screening management practices to address such planning questions. Suggestions are provided throughout the User Guide and in the case studies<sup>15</sup> for how to specify input data appropriately. It is important to note that while the model does help users identify which management practices are the most cost effective and understand the state of the watershed and human system at the end of the planning period if the management practices are implemented, it does not provide an annual implementation plan or specifics on operations of systems. The following sections describe what input data managers should assemble for a detailed model run and discuss how to set up a model run and obtain and interpret the results.

### 2.1 Preparing for a Model Run

This section describes model specifications the user must consider prior to applying WMOST v3. Data sources used in the case studies will be detailed in subsequent reports. Some of those data sources, such as costs for riparian buffer land conversion, are state or national level and can serve as a data source for most study areas. If this is not the case, environmental or economic data may be found in the literature (particularly grey literature sources, such as governmental and technical reports or guidelines). The majority of the data related to the human water system should be available to municipalities from their own internal sources. Water utilities may need to seek out information from other public works facilities that operate in the study area, such as separate wastewater and stormwater utilities or neighboring water districts. Sections 3.2 through 3.5 in this User Guide address both hydrologic and water quality input data. Users that are interested in hydrologic flows only should disregard any mentions of water quality considerations.

#### Defining Hydrologic Response Units

A main input data requirement is time series of both runoff and recharge rates (RRR) and runoff and recharge loadings (RRL) for HRUs<sup>16</sup> in the study area and the corresponding area for each HRU. The RRR time series are not volumetric but rates that must be input as depth per unit area per time step (e.g.,

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<sup>15</sup> Case study documents are available on the WMOST website.

<sup>16</sup> Land cover, land use, soil, slope and other land characteristics affect the fraction of precipitation that will runoff, recharge and evapotranspire. Areas with similar characteristics – hydrologic response units (HRUs) – respond similarly to precipitation.

inches per acre<sup>17</sup> per day). The RRL time series are mass rates that must be input as mass per unit area (e.g., pounds per day). The Baseline Hydrology Module in WMOST v3 assists users in obtaining and pre-processing the time series data. The Baseline Hydrology Module connects to the runoff and recharge time series databases stored online via EPA's Estuary Data Mapper (EDM) server<sup>18</sup>.

If watersheds in the available databases do not have similar slopes, land uses, or soils in the study area's watershed, the user may derive these data from a calibrated/validated simulation model such as Hydrological Simulation Program Fortran (HSPF)<sup>19</sup>, Soil Water and Assessment Tool (SWAT)<sup>20</sup> and/or Storm Water Management Model (SWMM)<sup>21</sup>. The WMOST HydroProcessor is a tool that processes HSPF and SWAT model files to create WMOST hydrology and loadings input databases<sup>22</sup>. Furthermore, several post-processors such as GenScn and WDMutil in EPA BASINS<sup>23</sup> are available to facilitate extraction of hydrology time series from HSPF model output wdm files.

If a watershed simulation model is not available for the study area (e.g., from U.S. Geological Survey) and resources do not allow for the creation and setup of a model, then the user may try using default rates from models run for watersheds with similar characteristics (i.e., similar land-use, soils, climate). Additionally there may be generic RRRs and RRLs available from state or regional studies (Maurer et al. 2001). The generic rates would specify the HRU characteristics for which the rates are applicable. A geographic information system (GIS) or local land use data can be used to determine the area associated with each HRU in the study area. We suggest using 8 to 16 HRUs (with input field limit of 50) in the model to control the complexity of the optimization problem. HRU types may be aggregated to reduce this number if the GIS analysis suggests more than 16 HRUs.

In addition to a baseline set of HRUs, up to nine sets of "managed" HRUs may be specified with corresponding areas, RRRs, RRLs, and management costs. The baseline set is used to specify runoff and recharge for HRUs for the baseline conditions of the model run. For managed sets, you may specify runoff and recharge rates that reflect some form of land management practice and the associated cost such as stormwater management. With such information, the model can evaluate the cost-effectiveness of stormwater management relative to other practices.

For urban HRUs, the "managed set" may reflect RRRs and RRLs resulting from use of a stormwater best management practice (e.g., bioretention basin, swales) and/or low impact development with reduced impervious area. Managed RRRs and RRLs may be used to represent any change in land use or land

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<sup>17</sup> Runoff depth is actually independent of area; however this value is multiplied by HRU areas in WMOST to yield runoff volume.

<sup>18</sup> The Estuary Data Mapper (EDM) application uses the Remote Sensing Information Gateway (RSIG) web servers as conduits for accessing data. The datasets that are available can be viewed through the EDM application or found on the EDM Data Inventory site, <https://www.epa.gov/edm>.

<sup>19</sup> <http://water.usgs.gov/software/HSPF/>

<sup>20</sup> <http://swat.tamu.edu/>

<sup>21</sup> <https://www.epa.gov/water-research/storm-water-management-model-swmm>

<sup>22</sup> The WMOST HydroProcessor is available on the WMOST website.

<sup>23</sup> <http://water.epa.gov/scitech/datait/models/basins/framework.cfm#tools>

management practice that changes runoff and recharge volume or timing. For example, results of detailed modeling of LID or other practices may be entered as a managed set of RRRs and RRLs. Within WMOST, the user may model LID that results in less impervious surface. The user must run the Baseline Hydrology Module in a separate WMOST file to obtain the RRRs corresponding to a developed HRU with a lower impervious surface percent. These RRRs can be entered as a managed set with a corresponding cost, if any, in the primary WMOST file. Alternatively, if a BMP with the equivalent effect is known, it may be requested in the Stormwater Module. In WMOST v3, the Stormwater Hydrology Module assists the user in pre-processing the time series and other data necessary for including stormwater management. Alternatively, these managed RRRs and RRLs may be derived using SWMM or other stormwater management models outside of WMOST and then manually input to WMOST. For agricultural HRUs, the “managed set” may reflect RRRs and RRLs resulting from implementation of edge of site BMPs or vegetative filter strips on undeveloped areas.

For each set, you can specify the area of each HRU on which the management practice may be implemented. For each stormwater managed set, urban BMPs are applied to urban HRUs only, and agricultural BMPs are applied to undeveloped HRUs only. In addition, if stormwater management exists in part of the watershed, HRUs may be defined separately for areas that already have stormwater management and remaining areas that can still be placed under management. Then, the addition of new stormwater management may be limited to the unmanaged HRUs and excluded for managed HRUs.

### Defining the Study Area

Ideally, the study area is the entire land area draining to the stream reach of interest; however, jurisdictional boundaries often cut across subbasins. This requires that the hydrology and loadings runoff and recharge time series are modeled at the subbasin or watershed level<sup>24</sup> while management practices are limited to those areas within the jurisdiction(s) cooperating in the management plan. The case study of Danvers and Middleton, MA, shows the example of how to use the model in such circumstances. The case study of the Upper Taunton River Basin assumes that the entire watershed is cooperating in the management strategy such as in a water district and, therefore, management practices are specified to be applicable for the entire watershed<sup>25</sup>. In general, we suggest study areas that are roughly the size of a HUC10 or HUC12 subbasin, or smaller.

### Defining the Modeling Time Period

The model may be run on a daily or monthly time step. One exception is that the model must be run at the daily time step when using the Flood Damage Module to include flood damages in the calculation of the total management cost. The user may choose the time step depending on the temporal resolution of available input data, desired management practices and/or known system behavior. For example, if stormwater management practices will be considered, a daily time step is advised as storm events and

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<sup>24</sup> In cases where groundwater flows cross the watershed divide, the user can specify groundwater imports and exports beyond the watershed boundary.

<sup>25</sup> If the user wants to model multiple adjacent/downstream study areas, theoretically, the time series of surface water outflow from the upstream study area may be used as an input into the downstream study area. WMOST v3 outputs this time series in table form via the Advanced Results module. Enhanced spatial modeling is identified as an area for future development so that all areas or reaches can be optimized simultaneously rather than just consecutively from upstream to downstream reaches.

their effects are observable on a time scale closer to a daily rather than monthly time step. If the user desires to know the monthly or approximate water balance for watershed or human system components such as reservoir storage, then a monthly time step would be sufficient.

The user should run the model for multiple years that cover dry, average and wet years of precipitation. That is, input time series (e.g., RRRs, RRLs, human demand, and surface water inflow from upstream) should include a range of potential conditions. This approach will ensure that the management solution screened by the model will be sustainable over a range of potential future conditions. In addition, the user is advised to run not only a range of historical conditions but future, projected conditions. The WMOST EDM data inventory provides a library of time series based on down-scaled climate projections for specific watershed models. The climate projections available from EDM cover the years 2036–2065. Users may also derive potential future climate conditions, for example, by adjusting historical conditions for projected climate change. EPA’s Climate Resilience Evaluation and Awareness Tool provides projected changes in temperature and precipitation for climate stations throughout the United States<sup>26</sup>. These values may be used to adjust the detailed watershed simulation model from which watershed time series data is obtained for WMOST and to adjust the traditional methodology used for projecting human demand. Model-specific tools are available to adjust weather inputs to SWAT (climate change function), HSPF (BASIN CAT), and SWMM (SWMM CAT).

Note that running WMOST with data from a specific time period such as 2005–2010 does not necessarily represent watershed conditions that only occurred during those years but watershed conditions that would occur in a similar 5-year period of weather, water use and land conditions. Therefore, these data can be adjusted for climate change or other uncertainties and re-run to determine the sensitivity of the solution, that is, combination of management practices and costs, to potential future deviations from historical conditions. In fact, *the user is highly encouraged to perform sensitivity analyses especially on input data with least certainty to determine the robustness of the solution*. Section 6 briefly describes the process for performing sensitivity analyses.

### Performing a Simulation Run for Calibration

A simulation run is advised before optimization runs to determine the accuracy of WMOST and the input data in reproducing streamflow and water quality constituent concentrations. A simulation run excludes all management decisions; therefore, the input data are run through the model without changes in management of the system. This requires that certain input data be specified differently from an optimization setup which is described in the rest of this document.

There are two methods for setting up a calibration run: 1) with demand for water modeled explicitly as groundwater or surface water withdrawals, or 2) with demand for water modeled as withdrawals managed by the optimization with the **Potable Demand page**. The first method is used for calculating the water balance in your watershed and verifying that your data inputs result in a model that simulates the historical record. The second method is used for verifying that optimization selects similar quantities and timing for water withdrawals compared to the historical record. This method can help verify that the infrastructure costs and capacities are accurate, as those data inputs have an effect on water quantity

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<sup>26</sup> <https://www.epa.gov/crwu/build-resilience-your-utility>



selections made by the model. The case study of Danvers and Middleton, MA, in the User Guide for Version 1 and the case study for Halifax, MA, in the User Guide for Version 2 describe the process for performing a “simulation” run in more detail.

## 2.2 System Requirements

To open and run WMOST, you will need Microsoft® Excel 32bit version 2010, 2013, or 2016 installed on your computer. After opening WMOST, choose ‘Enable content’ or ‘Enable macros’ if these prompts are displayed. If using MS Excel 2013, please see “[WMOST 2.0 2013 Performance Fix](#)” file available on the WMOST download site to change configurations to correct an Excel performance bug.

To run the Baseline Hydrology Module of WMOST, users can process their data by 1) downloading WMOST databases using the Estuary Data Mapper ([www.epa.gov/edm](http://www.epa.gov/edm))<sup>27</sup>, or 2) accessing these databases from the WMOST v3 download. If you have data from a calibrated/validated model already, you can skip using the Baseline Hydrology Module and manually enter your data on the appropriate input pages.

To run the Stormwater Hydrology Module, you will need to download and install EPA’s stormwater management tool, System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) Version 1.2<sup>28</sup>. SUSTAIN has been available in two versions: non-GIS and ArcGIS 9.3. The non-GIS version is compatible with the Stormwater Hydrology Module. To prevent errors, do not move SUSTAIN files automatically created during installation from their default location.

When using WMOST, you may save various versions that are set up for different scenarios. It is not recommended that you run multiple scenarios at the same time from the same folder as the optimization files may be overwritten by a different scenario. When using the Baseline Hydrology and Stormwater Hydrology Modules, WMOST performs best when saved and run on a local drive, rather than a network drive, to save processing time. When using the Stormwater Hydrology Module, WMOST must be saved to a location with no spaces in the file path. Furthermore, most Windows computers cannot handle file path names that are longer than 260 characters. WMOST saves files to your project folder so ensure that the project folder path and scenario name are under this character limit.

Running optimization scenarios and the Results Module multiple times in succession can cause the memory on your computer to fill. If this happens, save and close your WMOST project and re-open to free up memory and speed up processing.

Finally, if you encounter software errors, please email Naomi Detenbeck at [detenbeck.naomi@epa.gov](mailto:detenbeck.naomi@epa.gov) with the subject “WMOST bug”. To register for notices of patches and new releases, please email the same address with the subject line “WMOST register”.

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<sup>27</sup> The inventory of available models in Estuary Data Mapper is available on the EDM and WMOST websites.

<sup>28</sup> <https://www.epa.gov/water-research/system-urban-stormwater-treatment-and-analysis-integration-sustain>



## 3. Model Setup and Runs

### 3.1 General Model Setup

When you open WMOST you will see the familiar Excel interface with one worksheet active called **Intro**. The **Intro page** allows you to set general specifications for your model and navigate to the more detailed input data page (blue section in the screenshot to the right), create optimization model files and process results (red section), and evaluate and calibrate results (green section).

Begin setting up your model by typing in a study area name to the appropriate input field. Input fields that are outlined but shaded white are not required but highly suggested for model optimization. By contrast, the input field below your study area name is shaded blue. Input fields that are shaded blue typically require data input<sup>29</sup>. This particular input field is already filled in as “Hydrology & Loadings” and if you click on it, its appearance changes (see below) because it holds a drop-down menu. For any input field with a drop-down menu, you are limited to the options listed in the drop-down menu, in this case either Hydrology & Loadings or Hydrology Only. One type of field that is not represented on the **Intro page** are those that are automatically populated, and subsequently, shaded yellow. Finally, the object below the model type is a button that allows you to navigate to the **Input page**. In general, you can identify buttons by hovering your mouse over the object in question. Your cursor should change from a cross to a pointer.

On this page, you may also enter a study area name or a scenario name. These input fields may help you document your WMOST projects and differentiate between scenario workbooks. These fields are used to name the “Scenario Log File”, which is a part of the Results Module output. Consequently, you may not use the following characters in the study area or scenario name: < > : “ / \ | ? \*.

Please note that any example screenshots (similar to the one above) with values displayed in them are from the Upper Taunton Wading River case study and are not necessarily appropriate values for your study area. WMOST performs several basic checks to ensure that input data requirements are met. For example, it will check that price elasticities are negative and minimum in-stream flow targets are smaller than maximum in-stream flow targets. If these basic requirements are not met, the user is informed with a message box and asked to re-enter the information. Appendix D in the Theoretical Documentation provides additional details on input data checks and user support.

To begin entering data for your study area, press the [Proceed to Input Data](#) button to navigate to the **Input page**. The **Input page** consists of seven<sup>30</sup> steps that will guide you through inputting the necessary data to set up your optimization model.

<sup>29</sup> Some pages and input fields can be left blank depending on desired management options.

<sup>30</sup> If you are modeling Hydrology and Loadings, step 5 (Combined Sewer Overflow module) will not be visible.

Throughout the manual, buttons will be underlined and workbook pages will be bolded. A full list of workbook pages and their related module can be found in Appendix A – Module and Page Summary.

### 3.2 Baseline Hydrology and HRU Areas

HRUs are areas of similar hydrology based on similar watershed characteristics such as land use, soil and/or slope. The number of HRUs will likely be determined by the diversity of these characteristics in your study area and your source of runoff and recharge rates. You have the option to either download existing hydrologic model outputs ready for input into WMOST or import hydrologic model outputs that you have prepared for input into WMOST. If you are downloading existing model outputs, continue with *Input Page Step 1A Assisted – Baseline Hydrology Module* section. If you would like to manually enter the data, skip to *Input Page Step 1A Manual – Baseline Hydrology* section for instructions.

#### *Input Page Step 1A Assisted – Baseline Hydrology Module*

If modeling Hydrology and Loadings, enter the name of your constituent of interest into the blue input field below the Baseline Hydrology Module button. Then, press the Baseline Hydrology Module button on the **Input page** (above screenshot) to begin importing HRU characteristic and RRR data.

Five steps comprise the Baseline Hydrology Module. To run the module, you will need WMOST-formatted databases containing watershed characteristics and runoff and recharge data for your study area. These databases can be downloaded from the EDM online server directly through the module using **Hydro page** Steps 1A – 5A. Alternatively, if you already have a set of databases stored on your computer from a previous download, you can import the data by selecting the database file paths in Steps 1B, 3B, and 5B, and disregards Steps 1A, 3A, and 5A.

To create a query to the EDM server through WMOST, you first must provide the file path for the “EDM WMOST Database Inventory” file<sup>31</sup> for WMOST to reference in substep #1. . The inventory file contains a list of the model datasets available from the server. The model details include the available 1) watershed name, 2) hydrologic model type, 3) land use time period, 4) climate scenario, 5) constituent names, and 6) time period. Additionally, the inventory contains a list of the HUC10 or HUC12 IDs for each watershed, and you may view or download the watershed maps from the WMOST website. (Users may also explore available model files interactively and download data from the US EPA Estuary Data Mapper application which can be downloaded from [www.epa.gov/edm](http://www.epa.gov/edm).) Move onto the next step once you have determined your model and HUC subbasin of interest from the inventory list. Users modeling water quality should check the inventory to make sure the selected watershed has data inputs for the constituent(s) of interest.

<sup>31</sup> The EDM WMOST Database Inventory is available for download on the WMOST website.

**1A. Retrieve Data from U.S. EPA's Estuary Data Mapper (EDM):** Make watershed selections and retrieve the HRU characteristics and weather data for your model.

1. Locate the EDM WMOST Database Inventory file on your computer drive:

2. Enter the name of your watershed:       3. Select the model type:       4. Select the land use scenario:       5. Select the climate scenario:       6. Enter the HUC ID for your subbasin:

7. After you have made the above selections, use "Retrieve Characteristics & Weather Data" to initiate the EDM data request:

In substeps #2 – 6, enter your model and subbasin selection and press Retrieve Characteristics & Weather Data. If the dataset selections do not match a model in the inventory, WMOST will inform you of the error after pressing this button. If the selections have a match, the button initiates the automatic data retrieval of the weather and HRU database zip file from the server. Once the download is complete, WMOST unzips your data to a folder labeled “EDM\_Server\_ZIP” within your project folder, and automatically imports the HRU characteristics and the precipitation time series for the available model time period.

If you would like to use files previously downloaded in a past query, you can import the HRU characteristics database in Step 1B by selecting the file path of your HRU characteristics file. To find and view the HRU characteristics file, navigate to the “EDM\_Server\_ZIP” folder in your project folder, and search for the Dbase (.dbf) file in the unzipped “wmostEDM\_weather” folder. This file can be opened and viewed with Excel.

After the files load, the table in **Hydro page** Step 2 “Hydrologic Response Units (HRUs)” will automatically populate the HRU types that were modeled in that watershed. Select the HRUs that exist within your study area and that you will be modeling by placing an “x” in the blue column next to each HRU name. Then, press Populate Land Use to set up appropriately sized input tables (i.e., Baseline Land Use table and Baseline Runoff and Recharge Hydrology and Loadings tables on **Land Use, Runoff, Recharge, Runoff\_L, and Recharge\_L**).

**2. Hydrologic Response Units (HRUs). The following HRU types are available in the selected watershed.**

2A. Select which HRUs exist in your study area by placing an x in blue box next to the HRU type      2B. Then press "Populate Land Use" to populate Land Use table with each HRU's name, infiltration rate and percent effective impervious area.

HRU types in the selected watershed	
Forest, Sand & Gravel & Gravel	x
Open/non-residential, Sand & Gravel & Gravel	x
Medium-low density, Sand & Gravel	x
Medium-high density, Sand & Gravel	x
Commercial-industrial, Sand & Gravel	x
Agriculture, Sand & Gravel	x
Forest, Till & Fine-Grained Deposits	x
Open/non-residential, Till & Fine-Grained Deposits	x
Medium-low density, Till & Fine-Grained Deposits	x
Medium-high density, Till & Fine-Grained Deposits	x
Commercial-industrial, Till & Fine-Grained Deposits	x
Agriculture, Till & Fine-Grained Deposits	x
Cranberry Bog	x
Forested Wetland	x
Nonforested Wetland	x
Water	x

Once the table setups are complete, you will be taken to the **Land Use page** showing the baseline area, percent effective impervious area (EIA) and infiltration rate for each HRU. These values were automatically populated based on the selected watershed model. Review the value for these HRU characteristics to make sure that they are appropriate for the HRUs in your study area. If you plan to use the Stormwater Hydrology Module to create adjusted hydrology time series, HRUs with non-zero EIA

will be utilized with any urban BMPs and HRUs with zero EIA will be utilized with any agricultural BMPs. However, you can edit any Percent Effective Impervious value in the HRU series to change the BMP types that are applied.

Baseline HRU Characteristics				
HRU ID	HRU Name <sup>1</sup>	Baseline Area [acre]	Percent Effective Impervious <sup>1</sup>	Infiltration Rate [in/hr] <sup>1</sup>
HRU1B	Forest, Sand & Gravel & Gravel	13,647	0.00%	9.5
HRU2B	Open/non-residential, Sand & Gravel & Gravel	2,296	4.26%	8.455
HRU3B	Medium-low density, Sand & Gravel	5,949	4.40%	8.075
HRU4B	Medium-high density, Sand & Gravel	973	15.31%	5.95
HRU5B	Commercial-industrial, Sand & Gravel	2,537	65.72%	3.08
HRU6B	Agriculture, Sand & Gravel	634	0.00%	8.01
HRU7B	Forest, Till & Fine-Grained Deposits	12,553	0.00%	0.938
HRU8B	Open/non-residential, Till & Fine-Grained Deposits	1,083	4.34%	0.832
HRU9B	Medium-low density, Till & Fine-Grained Deposits	2,821	4.40%	0.806
HRU10B	Medium-high density, Till & Fine-Grained Deposits	448	14.93%	0.605
HRU11B	Commercial-industrial, Till & Fine-Grained Deposits	1,104	65.79%	0.336
HRU12B	Agriculture, Till & Fine-Grained Deposits	241	0.00%	0.768
HRU13B	Cranberry Bog	98	0.00%	0.2
HRU14B	Forested Wetland	6,474	0.00%	0.2
HRU15B	Nonforested Wetland	2,132	0.00%	0.2
HRU16B	Water	1,330	0.00%	0

Next, return to the **Hydro page** and continue with **Hydro page Step 3** –

selecting the modeling time period. The time period of available data for the selected watershed is displayed in the yellow box. You may use the [View Precipitation Data](#) button to open a new page and see the entire precipitation time series available for the selected watershed model if you retrieved the data using the EDM data library. Otherwise, press [Load Precipitation Data](#) in **Hydro page Step 3B**, and select the hydrology database file to import the precipitation time series. Viewing the precipitation data may help in selecting wet, dry or average precipitation time periods.

A model setup with a daily time step for five years takes about 5-90 minutes to run, depending on the complexity of the optimization problem. We do not recommend longer time periods than five years and instead suggest running scenarios with five-year periods that include wet, dry and average conditions. Enter the desired start and end of the modeling time period in the appropriate blue input boxes.

**3. Time period**

Hydrology data for the selected watershed is available for the following time period: 1/1/1960 to 12/31/2009 View Precipitation Data

Five years of data is the maximum recommended model time period length. You can view the daily precipitation time series to help you determine the period of interest.

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**3A.** If you used EPA's EDM to retrieve your data, the precipitation data is available on the "Precipitation" sheet. You may use "View Precipitation Data" at any time to refer to the data.

**3B.** If you are using files that have already been downloaded, the precipitation data can be imported by clicking "Load Precipitation Data". Load Precipitation Data

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Enter the time period of interest for your modeling study:

Start	1/1/2002	1/1/2002	1/1/2002	1/1/2002	1/1/2002
End	12/31/2006	12/31/2006	12/31/2006	12/31/2006	12/31/2006

In **Hydro page Step 4**, use the drop-down box to indicate whether you will be running a daily or monthly model. If you intend to include flood damage costs in the modeling, you must run a daily model.

**4. Model time step**

To use the Stormwater Module, you must setup a daily model. Would you like to setup a daily or monthly model? Daily ←

Finally, press [Retrieve Time Series Data & Populate Time Series](#) in **Hydro page Step 5A** to retrieve hydrology and loadings databases from the EDM data library and pre-process and populate the time series data. This action will download and unzip the appropriate files from the EDM data library using the

default unzipping program on your computer. If this process fails, check to make sure the zip file that was downloaded has files stored in it. If there are files in the zip file (i.e., the zip file size is greater than 0), then unzip the files to your desired folder, and continue with **Hydro page** Step 5B to pre-process and populate the time series data.

If you did not use the EDM data library or your file did not unzip correctly, select the file paths for the WMOST hydrology and loadings databases in **Hydro page** Step 5B, and press Process and Populate Time Series Data. This action pre-processes and populates the runoff and recharge hydrology and loadings time series data for your watershed of interest.

**5. After completing steps 1 through 4, follow Step 5A or 5B to process and populate the time series data:**

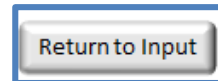
5A. Use "Retrieve Time Series Data & Populate Time Series" to retrieve the data for your time period, and populate the HRU time series. Retrieve Time Series Data & Populate Time Series

5B. Select the file path(s) for your time series database(s). Use "Process and Populate Time Series Data" to process and populate. Process and Populate Time Series Data: Runoff and Recharge for Hydrology and Loadings

Select the file that contains the hydrology timeseries for your watershed. Select Hydrology File Path ←

Select the file that contains for the loadings timeseries for your watershed. Select Loadings File Path

Once the processing is complete, you can view the baseline runoff and recharge time series on **Runoff, Recharge, Runoff\_L, and Recharge\_L pages**. Navigate back to the **Input page** using the Return to Input button. The module automatically enters the number of HRUs you selected with the Baseline Hydrology Module into the blue box. Check the box next to the Baseline Hydrology Module button to indicate that the data input is complete (the button color will change from blue to grey once the box is checked). This will help you track all completed input pages. Continue with data entry and model setup under **Input page** Step 1B.



**1. Baseline: Data for unmanaged land conditions.**

A. Time series data:  
Use Baseline Hydrology module for assisted data acquisition and entry OR manually enter your own data.

Baseline Hydrology Module 1. Enter the number of HRUs in your study area: 16 ← Setup Baseline Tables

Name of Constituent 1: TN

2. Press "Setup Baseline Tables" button to prepare baseline land use, runoff, and recharge input tables

3. Navigate to each input table and enter data:

Runoff  Recharge  Runoff Loadings  Recharge Loadings

B. Land use data: Enter HRU areas available for land conservation and associated costs  Land Use

**Input Page Step 1A Manual – Baseline Hydrology**

Follow the steps below to enter your own baseline hydrology data manually.

Enter the number of HRU types that you intend to model and the name of your constituent of interest<sup>32</sup>, and press the Setup Baseline Tables button. This will automatically prepare appropriately sized input tables for land use, runoff and recharge data. *The process creates blank input tables; therefore, do not press this button again unless you have your input data saved elsewhere and want to change the number of HRUs.*

<sup>32</sup> Any constituent that you have loadings and managed loadings time series for can be entered here. However, when using the Stormwater module, users should note that default stormwater BMP parameters are only available for TN, TP, TSS, and Zn.



**1. Baseline:** Data for unmanaged land conditions.

A. Time series data:

Use Baseline Hydrology module for assisted data acquisition and entry  **Baseline Hydrology Module** OR manually enter your own data.

Name of Constituent 1:

1. Enter the number of HRUs in your study area:  **Setup Baseline Tables**

2. Press "Setup Baseline Tables" button to prepare baseline land use, runoff, and recharge input tables

3. Navigate to each input table and enter data:

**Runoff**  **Recharge**  **Runoff Loadings**  **Recharge Loadings**

B. Land use data: Enter HRU areas available for land conservation and associated costs  **Land Use**

**Runoff**  **Recharge**

Next, select the Runoff button to navigate to the input table and enter time series data of runoff rate for each HRU for the modeling time period. The runoff rate must be input per unit time (e.g., inches per

day). Values can be cut and pasted from another file or imported using Data – (Get External Data) From Text options in Excel to add contents of a delimited file with no headers. Dates, in the format of mm/dd/yyyy, are only required for data on the **Runoff** page. All other pages automatically populate the dates from the **Runoff** page. This table requires a time series of runoff rates for baseline HRUs at the daily or monthly time step. For a monthly time step, the day of the month does not matter. The dates entered in this table will populate the dates in all other input tables that require a time series. **Time series data must be consecutive and complete**, that is, there must not be any missing dates or data. Refer to Defining Hydrologic Response Units in Section 2.1, for more information regarding data sources for runoff and recharge rates.

Date (mm/dd/yyyy)	Quantity in inches/time step							
	HRU1	HRU2	HRU3	HRU4	HRU5	HRU6	HRU7	HRU8
1/1/2002	0.019666	0.018828	0.018801	0.016655	0.006742	0.019666	0.014168	0.013553
1/2/2002	0.016656	0.015946	0.015923	0.014106	0.00571	0.016656	0.011559	0.011057
1/3/2002	0.014408	0.013794	0.013774	0.012202	0.004939	0.014408	0.009873	0.009445
1/4/2002	0.013204	0.012642	0.012623	0.011183	0.004526	0.013204	0.009071	0.008677
1/5/2002	0.010676	0.010221	0.010206	0.009041	0.00366	0.010676	0.006703	0.006412
1/6/2002	0.008428	0.008069	0.008057	0.007138	0.002889	0.008428	0.004656	0.004454
1/7/2002	0.135054	0.129298	0.129112	0.114375	0.046296	0.135054	0.190762	0.182481
1/8/2002	0.108846	0.104207	0.104057	0.09218	0.037312	0.108846	0.109809	0.105043
1/9/2002	0.064979	0.062209	0.062119	0.055029	0.022275	0.064979	0.056952	0.054479
1/10/2002	0.042383	0.040576	0.040518	0.035893	0.014529	0.042383	0.033914	0.032
1/11/2002	0.06827	0.06536	0.065266	0.057816	0.023403	0.06827	0.079026	0.075

**Runoff**  **Recharge**

Once you have entered these data, select Return to Input and check the box indicating that this section is complete. Select Recharge to navigate to the input table for recharge time series. Similar to the runoff input table, the recharge input table also requires a time series of recharge rates for baseline HRUS at the daily or monthly time step. Similarly, it should be consecutive and complete.

Once you have entered these data, select Return to Input and check the box indicating that this section is complete. Select Runoff Loadings to navigate to the input table for runoff loadings time series.

**Runoff Loadings**  **Recharge Loadings**

Date (mm/dd/yyyy)	Loadings in lbs/time step							
	Baseline HRU Set - C1							
	HRU1C1	HRU2C1	HRU3C1	HRU4C1	HRU5C1	HRU6C1	HRU7C1	HRU8C1
1/1/2002	0	0	0	0	0	0	0	0
1/2/2002	0	0	0	0	0	0	0	0
1/3/2002	0	0	0	0	0	0	0	0
1/4/2002	0	0	0	0	0	0	0	0
1/5/2002	0	0	0	0	0	0	0	0
1/6/2002	0	0	0	0	0	0	0	0
1/7/2002	0	0.010022	0.013185	0.04588	0.211938	0	0	0.010206
1/8/2002	0	0.000115	0.000149	0.000517	0.002378	0	0	0.000117
1/9/2002	0	0	0	0	0	0	0	0
1/10/2002	0	0	0	0	0	0	0	0
1/11/2002	0	0.005146	0.006762	0.02353	0.108655	0	0	0.005241

Once you have entered these data, select Return to Input and check the box indicating that this section is complete. Select Recharge Loadings to navigate to the input table for recharge loadings time series.

Runoff Loadings     **Recharge Loadings**

Once you have entered these data, select Return to Input and check the box indicating that this section is complete. This completes **Input page** Step 1A manual entry. Continue to **Input page** Step 1B.

Runoff Loadings     Recharge Loadings

**Input Page Step 1B – Land Use and Its Management**

Select the Land Use button on the **Input page** to navigate to the **Land Use page**. On this page, you must enter HRU areas for baseline conditions and may enter information for land conservation as a management option. Within the Baseline HRU Characteristics table, the baseline areas for HRUs can represent existing conditions or future conditions that you would like to model. For example, if you intend to run the model to prioritize management options to achieve by 2050, you would enter the projected area of each HRU in 2050. If you manually entered data for **Input page** Step 1A, then you must enter information on the percent effective impervious area and infiltration rate for each HRU if you plan to use the Stormwater Hydrology Module. If you used the EDM Data Inventory, the baseline HRU areas are automatically populated from the characteristics database. Otherwise, you will need to use GIS to calculate the baseline area of each land-use/soil type combination for your subwatershed of interest.

Baseline HRU Characteristics				
HRU ID	HRU Name <sup>1</sup>	Baseline Area [acre]	Percent Effective Impervious <sup>1</sup>	Infiltration Rate [in/hr] <sup>1</sup>
HRU1B	Forest, Sand & Gravel & Gravel	13,647	0.00%	9.5
HRU2B	Open/non-residential, Sand & Gravel & Gravel	2,296	4.26%	8.455
HRU3B	Medium-low density, Sand & Gravel	5,949	4.40%	8.075
HRU4B	Medium-high density, Sand & Gravel	973	15.31%	5.95
HRU5B	Commercial-industrial, Sand & Gravel	2,537	65.72%	3.08
HRU6B	Agriculture, Sand & Gravel	634	0.00%	8.01
HRU7B	Forest, Till & Fine-Grained Deposits	12,553	0.00%	0.938
HRU8B	Open/non-residential, Till & Fine-Grained Deposits	1,083	4.34%	0.832
HRU9B	Medium-low density, Till & Fine-Grained Deposits	2,821	4.40%	0.806
HRU10B	Medium-high density, Till & Fine-Grained Deposits	448	14.93%	0.605
HRU11B	Commercial-industrial, Till & Fine-Grained Deposits	1,104	65.79%	0.336
HRU12B	Agriculture, Till & Fine-Grained Deposits	241	0.00%	0.768
HRU13B	Cranberry Bog	98	0.00%	0.2
HRU14B	Forested Wetland	6,474	0.00%	0.2
HRU15B	Nonforested Wetland	2,132	0.00%	0.2
HRU16B	Water	1,330	0.00%	0

Data for Land Conservation Option			
Minimum Area [acre]	Maximum Area [acre]	Initial Cost to Conserve [\$ /acre]	O&M Cost [\$ /acre/yr]
13647	13647	-9	-9
2296	2296	-9	-9
5949	5949	-9	-9
973	973	-9	-9
2537	2537	-9	-9
634	634	-9	-9
12553	12553	-9	-9
1083	1083	-9	-9
2821	2821	-9	-9
448	448	-9	-9
1104	1104	-9	-9
241	241	-9	-9
98	98	-9	-9
6474	6474	-9	-9
2132	2132	-9	-9
1,330	1,330	-9	-9

For the Data for Land Conservation Option table (see screenshot to the left), the following examples are provided to help guide inputting appropriate values:

- “Minimum” areas for each HRU – For urban HRUs, this may be the existing area of urban HRUs since these areas are not expected to be reforested or otherwise be “undeveloped”. For forest lands, it may be the area of conserved/protected forest lands which must exist in the future due to their protected status.
- “Maximum” areas for each HRU – For urban HRUs, this may be the projected, built-out area or maximum allowable area under zoning regulations. For forest lands, it may be the existing area of forest land given that other HRU types will not be used to regrow forest for urban recreation or start a forestry business.
- Cost to conserve HRUs – It may be environmentally beneficial to purchase and conserve forest or wetlands. For these HRUs, enter the initial cost of purchasing the land (i.e., capital costs) and any annual operations and maintenance (O&M) costs that may continue to be associated with the purchase.

A primary source of the capital cost to conserve data is from records of land purchased by the municipality for conservation. If records of that kind are not available, you can use real estate appraisal websites to estimate the cost of open land for a land use type. We typically estimate O&M costs as 5% of the capital cost. If land conservation is not possible or desirable for an HRU, then enter “-9” for initial and O&M costs<sup>33</sup> (as shown in the screenshot).

Once both tables are complete, navigate back to the **Input page** and check the box next to the Land Use button and continue to **Input page** Step 2.

**I. Baseline:** Data for unmanaged land conditions.

A. Time series data:

Use Baseline Hydrology module for assisted data acquisition and entry

Baseline Hydrology Module

Name of Constituent 1: TN

OR manually enter your own data.

1. Enter the number of HRUs in your study area: 16

2. Press "Setup Baseline Tables" button to prepare baseline land use, runoff, and recharge input tables

3. Navigate to each input table and enter data:

Runoff  Recharge  Runoff Loadings  Recharge Loadings

Setup Baseline Tables

B. Land use data: Enter HRU areas available for land conservation and associated costs  Land Use

### 3.3 Managed Hydrology and HRU Areas/Stormwater Management

To incorporate stormwater BMPs to manage the land use area within your watershed, you must complete this step. You have the option to either get assistance with deriving and populating stormwater

<sup>33</sup> WMOST allows users to turn any management option “on” or “off” when setting up the model. The data input “-9” typically acts as the management option exclusion flag, but only use this flag as directed by this user guide. This data input is different than a capital cost of zero, which indicates that the management option may be applied and at zero cost to the user.



management related inputs or manually entering stormwater hydrology and loadings data. If you need assistance, continue with *Input Page Step 2A Assisted – Stormwater Hydrology Module* section. If you would like to manually enter the data, skip to *Input Page Step 2A Manual – Stormwater Hydrology* for instructions.

**Input Page Step 2A Assisted – Stormwater Hydrology Module**

Navigate to the Stormwater Hydrology Module by clicking on the Stormwater Hydrology Module button.

Five steps comprise the Stormwater Hydrology Module. In **Stormwater page** Step 1, use the drop-down menu to indicate whether you used the Baseline Hydrology Module or manually entered your own baseline data. If you used the Baseline Hydrology Module, select “Baseline Hydrology Module” and press Import Hourly Time Series.

If you used the Baseline Hydrology Module, the Import Hourly Time Series button will populate all additional stormwater data based on your model setup in **Input page** Step 1.

If you manually entered your own data, select “Entered Own Data” and press Manually Enter Hourly Time Series where you will be asked for additional information.

Additional Stormwater Data: Three types of additional data are required if you entered your own baseline hydrology:

- Latitude of your study area
- Hourly or daily temperature time series for your study area
- Hourly runoff and runoff loadings time series for your HRUs. More detailed guidance is below.

First, enter the model time period. This time period must match the time period of the baseline runoff and recharge time series. Second, enter the latitude of your study area.

**1. Enter the model time period. Time series data must match the time period of the baseline hydrology.**

<b>Baseline hydrology start:</b>	1/1/2002
<b>Baseline hydrology end:</b>	12/31/2006

**2. Enter the latitude of your study area in the blue box.**

Latitude (decimal degrees)

Next, enter the hourly or daily temperature time series that best suits your study area and spans the entire modeling time period. SUSTAIN can accept either hourly or daily temperature data. The temperature data is used for estimating evapotranspiration from the BMP. If you are using runoff and recharge data from an existing model, you should check the model documentation to determine developers' data sources for compatible weather time series.

Date/Time	Temperature (deg F)	Date/Time	Runoff (in/hr)	Forest, Sand	Open/non-residential, Sand	Medium-low density, Sand	Medium-high density, Sand
(dd-mm-yyyy hh)		(dd-mm-yyyy hh)					
1/1/2002 12:00 AM	23	1/1/2002 12:00 AM	0	0	0	0	0
1/1/2002 1:00 AM	22	1/1/2002 1:00 AM	0	0	0	0	0
1/1/2002 2:00 AM	21	1/1/2002 2:00 AM	0	0	0	0	0
1/1/2002 3:00 AM	21	1/1/2002 3:00 AM	0	0	0	0	0
1/1/2002 4:00 AM	20	1/1/2002 4:00 AM	0	0	0	0	0
1/1/2002 5:00 AM	19	1/1/2002 5:00 AM	0	0	0	0	0
1/1/2002 6:00 AM	20	1/1/2002 6:00 AM	0	0	0	0	0
1/1/2002 7:00 AM	19	1/1/2002 7:00 AM	0	0	0	0	0
1/1/2002 8:00 AM	19	1/1/2002 8:00 AM	0	0	0	0	0
1/1/2002 9:00 AM	19	1/1/2002 9:00 AM	0	0	0	0	0
1/1/2002 10:00 AM	24	1/1/2002 10:00 AM	0	0	0	0	0

Finally, enter hourly runoff flows and loadings data for all developed HRUs. The daily time step is too coarse to accurately represent a time series of storm events so SUSTAIN requires

hourly runoff and runoff loadings time series data in order to model the BMP response to an event. Press [Populate HRU names from Land Use](#) to prepare the input table for the runoff data. This will create time series columns for all HRUs.

TN Runoff (lbs/hr)						
Forest, Sand	Open/non-residential, Sand	Medium-low density, Sand	Medium-high density, Sand	Commerical-industrial, Sand	Agriculture, Sand	
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

Depending on which type of BMPs you plan to model, you may only need to enter runoff data for certain HRUs.

For example, urban BMPs are modeled on developed HRUs (i.e., HRUs with non-zero EIA), and agricultural BMPs are modeled on undeveloped HRUs (i.e., HRUs with zero EIA) and a curve number (CN) less than 100. Refer to the Theoretical Documentation for details on the difference between developed and undeveloped BMP modeling. You do not need to provide hourly runoff time series for HRUs that you will not model.

Use the [Return to Stormwater Hydrology Module](#) button to navigate back.

Select the model time step you are using in **Stormwater page** Step 2. If you are including

**2. Model time step** Did you run a daily or monthly model?  Daily  Daily

flood damages in the optimization of costs, you must set up a daily model.

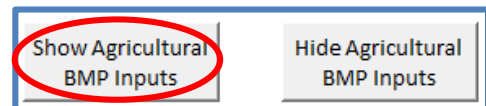
In **Stormwater page** Step 3, select the stormwater BMP types and indicate the runoff design depths that you would like to model and the associated 1<sup>st</sup> order decay rate. You can model up to nine combinations of BMP type and runoff design depth. This limitation is imposed to ensure manageable processing time and completion. The first 13 of the BMPs in the drop-down menu are urban BMPs, which apply to HRUs with non-zero EIA. The final four BMPs are agricultural BMPs (with the designation “Ag”), which apply to HRUs with zero EIA and CN less than 100. Each selected BMP is simulated on a distinct one-acre drainage area, such that each BMP receives the runoff from one acre of the HRU.

BMP Type	Design Depth For BMP [in]	TN 1st Order Decay Rate [1/hr]
Biofiltration w/UD	1	0.03
Gravel Wetland	1	0.13
Infiltration Trench	1	0.42
Ag: Subsurface Gravel Wetland	1	0.54
Ag: Sediment Basin	1	0.1
Ag: Vegetative Filter Strip	1	0.46



You can import default decay rates for TN, TP, TSS, and zinc using the Import Default Decay Rates button. The default decay rates are consistent with values provided in EPA’s OptiTool (US EPA 2017) which were calibrated based on field measurements at the University of New Hampshire Stormwater Center facilities. For each combination, the Stormwater Hydrology Module will calculate the appropriate BMP design parameters, run a simulation for all appropriate HRUs, calculate the final “managed” runoff and recharge time series, and populate the appropriate WMOST input table. As indicated in Section 2.2, in order for the Stormwater Hydrology Module to run, the WMOST .xslm file must be saved in a folder location with no spaces in the file path.

If you are using agricultural BMPs, you must enter additional data inputs to run the Stormwater Hydrology Module. Use the Show Agricultural BMP Inputs button to display the input tables and fields for this data, which include **Stormwater page** Steps 4A – 4E. If you are not using any agricultural BMPs, hide these inputs using the Hide Agricultural BMP Inputs button and continue on to **Stormwater page** Step 5.

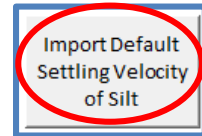


First, using instructions from **Stormwater page** Step 4A, enter the total area that will be managed by the selected BMP in **Stormwater page** Step 3. Agricultural BMPs are typically designed to manage runoff from larger land areas than urban BMPs. The default managed area is 15 acres.

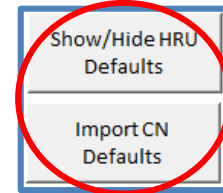
Area Managed by Agriculture BMP [acres]	For Sediment Basins only: TN Settling Velocity [in/s]
NA	NA
NA	NA
NA	NA
15	0
15	0.0035
15	0

Then, **Stormwater page** Steps 4B – 4D provide instructions for defining special inputs for agricultural BMPs. For all agricultural BMP types, you must provide a CN for each undeveloped HRU. You may exclude any undeveloped land use from modeling by entering a -9 or a 100 in the CN input field. Furthermore, you may use the Import CN Defaults button to import default CN values based on the land use name and soil group of your HRUs. The Show/Hide HRU Defaults button displays the source data for the default values and can be referenced if the Import CN Defaults button did not return any matches or if it returned multiple matches.

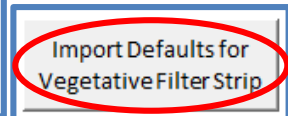
Then, if you are modeling a sediment basin, you must enter the settling velocity of the constituent of interest in **Stormwater page** Step 3. You may use the Import Default Settling Velocity of Silt button to import values for fine, medium, or coarse silt.



Finally, enter the additional BMP parameters needed for modeling vegetative filter strips if you have selected that BMP in **Stormwater page** Step 3. This must be done for each undeveloped HRU being modeled. The additional parameters include flow length, surface depression storage, Manning’s N coefficient, and overland slope. You may use the Import Defaults for Vegetative Filter Strip button to import default values for modeled HRUs based on their land use.

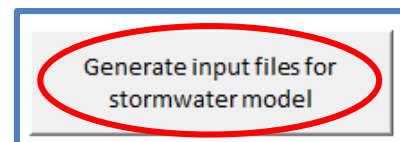


HRU Name	Percent Effective Impervious	Hydrologic Soil Group (A,B,C,D)	CN Number
Forest, Sand & Gravel & Gravel	0.00%	A	36
Open/non-residential, Sand & Gravel & Gravel	4.26%	B	NA
Medium-low density, Sand & Gravel	4.40%	B	NA
Medium-high density, Sand & Gravel	15.31%	C	NA
Commercial-industrial, Sand & Gravel	65.72%	D	NA
Agriculture, Sand & Gravel	0.00%	A	68
Forest, Till & Fine-Grained Deposits	0.00%	B	60
Open/non-residential, Till & Fine-Grained Deposits	4.34%	B	NA
Medium-low density, Till & Fine-Grained Deposits	4.40%	C	NA
Medium-high density, Till & Fine-Grained Deposits	14.93%	D	NA
Commercial-industrial, Till & Fine-Grained Deposits	65.79%	D	NA
Agriculture, Till & Fine-Grained Deposits	0.00%	B	79
Cranberry Bog	0.00%	A	100
Forested Wetland	0.00%	A	100
Nonforested Wetland	0.00%	A	100
Water	0.00%	A	NA



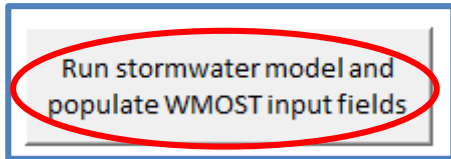
HRU Name	Percent Effective Impervious	Flow Length [ft]	Surface Depression Storage [in]	Manning's Coefficient [unitless]	Overland Slope [ft/ft]
Forest, Sand & Gravel & Gravel	0.00%	75	0.25	0.3	0.05
Open/non-residential, Sand & Gravel & Gravel	4.26%	NA	NA	NA	NA
Medium-low density, Sand & Gravel	4.40%	NA	NA	NA	NA
Medium-high density, Sand & Gravel	15.31%	NA	NA	NA	NA
Commercial-industrial, Sand & Gravel	65.72%	NA	NA	NA	NA
Agriculture, Sand & Gravel	0.00%	75	0.25	0.3	0.05
Forest, Till & Fine-Grained Deposits	0.00%	75	0.25	0.3	0.05
Open/non-residential, Till & Fine-Grained Deposits	4.34%	NA	NA	NA	NA
Medium-low density, Till & Fine-Grained Deposits	4.40%	NA	NA	NA	NA
Medium-high density, Till & Fine-Grained Deposits	14.93%	NA	NA	NA	NA
Commercial-industrial, Till & Fine-Grained Deposits	65.79%	NA	NA	NA	NA
Agriculture, Till & Fine-Grained Deposits	0.00%	75	0.25	0.3	0.05
Cranberry Bog	0.00%	75	0.25	0.15	0.05
Forested Wetland	0.00%	75	0.25	0.15	0.05
Nonforested Wetland	0.00%	75	0.25	0.15	0.05
Water	0.00%	NA	NA	NA	NA

After entering the BMP management combinations, press Generate input files for stormwater model under **Stormwater page** Step 5. This button creates three types of input files for the stormwater simulation:



- Main input file (Input.inp)
- Climate time series file (Climate.swm)
- Multiple HRU runoff time series files based on the number of developed HRUs (HRU#.txt).

The input file generation step may take a few minutes to complete. When the files are complete, a message box stating “Input files are complete. Stormwater model is ready to be run” will appear. Press “Ok” to continue.



The generated input files are saved to a folder titled “Input” in same location as the WMOST .xslm file. Next, press Run stormwater model and populate WMOST input fields. When the SUSTAIN simulation is complete, a message box stating “BMP simulation is complete”. Press “Ok” to move on to the stormwater results processing. After the results processing is complete, a message box stating “Runoff and recharge time series for managed hydrology have been populated. Return to Input data page to continue” will appear. Press “Ok” to continue.

The stormwater model simulation determines how much of the runoff flow and loadings are infiltrated or detained by a BMP. Simulation outputs are automatically processed and the appropriate input tables for managed HRU sets are populated on the **Runoff, Recharge, Runoff\_L, and Recharge\_L** pages.

Once the module completes processing, select Return to Input and check the box next to Stormwater Hydrology Module to indicate that the module and data entry is complete. Enter the total number of HRU sets including the one created by the Baseline Hydrology Module (always one) and those created by the Stormwater Hydrology Module (depends on the number of HRUs and BMP types entered onto the **Stormwater** page). Proceed to **Input page Step 2B** using instructions from *Input Page Step 2B – Land Use and Its Management*.

**2. Stormwater Management:** Data for stormwater managed land conditions. This section is only required if you wish to consider stormwater management.

<p>A. Time series data:</p> <p>Use Stormwater Hydrology module for assisted data acquisition and entry</p> <p><input checked="" type="checkbox"/> <b>Stormwater Hydrology Module</b></p>	<p>OR</p> <p>manually enter your own data.</p> <p>1. Enter the number of HRU sets (baseline plus managed): <input type="text" value="7"/> </p> <p>2. Press "Setup Stormwater Tables" button to prepare managed land use, runoff, and recharge input tables:</p> <p>3. Navigate to each input table and enter data:</p> <p><input type="checkbox"/> <b>Runoff</b> <input type="checkbox"/> <b>Recharge</b> <input type="checkbox"/> <b>Runoff Loadings</b> <input type="checkbox"/> <b>Recharge Loadings</b></p> <p style="text-align: right;"><b>Setup Stormwater Tables</b></p>
--	--

### *Input Page Step 2A Manual – Stormwater Hydrology*

For manually entering your own stormwater hydrology data, follow the instructions below.

Decide on the number of BMPs you would like to evaluate, that is, the number of BMP type and size combinations. For example, assessing a bioretention basin and a detention pond each at the 0.6 inch and 1.0 inch design depth would require a total of four BMP setups. The runoff and recharge time series associated with one BMP setup for all modeled HRUs constitutes a managed HRU set.

Enter the number of HRU sets that you intend to model including the baseline set (i.e., add one to the number of stormwater BMP setups you intend to model).

**2. Stormwater Management:** Data for stormwater managed land conditions. This section is only required if you wish to consider stormwater management.

A. Time series data:

Use Stormwater Hydrology module for assisted data acquisition and entry  **Stormwater Hydrology Module** OR manually enter your own data.

1. Enter the number of HRU sets (baseline plus managed):  **Setup Stormwater Tables**

2. Press "Setup Stormwater Tables" button to prepare managed land use, runoff, and recharge input tables:

3. Navigate to each input table and enter data:

**Runoff**  **Recharge**  **Runoff Loadings**  **Recharge Loadings**

B. Land use: Enter data on HRU areas available for stormwater management and stormwater management costs  **Land Use**

Press Setup Stormwater Hydrology to automatically prepare appropriately sized input tables for managed land use, runoff and recharge data. *The process creates blank input tables; therefore, do not press this button again unless you have your input data saved elsewhere and want to change the number of HRU sets.*

Managed HRU Set (HRUM1)										
HRU1M1	HRU2M1	HRU3M1	HRU4M1	HRU5M1	HRU6M1	HRU7M1	HRU8M1	HRU9M1	HRU10M1	
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0.007916	0.008172	0.028437	0.122041	0	0	0.008062	0.008176	0.027728	
0	0.000394	0.000407	0.001416	0.006078	0	0	0.000401	0.000407	0.001381	
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0.012991	0.013411	0.046667	0.200303	0	0	0.013231	0.013418	0.045503	
0	0	0	0	0	0	0	0	0	0	0
0	0.033439	0.03452	0.120121	0.515575	0	0	0.034055	0.034538	0.117125	
0	0	0	0	0	0	0	0	0	0	0
0	0.009511	0.009818	0.034164	0.146638	0	0	0.009686	0.009823	0.033312	

Next, select Runoff to navigate to the input table and enter time series data of runoff rate for each HRU.

This table requires a time series of runoff rates for each managed land use set at the daily or monthly time step. For a monthly time step, the day of the month does

not matter. **Time series data must be consecutive**, that is, there must not be any missing dates. Refer to Defining Hydrologic Response Units in Section 2.1, for more information regarding data sources for runoff and recharge rates.

The time series are input vertically and HRUs and HRU sets horizontally. You can exclude an HRU from a “managed set” by entering “-9” for the capital and O&M costs associated with managing the HRU; this action will make the values specified for those HRUs inconsequential. To the right of the Baseline HRU set, which was completed in **Input page** Step 1, you will see the continuation of HRU columns for the managed sets.

Once you have entered runoff hydrology data, select Return to Input and check the box indicating that this section is complete. Next select Recharge to enter time series data of recharge rates for each HRU.

**Runoff**  **Recharge**

Similar to the runoff input table, the recharge input table also requires a time series of recharge rates for baseline and each managed land use set at the same daily or monthly time step. Similarly, it should be consecutive and complete and input as depth per time step (e.g., inches per day). Select Return to Input and check the box next to the Recharge button indicating that this section is complete.



**Runoff Loadings**  **Recharge Loadings**

Next, select Runoff Loadings to navigate to the input table for runoff loadings time series.

Managed HRU Set (HRUM1C1)								
HRU1M1C	HRU2M1C	HRU3M1C	HRU4M1C	HRU5M1C	HRU6M1C	HRU7M1C	HRU8M1C	
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

Once you have entered these data, select Return to Input and check the box indicating that this section is complete. Finally, select Recharge Loadings to navigate to the input table for recharge loadings time series. Input the recharge loadings data on this page. Once you have entered these data, select Return to Input and check the box indicating

**Runoff Loadings**  **Recharge Loadings**

that this section is complete.

**Runoff Loadings**  **Recharge Loadings**

This completes **Input page Step 2A** manual entry. Continue to **Input page Step 2B**.

**Input Page Step 2B – Land Use and Its Management**

Select the Land Use button to navigate to the **Land Use page**. Beneath the Baseline HRU Characteristics input table, you will see table(s) for managed HRU sets. There is one table for each BMP or managed HRU set. Depending on whether you used the automated or manual version of the stormwater hydrology input (**Input page Step 2A**), some fields will be pre-filled.

Enter or verify the name of the BMP in the blue box in the upper right hand corner of each Managed Land Uses and Their Limits table. The following input data are requested for each HRU:

- Minimum area on which the management practice may be implemented – For urban HRUs, regulations may require that a specific stormwater management practice is implemented.
- Maximum area on which the management practice may be implemented – For urban HRUs, some of the HRU may be already managed by a different stormwater practice and is, therefore, unavailable for that treatment.
- Initial costs associated with the management practice – For example, design and construction of a bioretention basin to retain one inch of runoff.
- O&M costs associated with the management practice – For example, annual clean out and other upkeep of the bioretention basin to maintain performance.

The Stormwater Hydrology Module will automatically enter initial costs and O&M costs based on the cost of stormwater BMPs in terms of dollars per treated cubic feet of stormwater. The unit cost values are derived from previous applications of SUSTAIN<sup>34</sup> and Opti-Tool (EPA 2017). These default costs are for stormwater BMP retrofits in 2016 dollars. For comparable cost values for BMPs installed in newly

<sup>34</sup> U.S. Environmental Protection Agency (EPA) and Massachusetts Department of Environmental Protection (MassDEP). 2009. Optimal Stormwater Management Plan Alternatives: A Demonstration Project in Three Upper Charles River Communities.

developing areas, see the Theoretical Documentation. If a management practice is not applicable or desirable for an HRU, “-9” is entered for initial and O&M costs.

First Set of Managed Land Uses and Their Limits					1" Biofiltration w/UD
HRU ID	HRU Name	Minimum Area [acre]	Maximum Area [acre]	Initial Cost to Conserve [\$/acre]	O&M Cost [\$/acre/yr]
HRU1M1	Forest, Sand & Gravel & Gravel	0	0	-9	-9
HRU2M1	Open/non-residential, Sand & Gravel & Gravel	0	1710	4570.69	228.53
HRU3M1	Medium-low density, Sand & Gravel	0	3602	4718.34	235.92
HRU4M1	Medium-high density, Sand & Gravel	0	415	16418.77	820.94
HRU5M1	Commercial-industrial, Sand & Gravel	0	1075	70471.9	3523.60
HRU6M1	Agriculture, Sand & Gravel	0	0	-9	-9
HRU7M1	Forest, Till & Fine-Grained Deposits	0	0	-9	-9
HRU8M1	Open/non-residential, Till & Fine-Grained Deposits	0	905	4654.86	232.74
HRU9M1	Medium-low density, Till & Fine-Grained Deposits	0	497	4720.81	236.04
HRU10M1	Medium-high density, Till & Fine-Grained Deposits	0	9	16009.25	800.46
HRU11M1	Commercial-industrial, Till & Fine-Grained Deposits	0	398	70548.68	3527.43
HRU12M1	Agriculture, Till & Fine-Grained Deposits	0	0	-9	-9
HRU13M1	Cranberry Bog	0	0	-9	-9
HRU14M1	Forested Wetland	0	0	-9	-9
HRU15M1	Nonforested Wetland	0	0	-9	-9
HRU16M1	Water	0	0	-9	-9

In the above screenshot, all urban HRUs are receiving biofiltration management. There are no minimum acres of HRU area that must be managed but the maximum values are entered based on projected build-out (therefore, same as maximum areas in the baseline table). In addition, as described in Section 2.1 in the Theoretical Documentation, the maximum area of an HRU that can be managed with bioretention is limited to the area of that HRU that exists considering land conservation decisions (i.e., land area is conserved and no more can be treated than exists as decided is optimal by the model). All specifications are “per acre of HRU”; therefore, the initial cost of \$4,571 and O&M cost of \$229 for open/non-residential on sand and gravel surficial geology is the cost to treat one acre of that HRU. The actual footprint of the bioretention basin will only be a small part of that acre of land. The costs for agricultural BMPs are also specified as per acre of managed land, but they can be used to manage areas larger than one acre as specified by the user. WMOST calculates the final costs for implementation taking into account the quantity of BMPs implemented. Neither SUSTAIN nor WMOST include the associated cost of land the BMP is constructed upon but users can adjust values accordingly based on local land costs.

Repeat the same instructions for additional BMPs/managed sets. Up to ten stormwater management options, including traditional, green infrastructure, LID, agricultural runoff control practices or other land management practices that modify runoff and recharge may be specified. A managed set may include multiple simultaneous practices that achieve some standard such as retaining a one inch storm event using rooftop disconnection, bioretention basins and swales.

Once you have entered all the land use information related to managed sets, navigate to the input screen by pressing Return to Input. Check the box next to Land Use to indicate that you have completed data entry for this category of input.



**2. Stormwater Management:** Data for stormwater managed land conditions. This section is only required if you wish to consider stormwater management.

A. Time series data:  
Use Stormwater Hydrology module for assisted data acquisition and entry  **Stormwater Hydrology Module** OR manually enter your own data.

1. Enter the number of HRU sets (baseline plus managed):   
 2. Press "Setup Stormwater Tables" button to prepare managed land use, runoff, and recharge input tables: **Setup Stormwater Tables**  
 3. Navigate to each input table and enter data:  
 **Runoff**  **Recharge**  **Runoff Loadings**  **Recharge Loadings**

B. Land use: Enter data on HRU areas available for stormwater management and stormwater management costs  **Land Use**

### Input Page Step 2C – Water Quality BMPs

The water quality BMPs are a suite of optional BMPs that, if implemented, reduce loadings to the stream or reservoir, which may help the system meet water quality targets in the stream or reservoir. Select the **WQ BMPs** button to navigate to the **WQ BMPs page**.

C. Water Quality BMPs: If you wish to consider water quality management options to change loadings on HRU area or to a waterbody, proceed to the WQ BMPs module.  **WQ BMPs**

The first type of water quality BMP models streambank restoration/stabilization and outfall enhancement/stabilization. Unlike other types of BMPs in WMOST, these BMPs are not associated with specific HRUs. This water quality BMP requires four data inputs under **WQ BMPs page** Step 1A or Step 1B. The following input data are requested for each stabilization management option:

- Constituent removal rate – For each unit treated (stream foot or outfall), the mass of the constituent that is prevented from entering the waterbody at each time step in pounds.
- Capital cost per treatment unit – The cost related to treatment of one stream foot or outfall in dollars per unit treated.
- Maximum number of units that can be treated– The maximum number of units that are available for stabilization.
- Waterbody type where stabilization occurs – The waterbody type (stream or reservoir) where the stabilization project is located, and thus, receives the target adjustment.

The screenshots below display example data inputs for streambank stabilization where the units are feet of stream length. Outfall stabilization requires corresponding data inputs where the units are outfalls.

**1A. Streambank Restoration or Stabilization**

Enter the constituent removal rate resulting from a streambank project.  lb/ft/time step

Enter the cost per stream length treated and the maximum stream length that can be treated.

Cost per linear stream length	\$152.40 \$/foot
Maximum linear stream length	65616.8 feet

Specify whether the stabilization project applies to the in-stream or reservoir loading target.  In-Stream Loadings Target

The second type of water quality BMP models different types of land management BMPs, including street sweeping, tree canopy, and urban nutrient management plans. These BMPs are grouped together as “Runoff Loadings Direct Reduction BMPs” because they all result in reduced runoff loadings and have a negligible impact on runoff flows. Therefore, WMOST models these BMPs by reducing runoff loadings on the HRUs receiving the BMP application with a percent reduction.

To model any direction reduction water quality BMPs, continue to **WQ BMPs page** Step 2.

**2. Runoff Loadings Direct Reduction BMPs: Apply direct runoff loadings reduction to an HRU area by implementing a direct reduction BMP.**  
**2A. Runoff Loadings Direct Reduction Management Sets**

You can model the following three management options:

Select the name of the direct reduction BMP(s) that you would like to model.

- 1) Street Sweeping
- 2) Tree Canopy over Impervious/Turf Area
- 3) Urban Nutrient Management

Select the number of direct reduction managed sets:

[Setup Direct Reduction Tables](#)

Set No.	Direct Reduction Management Name
DRM1	Street Sweeping
DRM2	Tree Canopy over Impervious/Turf
DRM3	Urban Nutrient Management

Enter the application area, cost of application, and load adjustment for each constituent in the tables below.  
 If an HRU does not receive any treatment from the management practice, enter 0 for the load removal rate.

First, as shown in the screenshot above, select the number and types of direct reduction management sets you would like to model. You may model up to three of these BMPs in one model run. If you select the same management set type more than once in the set of three in order to evaluate varying levels of treatment and their associated costs, the model is limited such that it will only choose to apply the most cost-effective option from those sets. This condition ensures that the model cannot apply the same type of management on the same HRU type. Press [Setup Direct Reduction Tables](#) to set up the tables under **WQ BMPs page Step 2B**.

For each HRU, you must enter four data inputs:

- Application area that receives the management practice – This area affects the capital and O&M costs incurred.
- Initial cost of application of the management practice – For example, purchase of street sweeping equipment.
- O&M costs associated with the management practice – For example, labor required to operate the equipment.
- Percentage of loading removed – the resulting reduction in loadings as a result of the management practice.

HRU ID	HRU Name	Application Area [acre]	Initial Cost of Application [\$ /acre]	O&M Cost [\$ /acre/yr]	TP Load Removal Rate [%]
HRU1DRM1	Forest, Sand & Gravel & Gravel	0.00	0.00	0.00	0.00
HRU2DRM1	Open/non-residential, Sand & Gravel & Gravel	0.00	0.00	0.00	0.00
HRU3DRM1	Medium-low density, Sand & Gravel	494.21	8.09	2.00	10.00
HRU4DRM1	Medium-high density, Sand & Gravel	247.11	12.14	3.50	15.00
HRU5DRM1	Commercial-industrial, Sand & Gravel	44.48	12.14		15.00
HRU6DRM1	Agriculture, Sand & Gravel	0.00	0.00	0.00	0.00
HRU7DRM1	Forest, Till & Fine-Grained Deposits	0.00	0.00	0.00	0.00
HRU8DRM1	Open/non-residential, Till & Fine-Grained Deposits	0.00	0.00	0.00	0.00
HRU9DRM1	Medium-low density, Till & Fine-Grained Deposits	19.77	8.09	2.00	10.00
HRU10DRM1	Medium-high density, Till & Fine-Grained Deposits	49.42	12.14	3.50	15.00
HRU11DRM1	Commercial-industrial, Till & Fine-Grained Deposits	1.73	12.14	3.50	15.00
HRU12DRM1	Agriculture, Till & Fine-Grained Deposits	0.00	0.00	0.00	0.00
HRU13DRM1	Cranberry Bog	0.00	0.00	0.00	0.00
HRU14DRM1	Forested Wetland	0.00	0.00	0.00	0.00
HRU15DRM1	Nonforested Wetland	0.00	0.00	0.00	0.00
HRU16DRM1	Water	0.00	0.00	0.00	0.00

For any HRUs within a management set that do not receive the management practice, you must enter “0” for all four data inputs (e.g., the water HRU in the screenshot above). Costs associated with each management practice type vary by region; consult local utilities or stakeholders regarding the capital and O&M costs required to implement the management practice of interest.

Once this section of the **WQ BMPs page** is complete, navigate to the input screen by pressing [Return to Input](#). Check the box next to [WQ BMPs](#) to indicate that you have completed data entry for this category of input.

### *Input Page Step 2D – Riparian Buffers*

Riparian buffers are a water quality related BMP that also reduces loadings to the stream or reservoir by converting land uses in riparian zones from more developed land uses. Loading reductions can be associated both with the conversion of the riparian area itself and the riparian area's ability to prevent loadings from upgradient land areas from entering the stream reach. If you want to include riparian buffers as a management option, select the [Riparian Buffers](#) button to navigate to the **Riparian Buffer page**.

Enter the number of land use conversions:  
(max 10)

Enter the number of relative loads groups:  
(max 5)

First, indicate the number of land use conversions in the stream buffer zone that you would like to model and the number of relative loads groups. Depending on the location of the riparian area, the buffer receives varying loads from upgradient land areas. For example, some riparian areas



with urban HRUs upgradient may receive relatively high loadings in comparison with riparian areas with undeveloped HRUs upgradient. Next, press [Setup Riparian Buffer Tables](#).

After your table has been set up, choose the HRU name that you are converting from and the HRU name that you are converting to for each land use conversion in the buffer zone. The From HRU ID and To HRU ID columns will be automatically populated.

Land Use Conversion No.	From HRU ID	To HRU ID	From HRU Name	To HRU Name
RBM1LC1	2	1	Open/non-residential, Sand & Gravel & Gravel	Forest, Sand & Gravel & Gravel
RBM1LC2	3	1	Medium-low density, Sand & Gravel	Forest, Sand & Gravel & Gravel
RBM1LC3	4	1	Medium-high density, Sand & Gravel	Forest, Sand & Gravel & Gravel
RBM1LC4	5	1	Commercial-industrial, Sand & Gravel	Forest, Sand & Gravel & Gravel
RBM1LC5	6	1	Agriculture, Sand & Gravel	Forest, Sand & Gravel & Gravel
RBM1LC6	8	7	Open/non-residential, Till & Fine-Grained Deposits	Forest, Till & Fine-Grained Deposits
RBM1LC7	9	7	Medium-low density, Till & Fine-Grained Deposits	Forest, Till & Fine-Grained Deposits
RBM1LC8	10	7	Medium-high density, Till & Fine-Grained Deposits	Forest, Till & Fine-Grained Deposits
RBM1LC9	11	7	Commercial-industrial, Till & Fine-Grained Deposits	Forest, Till & Fine-Grained Deposits
RBM1LC10	12	7	Agriculture, Till & Fine-Grained Deposits	Forest, Till & Fine-Grained Deposits

Then, for each land use conversion, you must enter four additional data inputs:

- Riparian area available for land use conversion – Riparian areas differ in the relative amount of loads removed depending on land use, soil, and slope.
- Capital cost of riparian area conversion – For example, costs related to planting forests or vegetation and landscaping.
- O&M costs related to riparian area upkeep and management– For example, landscaping and erosion protection.
- Load adjustment efficiency, or percent reduction or addition of upgradient loads as a result of the riparian area conversion.

- Buffer conversion implementation mode—users may select “Excluded” to exclude a conversion from modeling, “Simulation” to ensure that the conversion is implemented, or “Optimization” to determine whether the conversion is implemented in a least-cost optimized solution. If this cell is left blank, the conversion will be considered in the optimization scenario.

Riparian Area, Relative Loads Group 1 [acre]	Riparian Area, Relative Loads Group 2 [acre]	Riparian Area, Relative Loads Group 3 [acre]	Initial Cost to Convert [\$/acre]	O&M Cost [\$/acre/yr]	TN Load Adj Efficiency [%]	Riparian Buffer Implementation Mode
0.96	16.75	38.38	2153.43	3599	-60	Excluded
0.96	56.76	58.02	2153.43	3599	-60	Excluded
0.00	21.49	12.97	2153.43	3599	-60	Excluded
0.30	49.72	67.51	2153.43	3599	-60	Optimization
0.00	6.37	22.75	2153.43	1865	-60	Simulation
1.11	16.75	4.59	2153.43	3599	-60	Excluded
3.48	33.05	5.78	2153.43	3599	-60	Excluded
0.52	12.37	0.44	2153.43	3599	-60	Excluded
0.44	27.94	5.85	2153.43	3599	-60	Optimization
0.00	2.82	3.26	2153.43	1865	-60	Simulation

Each relative loads group signifies riparian areas that receive similar loads from upgradient areas. In **Riparian Buffers** page Step 1B, enter the acres that are upgradient or upland from the riparian areas for each relative loads groups.

HRU ID	HRU Name	Upland Area, Relative Loads Group 1 [acres]	Upland Area, Relative Loads Group 2 [acres]	Upland Area, Relative Loads Group 3 [acres]
RBM1HRU1	Forest, Sand & Gravel & Gravel	0.00	0.00	0.00
RBM1HRU2	Open/non-residential, Sand & Gravel & Gravel	249.45	1,006.51	518.90
RBM1HRU3	Medium-low density, Sand & Gravel	1,457.23	3,506.52	857.65
RBM1HRU4	Medium-high density, Sand & Gravel	811.86	542.25	83.56
RBM1HRU5	Commercial-industrial, Sand & Gravel	520.54	1,857.49	860.58
RBM1HRU6	Agriculture, Sand & Gravel	24.19	267.29	293.69
RBM1HRU7	Forest, Till & Fine-Grained Deposits	0.00	0.00	0.00
RBM1HRU8	Open/non-residential, Till & Fine-Grained Deposits	255.73	628.12	148.13
RBM1HRU9	Medium-low density, Till & Fine-Grained Deposits	591.39	1,756.33	625.71
RBM1HRU10	Medium-high density, Till & Fine-Grained Deposits	435.23	263.97	57.33
RBM1HRU11	Commercial-industrial, Till & Fine-Grained Deposits	393.31	1,015.34	315.48
RBM1HRU12	Agriculture, Till & Fine-Grained Deposits	21.24	58.93	117.45
RBM1HRU13	Cranberry Bog	0.00	0.00	0.00
RBM1HRU14	Forested Wetland	0.00	0.00	0.00
RBM1HRU15	Nonforested Wetland	0.00	0.00	0.00
RBM1HRU16	Water	0.00	0.00	0.00

One tool available for identifying potential riparian areas for restoration based on upgradient loads is the Riparian Analysis Toolbox<sup>35</sup>. WMOST v3 case studies will be added to the WMOST web site will

<sup>35</sup> <http://ches.communitymodeling.org/models.php#buffer>

illustrate this approach. Costs associated with riparian buffer land conversion or restoration may be found in technical reports, guidance, or homeowners resources. National Resource Conservation Services (NRCS) provides an Environmental Evaluation Planning Tool that includes guidelines for estimating capital and O&M costs, and its state offices may provide regional fact sheets<sup>36</sup>. Once **Riparian Buffers** page Step 1B is complete, navigate to the input screen by pressing **Return to Input**. Check the box next to the **Riparian Buffers** button to indicate that you have completed data entry for this category of input.

### 3.4 Water Use and Demand Management

On the **Input page**, enter the number of water user types. Do not include unaccounted-for-water (UAW) as it is automatically included in all relevant input tables. UAW in WMOST is assumed to be real losses from the system lost as leakage to the subsurface.

Press **Setup Input Tables** to automatically prepare input tables for potable, nonpotable, demand management, and septic components of your system. *The process creates blank input tables; therefore, do not press this button again unless you have your input data saved elsewhere and want to change the number of water user types.*

3. Water use and demand management.  
 Enter the number of water use types but do not include unaccounted water; it is automatically included:   
 Press "Setup Input Tables" button to prepare appropriately sized input tables for potable and nonpotable demand and septic systems data based on number of water use types.  
 Navigate to each input tab associated with water use.

Potable Demand     Nonpotable Demand     Demand Management     Septic and Sewer Systems

Setup Input Tables

#### *Input Page Step 3A – Water Users and Water Demand*

Select **Potable Demand** to navigate to the input table.

Potable Demand     Nonpotable Demand     Demand Management     Septic and Sewer Systems

This table requires a time-series of the total water demand for all users entered for **Input page** Step 3, plus demand attributable to unaccounted-for-water. This time series should be: 1) at the time step of your model, that is, the same time step as runoff and recharge rates; 2) complete and consecutive; and 3) the exact same time period as the runoff and recharge rate data.

<sup>36</sup> <https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/ecosciences/ec/>  
[https://www.co.benton.or.us/sites/default/files/fileattachments/community\\_development/page/2516/willametteripcost030310.pdf](https://www.co.benton.or.us/sites/default/files/fileattachments/community_development/page/2516/willametteripcost030310.pdf)

Date (mm/dd/yyyy)	Total Water Demand [million gallons /time step]								
	Unaccounted	Residential	Institutions	Commercial /Business	Agricultural	Industrial	Municipal	Other	
1/1/2002	0.36	2.46	0.03	0.36	0.00	0.17	0.14	0.02	
1/2/2002	0.36	2.46	0.03	0.36	0.00	0.17	0.14	0.02	
1/3/2002	0.36	2.46	0.03	0.36	0.00	0.17	0.14	0.02	
1/4/2002	0.36	2.46	0.03	0.36	0.00	0.17	0.14	0.02	
1/5/2002	0.36	2.46	0.03	0.36	0.00	0.17	0.14	0.02	
1/6/2002	0.36	2.46	0.03	0.36	0.00	0.17	0.14	0.02	
1/7/2002	0.36	2.46	0.03	0.36	0.00	0.17	0.14	0.02	
1/8/2002	0.36	2.46	0.03	0.36	0.00	0.17	0.14	0.02	
1/9/2002	0.36	2.46	0.03	0.36	0.00	0.17	0.14	0.02	
1/10/2002	0.36	2.46	0.03	0.36	0.00	0.17	0.14	0.02	

This section also includes an input table for the average percent consumptive water use<sup>37</sup> by month. These values can reflect any seasonal changes in consumptive use over the year, such as increased outdoor watering in the summer and among water user types.

Water withdrawal and demand and consumptive use data may be available from state or regional sources. For example, in Massachusetts, the Department of Environmental Protection receives such data in the form of Annual Statistical Reports from water utilities<sup>38</sup>.

Enter data in blue input fields for each water use for each month.								
Average Percent Consumptive Water Use (%)								
Month	Residential	Institutions	Commercial /Business	Agricultural	Industrial	Municipal .profits	Other	
January	4	4	4	4	4	4	4	4
February	4	4	4	4	4	4	4	4
March	4	4	4	4	4	4	4	4
April	6	6	6	6	6	6	6	6
May	20	20	20	20	20	20	20	20
June	26	26	26	26	26	26	26	26
July	29	29	29	29	29	29	29	29
August	25	25	25	25	25	25	25	25
September	20	20	20	20	20	20	20	20
October	4	4	4	4	4	4	4	4
November	4	4	4	4	4	4	4	4
December	4	4	4	4	4	4	4	4

The final table on this page specifies the loadings added by each user type to potable water use and sent to the wastewater treatment plant. The value should reflect the loadings added by the total number of users in the watershed for each user type (e.g., if each user adds 0.2 lbs per time step, then multiply 0.2 lbs by the user type population in your study area). Per capita loading rates to wastewater or septic flow can be applied to the public water population; these values may be found in the literature.

Enter average daily wastewater loadings of each constituent from each potable water user.							
Loadings (lbs/time step)							
Constituent	Residential	Residential	Commercial	Agricultural	Industrial	Municipal	Other
TN	386.177506	0	0	0	0	0	0

<sup>37</sup> Consumptive water use is water removed from the system and not returned to the ground or stream. Examples include water used for cooking, watering lawns, agriculture, and evaporation. Consumptive use may vary depending on the time of year so the average percentage value may be entered by month.

<sup>38</sup> <http://www.mass.gov/eea/agencies/massdep/service/approvals/public-water-supply-annual-statistical-reporting.html>



Select Return to Input and check the box next to Potable Demand when this section is complete. Next, select Nonpotable Demand to navigate to the **Nonpotable Demand page**.

The screenshot shows a horizontal toolbar with four buttons. From left to right: 'Potable Demand' with a checked checkbox, 'Nonpotable Demand' with an unchecked checkbox and a red circle around it, 'Demand Management' with an unchecked checkbox, and 'Septic and Sewer Systems' with an unchecked checkbox.

**Input Page Step 3B – Nonpotable Water Use**

The total water demand can be attributed to potable and nonpotable water use. Enter the percent nonpotable water use and percent consumptive use for nonpotable applications. The percent nonpotable water use is the maximum amount of potable use that could be met using nonpotable water such as toilet flushing or outdoor irrigation. The values in the columns or rows do not need to add to 100% for either table.

Maximum Potential Nonpotable Water Use (%)							
Month	Residential	Residential.Inst	Commercial.Bu: Agricultural	Industrial	Municipal.	Other	
January	45	45	45	45	45	45	45
February	45	45	45	45	45	45	45
March	45	45	45	45	45	45	45
April	45	45	45	45	45	45	45
May	45	45	45	45	45	45	45
June	45	45	45	45	45	45	45
July	45	45	45	45	45	45	45
August	45	45	45	45	45	45	45
September	45	45	45	45	45	45	45
October	45	45	45	45	45	45	45
November	45	45	45	45	45	45	45
December	45	45	45	45	45	45	45

Based on these nonpotable input data, the consumptive use percent of potable water is recalculated. It is possible to enter values for Maximum Potential Nonpotable Water Use and Average Percent Consumptive

Average Percent Consumptive Nonpotable Water Use (%)							
Month	Residential	Residential.Inst	Commercial.Bu: Agricultural	Industrial	Municipal.	Other	
January	1	1	1	1	1	1	1
February	1	1	1	1	1	1	1
March	1	1	1	1	1	1	1
April	3	3	3	3	3	3	3
May	17	17	17	17	17	17	17
June	21	21	21	21	21	21	21
July	24	24	24	24	24	24	24
August	20	20	20	20	20	20	20
September	14	14	14	14	14	14	14
October	1	1	1	1	1	1	1
November	1	1	1	1	1	1	1
December	1	1	1	1	1	1	1

Nonpotable Water Use that result in Adjusted Consumptive Potable Water Use values that are outside of the feasible range of 0-100%. To help the user confirm that nonpotable input data do not create infeasible Adjusted Consumptive Potable Water Use values, a third table on the **Nonpotable Demand page** pre-calculates these adjusted values (see below). If any of the values are outside of the feasible range, they are highlighted in red. In addition, the model will not run and the user is prompted with an error message to change input values for Maximum Percent Nonpotable Use and/or Average Percent Consumptive Nonpotable Water Use. Therefore, ensure that values are not highlighted in red in the table shown below before proceeding.



Adjusted Consumptive Potable Water Use (%)							
Month	Residential	Residential.Inst	Commercial.Bu:	Agricultural	Industrial	Municipal.	Other
January	6	6	6	6	6	6	6
February	6	6	6	6	6	6	6
March	6	6	6	6	6	6	6
April	8	8	8	8	8	8	8
May	22	22	22	22	22	22	22
June	30	30	30	30	30	30	30
July	33	33	33	33	33	33	33
August	29	29	29	29	29	29	29
September	25	25	25	25	25	25	25
October	6	6	6	6	6	6	6
November	6	6	6	6	6	6	6
December	6	6	6	6	6	6	6

The final table on this page specifies the loadings added by each user type to nonpotable water use and sent to the wastewater treatment plant. The value should reflect the loadings added by the total number of water users in the watershed for each user type. Per capita loading rates to wastewater or septic flow can be applied to the public water population; these values may be found in the literature.

Enter average daily wastewater loadings of each constituent from each nonpotable water user.							
Loadings (lbs/time step)							
Constituent	Residential	Residential	Commercial	Agricultural	Industrial	Municipal	Other
TN	315.9634	0	0	0	0	0	0

Select Return to Input and check the box next to Nonpotable Demand when this section is complete. Press Demand Management to enter information about how changes in price and other demand management practices may affect demand in your study area.

<input checked="" type="checkbox"/>	<b>Potable Demand</b>	<input checked="" type="checkbox"/>	<b>Nonpotable Demand</b>	<input type="checkbox"/>	<b>Demand Management</b>	<input type="checkbox"/>	<b>Septic and Sewer Systems</b>
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**Input Page Step 3C – Demand Management**

The first option is reducing demand by increasing the price of water

Price Elasticities [% demand reduction / % price increase]							
Residential		Commercial/		Agricultural	Industrial	Municipal	Other
Residential	Institutions	Business					
-0.2	-0.2	-0.2	-0.2	-0.5	-0.1	-0.2	-0.2

services. Specify the price elasticity – percent change in water use divided by percent change in price – for each type of water user. Price elasticities should be negative given that an increase in price is expected to decrease water use. Price elasticities may be found in the literature but will depend on existing pricing and other local conditions<sup>39</sup>. For example, if the consumer’s purchase price of water is relatively high, price elasticities will be smaller than if the existing pricing is relatively low. This reflects the fact that increasing price indefinitely will not decrease demand indefinitely; therefore, it is not a linear effect. The

<sup>39</sup> For example, [http://www.hks.harvard.edu/fs/rstavins/Monographs\\_&\\_Reports/Pioneer\\_Olmstead\\_Stavins\\_Water.pdf](http://www.hks.harvard.edu/fs/rstavins/Monographs_&_Reports/Pioneer_Olmstead_Stavins_Water.pdf)

user may specify the maximum price change possible within the planning horizon, which may be used to limit price change over the range where the response is expected to be linear<sup>40</sup>.

Initial cost	23,000	\$
O&M cost	2,300	\$/yr
Maximum price change	49	%
Maximum percent increase in price of water services from existing price over the duration of the planning horizon		

The initial cost may reflect the cost of a study to determine effective pricing structure and values, billing frequencies, changes in billing logistics, and consumer outreach to convey the importance of efficient use of water resources and the planned change in pricing. O&M costs may reflect smaller studies to re-evaluate pricing every year or five years; however, be sure to enter the expected *annual* cost of such evaluations.

The second option is direct demand reductions that may be achieved using rebates for water efficient appliances, as well as changing building codes, educational outreach, and other practices. Initial and O&M costs may be specified for the aggregate cost of direct demand reduction practices. The aggregate effect of these practices should be specified as a percent reduction of overall demand.

Initial cost	200,000	\$
O&M cost	4,000	\$/yr
Total demand reduction	0.75	MGD
Total demand reduction value should equal the MGD reduction in demand across all user types achieved by all management practices encompassed in the initial and O&M cost.		

EPA's WaterSense website provides a calculator that together with local or Census data (e.g., number of households) can be used to determine the total potential reductions in water use with the installation of water efficient appliances<sup>41</sup>. *When acquiring input data for these practices, the user must be aware of the potential reduction in the individual effectiveness of demand management practices when multiple practices are implemented simultaneously<sup>42</sup>.*

For any options that are not possible or desirable, enter "-9" for costs.

Select Return to Input and check the box next to Demand Management when this section is complete. Press Septic and Sewer Systems to enter information about these systems in three sets of input tables.

<input checked="" type="checkbox"/>	Potable Demand	<input checked="" type="checkbox"/>	Nonpotable Demand	<input checked="" type="checkbox"/>	Demand Management	<input type="checkbox"/>	Septic and Sewer Systems
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<sup>40</sup> The effect of price on water is assumed to be linear with WMOST v3 but nonlinear assumption may be implemented in future version.

<sup>41</sup> [http://www.epa.gov/watersense/our\\_water/start\\_saving.html#tabs-3](http://www.epa.gov/watersense/our_water/start_saving.html#tabs-3)

<sup>42</sup> For example, rebates for water low flow shower heads will reduce the gallons per minute used in showering. If an increase in water rates is implemented at the same time, the anticipated water use reduction may not be as large with a low flow shower head as with a high flow shower head even if the new water rates induce shorter shower times.

### Input Page Step 3D – Septic and Sewer Systems

Of the three sets of input tables on the **Septic and Sewer Systems** page, set 1 is mandatory for all users, set 2 is mandatory for users using the CSO Module, and set 3 is mandatory for users modeling water quality.

In input table set 1 (see screenshot below), you must enter the percent of customers with septic systems inside and outside of your study area *that are on public water*. Customers that are not on public water should be represented as private withdrawals and discharges on the **Surface Water** or **Groundwater** pages depending on their source and discharge of water (see **Input page** Step 4 below for description of these input pages).

Customers with Public Water & Septic Systems Recharging Inside Study Area (%)							
Residential	Residential.Instit	Commercial.Busi	Agricultural	Industrial	Municipal.Institu	Other	
62	62	62	62	62	62	62	62
Customers with Public Water & Septic Systems Recharging Outside Study Area (%)							
Residential	Residential.Instit	Commercial.Busi	Agricultural	Industrial	Municipal.Institu	Other	
0	0	0	0	0	0	0	0

For public water users, it is important to distinguish public water customers who are on septic systems but are outside of the watershed of the study area being modeled. These septic systems do not recharge the groundwater and do not contribute to the baseflow of the stream in the study area’s watershed.

Input table set 2 on the **Septic and Sewer Systems** page specifies the capacities of the sewer system. WMOST inherently models a storm and/or sanitary sewer system when the CSO Module is not in use (i.e., routing all runoff through the storm sewer and all flows to the WWTP through the sanitary sewer). Therefore, when the CSO Module is not in use, users can enter “-9” in the corresponding cells to exclude defining sewer capacities. However, when the CSO Module is in use, WMOST has the option to model a separate storm/sanitary sewer system from the combined sewer system, making it necessary for sewer capacities to be set.

Storm Sewer	To exclude limits on the storm sewer, enter -9.
Maximum capacity of storm sewer	3 MGD

Municipal flows that go directly to sewer system (%)	
Month	Municipal
January	2
February	2
March	2
April	3
May	3
June	3
July	4
August	2
September	2
October	2
November	2
December	2

When the CSO Module is not in use, the storm sewer receives **all** flows from the runoff and any municipal flows that go directly to the sewer system and routes them to the surface water system. When the CSO Module is in use and sewer separation is a management option, the model will choose a percentage of flows that are intended for the combined sewer to flow through the storm sewer. Regardless of whether or not the CSO Module is in use, if the study area watershed includes municipal water users, users can enter the percentage of municipal water use that flows directly to the sewer system (screenshot to the left). If the study area watershed does not include any municipal water users, the percentages can be set to “0”.

watershed does not include any municipal water users, the percentages can be set to “0”.

Similar to the storm sewer, when the CSO Module is not in use, the sanitary sewer receives flows from potable and nonpotable users and routes them to the wastewater treatment plant. When the CSO Module is in use and sewer separation is a management option, the model will choose a percentage of flows that are intended for the combined sewer to flow through the sanitary sewer.

Sanitary Sewer		To exclude limits on the sanitary sewer, enter -9.
Maximum capacity of sanitary sewer	5 MGD	

The **Septic and Sewer Systems** page requires additional data inputs for modeling water quality that can be input into table set 3. If you are not modeling water quality, continue to *Input Page Step 4A – Surface Water & System Targets*.

For water quality users, first enter the average effluent concentration of your constituent from the septic system. Average septic effluent concentrations may be found in septic system guidelines, design reports, or in the literature. For example, EPA Office of Water provides guidelines in the report “Onsite Wastewater Treatment Systems Manual” (2002).

Enter the daily average effluent concentration for septic treatment of each constituent.

Constituent	Concentration (mg/L)
TN	24

Next, you have the option to enter inputs for upgrading septic systems in your watershed to “enhanced” septic treatment to reduce loadings to the groundwater.

To consider sewer system upgrades, you must enter the following data:

- Enhanced treatment average effluent concentration from the enhanced septic systems
- O&M cost related to enhanced septic treatment
- Maximum capacity of enhanced septic system upgrades. The maximum capacity should represent the sum of the maximum capacity for all potential system upgrades. To exclude this management option, enter “-9” in the management option exclusion input field.

Enter the daily average effluent concentration for enhanced septic treatment of each constituent.

Constituent	Concentration (mg/L)
TN	16

Enhanced Septic Treatment		To exclude enhanced septic treatment, enter -9.
O&M cost for enhanced septic capacity	800 \$/MG	
Maximum capacity of enhanced septic	1 MGD	

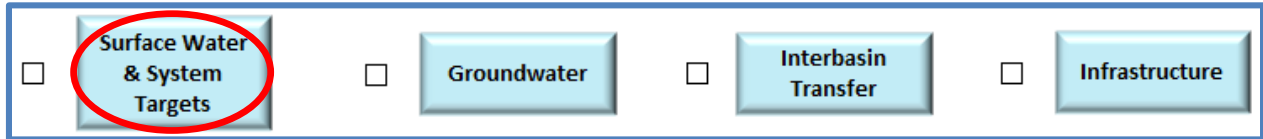
Select Return to Input and check the box next to Septic and Sewer Systems when the section is complete. Proceed to **Input Page** Step 4.

<input checked="" type="checkbox"/>	Potable Demand	<input checked="" type="checkbox"/>	Nonpotable Demand	<input checked="" type="checkbox"/>	Demand Management	<input checked="" type="checkbox"/>	Septic and Sewer Systems
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### 3.5 Water Supply Sources and Infrastructure

*Input Page Step 4A – Surface Water & System Targets*

Press Surface Water & System Targets to navigate to five sets of input tables.



In input table set 1 of this section (screenshot below), you can enter reservoir or surface storage properties and costs. Reservoir and surface storage may represent reservoirs, lakes or ponds used for water supply and/or surface storage tanks. Surface storage in wetlands or other lakes may be modeled as surface storage or as a separate HRU. Initial volume is the volume at the start of modeling period. Minimum target volume may represent the volume of water always maintained in storage for emergencies or inactive storage volume which is inaccessible due to the height of the storage outlet. Existing maximum volume is the total volume of existing storage.

Initial construction cost should include the costs to plan, design and build additional surface storage volume. O&M cost should include the annual cost for maintaining surface storage capacity in operational condition. Maximum additional volume is the volume that may be *added* by building surface storage volume. To exclude an increase in reservoir/surface storage volume as a management option, enter “-9” in the input field shown below.

Initial reservoir/surface storage volume	80	[MG]
Minimum target reservoir/storage volume	33	[MG]
Existing maximum reservoir/storage volume	1,240	[MG]
Initial construction cost	0	[\$/MG]
O&M costs	0	[\$/MG]
Maximum additional reservoir/storage volume	0	[MG]

Make-up water represents virtual water that the model needs to “purchase” to reach a feasible solution. To allow the model to use make-up water in the reservoir system, enter a cost in the input field shown and leave the exclusion flag input box blank (see screenshot below). Costs related to make-up water should be sufficiently high so that selecting this option is a last resort for the model.

To exclude new/additional capacity for a surface water storage, enter -9.		-9
Cost for make-up surface water penalty	1,000,000	\$/MG
To exclude make-up water penalty, enter -9.		

Finally, reservoir outflow can either be entered as a data time series or included as a decision variable based on the input to the field below. In this example, the model will optimize the outflow from the reservoir.

Enter Yes to use Reservoir/Sw Outflow as data time series or No to allow Reservoir/Sw Outflow to be a decision.	No
---	----

In input table set 2 (screenshot below), you may enter information about other withdrawals and discharges of surface water such as industrial users that are not on public water. These data may be available from state sources such as the Department of Environmental Protection or regional sources (e.g., regional EPA offices). In addition, if the stream into which your study area drains receives inflow from an upstream reach, enter a time series for the inflow of this surface water. These data should be available from the model from which you may have obtained your RRRs. If a reservoir exists in your study area, you may enter information on surface reservoir withdrawals, discharges, or outflow requirements. Withdrawals and discharges to reservoirs may be related to human activity or natural hydrologic processes over the reservoir, such as precipitation and evapotranspiration. Precipitation and evapotranspiration for water modelled as HRUs are automatically calculated by WMOST but must be specified for storage reservoirs.

Date (mm/dd/yyyy)	Other Sw Withdrawal [MG/time step]	Other Sw Discharge [MG/time step]	External Sw Inflow [cfs]	Withdrawals from Reservoir [MG/time step]	Discharge to Reservoir [MG/time step]	Outflow from Reservoir [MG/time step]
1/1/2002	0.794189	3.629	0	0	0	0.00
1/2/2002	0.794189	3.629	0	0	0	0.00
1/3/2002	0.794189	3.629	0	0	0	0.00
1/4/2002	0.794189	3.629	0	0	0	0.00
1/5/2002	0.794189	3.629	0	0	0	0.00
1/6/2002	0.794189	3.629	0	0	0	0.00
1/7/2002	0.794189	3.629	0	0	0	0.00
1/8/2002	0.794189	3.629	0	0	0	0.00
1/9/2002	0.794189	3.629	0	0	0	0.00
1/10/2002	0.794189	3.629	0	0	0	0.00
1/11/2002	0.794189	3.629	0	0	0	0.00

These time-series must be at the temporal resolution of your model (i.e., daily or monthly) and over the same time period as other time series. The dates will be pre-filled for you based on the time series on the **Runoff page**. As with other time series data, they must be complete and consecutive. For any of the time series, if you do not have data or they do not exist, enter “-9” for all dates. Note that upstream inflow is critical, especially if you will be specifying any streamflow requirements.

In input table set 3, you may provide management goals for minimum and/or maximum in-stream flow on a monthly basis. In addition, any requirements for flow to a downstream reach may be specified. Requirements or guidelines for minimum and/or maximum in-stream flow may be found at the state or regional level. For example, in New England, there are Stream Flow Recommendations<sup>43</sup> and in Massachusetts, there is a Sustainable

For minimum and maximum values, enter -9 and the model will not apply the constraint				
Month	Minimum In-Stream Flow [cfs]	Maximum In-stream flow [cfs]	Minimum Sw Outflow to External Sw [cfs]	Maximum Sw Outflow to External Sw [cfs]
January	16.6	-9	-9.0	-9.0
February	19.1	-9	-9.0	-9.0
March	17.3	-9	-9.0	-9.0
April	19.4	-9	-9.0	-9.0
May	15.9	-9	-9.0	-9.0
June	18.5	-9	-9.0	-9.0
July	18.4	-9	-9.0	-9.0
August	18.7	-9	-9.0	-9.0
September	18.8	-9	-9.0	-9.0
October	17.5	-9	-9.0	-9.0
November	17.5	-9	-9.0	-9.0
December	17.1	-9	-9.0	-9.0

<sup>43</sup> <http://www.fws.gov/newengland/pdfs/Flowpolicy.pdf>



Water Management Initiative Framework<sup>44</sup>. If any of these flow requirements do not exist in your study area, enter “-9” for each month of that set.

The **Surface Water & System Targets** page requires additional data inputs for modeling water quality. If you are not modeling water quality, continue to *Input Page Step 4B – Groundwater*.

In input table set 4, you must enter data inputs related to the constituent’s behavior in the stream and reservoir. First, enter the initial concentration of your constituent in the reservoir on the first day of your time period. Initial concentration for surface water is determined by the model. Next, enter the 0<sup>th</sup> or 1<sup>st</sup> order decay rate of your constituent in the reservoir. Decay rates may be found in the model documentation from which you may have obtained your RRRs. Representative rates can also be obtained from regional SPATIally Referenced Regressions On Watershed attributes (SPARROW)<sup>45</sup> models. You may exclude modeling of decay by entering “-9” in both input fields.

Finally, enter the stream or reservoir concentration or loadings target for your constituent. Of the four possible target types, you may only select one target type per model run. The in-stream concentration and loadings target apply to the water quality in the stream. The reservoir concentration target applies to the concentration in the reservoir, while the reservoir loadings target applies to the loadings from the stream to the reservoir (i.e., the loads entering the reservoir, not the loads stored in the reservoir). Requirements or guidelines for maximum concentrations or loadings may be found at the waterbody, state or regional level (e.g., Total Maximum Daily Load [TMDL] allocations).

	In-stream	Reservoir
	TN	TN
<i>Initial Condition: Enter the initial concentration of the reservoir.</i>		
Concentration (mg/L)	-	0.4
<i>Decay/Settling Rate: Enter a removal rate value and -9 for the excluded removal rate.</i>		
0th order rate (mg/L/time step)	-	-9
		OR
1st order rate (1/time step)	-	0.1
<i>Target Concentration/Loadings: Enter -9 if target concentration or loadings do not need to be met.</i>		
Target concentration (mg/L)	1	-9
	OR	OR
Target loading (lbs)	-9	-9

Yes Enter Yes if modeling 1st order removal in proportion to surface area or No if modeling removal based on decay rate only.

Reservoir surface area (acres)  If yes, enter the surface area of the reservoir in the blue box at left.

In this section, you have the option to proportionally model first order decay based on the surface area of your reservoir similar to the methods for estimating the fraction of the contaminant mass transported through a reservoir segment used within the SPARROW model. To do this, enter “Yes” in the first input field and the surface area of your reservoir

TN Loadings Time Series			
Private Sw Point Source	Private Reservoir Loadings	External Sw Loadings	
Loadings [Lbs/time step]	[Lbs/time step]	[Lbs/time step]	
199.27	0.00	0.00	
199.27	0.00	0.00	
199.27	0.00	0.00	
199.27	0.00	0.00	
199.27	0.00	0.00	
199.27	0.00	0.00	
199.27	0.00	0.00	
199.27	0.00	0.00	
199.27	0.00	0.00	
199.27	0.00	0.00	
199.27	0.00	0.00	
199.27	0.00	0.00	

<sup>44</sup> <http://www.mass.gov/eea/docs/eea/water/swmi-framework-nov-2012.pdf>

<sup>45</sup> <https://water.usgs.gov/nawqa/sparrow/>



in the second input field. To exclude this option, enter “No” in the first input field and leave the second blank.

In input table set 5, you may enter information about point source loadings to the stream or reservoir via private dischargers, and loadings entering the system via external surface water inflow. To calculate these time series, you can apply the concentration of the point source discharge to the “Other Surface water (Sw) Discharge” hydrology time series in your system to calculate the point source loadings time series. Point source discharge concentration data may be available from EPA’s Discharge Monitoring Tool<sup>46</sup> (DMR).

Select Return to Input and check the box next to Surface Water & System Targets when this section is complete. Select Groundwater to navigate to the next five sets of input tables.

The screenshot shows a horizontal row of five buttons: 'Surface Water & Streamflow Targets' (checked), 'Groundwater' (circled in red), 'Interbasin Transfer', and 'Infrastructure' (all unchecked).

### *Input Page Step 4B – Groundwater*

The same state and regional data sources used to populate the **Surface Water & System Targets** page are recommended for populating the **Groundwater** page. Within input table set 1, information about groundwater storage characteristics will likely be derived from the same model that you obtained the runoff and recharge rates. These data include:

- Groundwater recession coefficient or baseflow coefficient – fraction of groundwater volume that flows to the stream reach each time step
- Initial groundwater volume – volume of the active groundwater aquifer at the start of the modeling period
- Minimum volume – this volume may be based on the depth of wells which are used for water supply below which water is inaccessible and/or the volume at which the water table will be below the stream bed and therefore no longer emptying to the stream
- Maximum volume – this value represents the total storage capacity of the aquifer.

Groundwater recession coefficient	0.09	[1/time step]	To exclude make-up water penalty, enter -9.
Initial groundwater volume	1,000	[MG]	
Minimum volume	10	[MG]	
Maximum volume	80,000	[MG]	
Cost for make-up groundwater	1,000,000	\$/MG	

The maximum volume can be obtained from information available from model documentation or from ancillary documents describing groundwater resources for a region of interest.

If you used the Baseline Hydrology Module, you may use Calculate and Populate the Groundwater Recession Coefficient button to calculate this value.

If you used the Baseline Hydrology module, you may automate the calculation of the groundwater recession coefficient.

Calculate and Populate the Groundwater Recession Coefficient

<sup>46</sup> <https://cfpub.epa.gov/dmr/>

Within input table set 2, similar to the **Surface Water & System Targets page**, you can enter time series data for other groundwater withdrawals, discharges and inflow into the study area.

Depending on the model used, if you downloaded your baseline recharge time series from the EDM Data Inventory and used the Baseline Hydrology Module to create your baseline recharge time series, a small

Date [mm/dd/yyyy]	Other Gw Withdrawal [MG/time step]	Other Gw Discharge [MG/time step]	External Gw Inflow [MG/time step]	
1/1/2002	3.02	3.02	4.45	0.00
1/2/2002	3.02	3.02	4.45	0.00
1/3/2002	3.02	3.02	4.45	0.00
1/4/2002	3.02	3.02	4.45	0.00
1/5/2002	3.02	3.02	4.45	0.00
1/6/2002	3.02	3.02	4.45	0.00
1/7/2002	3.02	3.02	4.45	0.00
1/8/2002	3.02	3.02	4.45	0.00
1/9/2002	3.02	3.02	4.45	0.00
1/10/2002	3.02	3.02	4.45	0.00
1/11/2002	3.02	3.02	4.45	0.00

part of the water balance may not yet be present in the model. During preprocessing, all negative recharge values in the baseline recharge time series have been removed from the recharge time series in order to be compatible with WMOST. The negative recharge values are retained as positive values in the WMOST recharge

adjustment files. If this applies to your watershed, the data are available as a CSV file in the folder labeled: “\EDM\_Server\_ZIP\wmostEDM\_recharge” within your WMOST project folder. Enter the sum of all the recharge values for your HRUs and time period into the model as a part of the other groundwater withdrawals time series.

Enter a minimum value or zero if the ground and surface watersheds are coincident.

Month	Minimum External Gw Outflow [MG/time step]
January	0.00
February	0.00
March	0.00
April	0.00
May	0.00
June	0.00
July	0.00
August	0.00
September	0.00
October	0.00
November	0.00
December	0.00

In input table set 3, similar to the **Surface Water & Streamflow Targets page**, you can enter requirements for groundwater flowing out of the basin. In most cases, this groundwater flow will not exist as the groundwater will drain to the stream reach; however, this option provides flexibility in defining a study area or when groundwater and surface water watersheds do not overlap. If groundwater and surface water watersheds are coincident, enter all “0s” in this table.

The **Groundwater page** requires additional data inputs for modeling water quality. If you are not modeling water quality, continue to *Input Page Step 4C – Interbasin Transfer*

In Part 4, you must enter the initial concentration of your constituent in the groundwater system. You also have the option of specifying a 0<sup>th</sup> or 1<sup>st</sup> order attenuation rate. Attenuation rates may be found in the model documentation from which you may have obtained your RRRs. You may exclude modeling of attenuation by entering “-9” in both input fields.

Groundwater	
TN	
<i>Initial Condition: Enter the initial constituent concentration in groundwater.</i>	
Concentration (mg/L)	0.1
<i>Attenuation Rate: Enter a removal rate value and -9 for the excluded removal rate.</i>	
0th order rate (mg/L/time step)	-9
<b>OR</b>	
1st order rate (1/time step)	0.05

TN Loadings Time Series		
Private Gw Point	External Gw	
Source Loadings	Loadings	
[Lbs/time step]	[Lbs/time step]	
254.07	0.00	
254.07	0.00	
254.07	0.00	
254.07	0.00	
254.07	0.00	
254.07	0.00	
254.07	0.00	
254.07	0.00	
254.07	0.00	
254.07	0.00	
254.07	0.00	
254.07	0.00	

In Part 5, you may enter information about point source loadings to the groundwater via private dischargers, and loadings entering the system via external groundwater inflow. To calculate these time series, you can apply the concentration of the groundwater discharge to the “Other Groundwater (Gw) Discharge” time series in your system to calculate the point source loadings time series. Groundwater point source concentrations depend on the type of discharge and the region. These data may be available from state sources such as the Department of Environmental Protection or regional sources (e.g., regional EPA offices).

Select Return to Input and check the box next to Groundwater when this section is complete. Select Interbasin Transfer (IBT) to navigate to three sets of input data tables.

<input checked="" type="checkbox"/>	Surface Water & Streamflow Targets	<input checked="" type="checkbox"/>	Groundwater	<input type="checkbox"/>	<b>Interbasin Transfer</b>	<input type="checkbox"/>	Infrastructure
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**Input Page Step 4C – Interbasin Transfer**

In input table set 1, you can enter data for:

- Initial costs for water and wastewater rights in addition to any existing agreements including costs for any new infrastructure to utilize the additional rights<sup>47</sup>
- Costs to purchase water and wastewater from systems outside of your study area, which is what the utility pays to the provider of the imported source or the external wastewater facilities.

<b>If you do not want IBT as a management option, enter -9 for costs AND 0 for flow limits.</b>	
Purchase cost for potable water	670 [\$/MG]
Purchase cost for wastewater	946 [\$/MG]
Initial cost for new/increased IBT potable water limit	-9 [\$/MGD]
Initial cost for new/increased IBT wastewater limit	-9 [\$/MGD]

<sup>47</sup> The case study of Danvers and Middleton, MA provides costs associated with initial connection for water with the Massachusetts Water Resources Authority, a large regional water and wastewater provider.

In input table set 2, enter any existing monthly limits for interbasin transfer of water and wastewater in the left table and daily or annual limits in the right table. Depending on the time step of your model, the daily, monthly, and/or annual limits are adjusted to specify appropriate constraints in the model.

Enter existing limits on IBT for daily, monthly and/or annual basis. If flow is not limited, enter -9.

Existing Limits on IBT [MG per month]			
Month	Water	Wastewater	
January	-9.00	-9.00	-9.00
February	-9.00	-9.00	-9.00
March	-9.00	-9.00	-9.00
April	-9.00	-9.00	-9.00
May	-9.00	-9.00	-9.00
June	-9.00	-9.00	-9.00
July	-9.00	-9.00	-9.00
August	-9.00	-9.00	-9.00
September	-9.00	-9.00	-9.00
October	-9.00	-9.00	-9.00
November	-9.00	-9.00	-9.00
December	-9.00	-9.00	-9.00

Existing Limits on IBT		
	Water	Wastewater
Daily [MGD]	3.34	0.58
Annual [MG per year]	-9.00	-9.00

Additional Capacity		
	Water	Wastewater
Daily [MGD]	0.00	0.00

The following guidelines for specifying limits and initial costs for increasing limits are important to note:

- If you do not have interbasin transfer as an option, you must enter “0” for limits. Entering “-9” will indicate no restriction, that is, unlimited interbasin transfer is available. As such, if you enter “-9” for daily, monthly or annual limits, then you must specify the initial cost for new/increased IBT.
- If additional water or wastewater services can be purchased with *no additional initial costs or entry fees*, then enter the current agreement limit for services and specify \$0 for initial cost for a new/increased limit (i.e., do not enter “-9” for the existing limit).
- If your system provides water services to customers outside of the basin without a return flow via the wastewater treatment plant or septic systems, you may specify these customers as a separate water user type that entirely drains to septic outside of the study area. If your system provides out of basin wastewater services that discharge in your basin, you may enter this flow as a private discharge of surface water (or groundwater, depending on where the wastewater treatment plant discharges). WMOST does not support routing out of basin wastewater to the wastewater treatment plant. It may be added as functionality in future versions.
- If your system’s wastewater is treated outside of the basin at a larger, central facility and you want to model returning the treated wastewater for discharge locally, then you may enter a capital cost for a wastewater treatment plant that represents the construction of infrastructure necessary to return and discharge the treated wastewater. In addition, enter O&M costs that reflect the IBT O&M cost and exclude the use of IBT for wastewater. This will effectively model the desired scenario. If the returned wastewater will be discharged to groundwater rather than surface water, follow the same procedure but apply it to the aquifer storage and recharge facility rather than the wastewater treatment plant. See below under *Input Page Step 4D – Infrastructure* for input data tables related to wastewater treatment plant and aquifer and storage recharge facility.

The **Interbasin** page requires additional data inputs for modeling water quality. If you are not modeling water quality, continue to *Input Page Step 4D – Infrastructure*.

In input table set 3, you must enter the average concentration of your constituent in the potable interbasin flow if your system is using or considering using interbasin transfer for potable water. This concentration should reflect the concentration of the interbasin potable flow to users after the raw water has been treated.

Enter average concentration of constituent in interbasin transfer flow into the watershed.	
Constituent	Concentration (mg/L)
TN	1.2

Select Return to Input and check the box next to Interbasin Transfer when this section is complete. Select Infrastructure to navigate to the next section, where you can enter information about costs and capacity limits for a range of water and wastewater facilities. This section consists of six sets of input tables.

<input checked="" type="checkbox"/>	Surface Water & Streamflow Targets	<input checked="" type="checkbox"/>	Groundwater	<input checked="" type="checkbox"/>	Interbasin Transfer	<input type="checkbox"/>	Infrastructure
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### *Input Page Step 4D – Infrastructure*

In input table set 1, you enter the planning horizon for large capital improvement projects and the interest rate for loans for such projects. For any management option for which a project lifetime is not requested, the planning horizon is used for the lifetime over which the initial cost is annualized. The specified interest rate is used for the annualization of all initial and capital costs. For mathematical equations describing the annualization of capital costs, please refer to Section 3.2 in the Theoretical Documentation.

Planning horizon [years]	20
Interest rate [%]	3.00

In input table set 2 (see screenshot on the next page of the user guide), enter data related to providing water services including:

- Consumer’s price for potable water from the local utility–this may be specified as a monthly fixed fee and/or volume based fee
- Facility data for groundwater pumping, surface water pumping and water treatment plant including
  - Capital costs – cost for increasing capacity or cost for replacing existing capacity beyond the remaining lifetime
  - O&M costs – cost for operating based on the size and flow through the facility;
  - Existing maximum capacity of the facility
  - Lifetime remaining on existing infrastructure or the number of years expected to remain before major capital rehabilitation or new facility must be built
  - Lifetime of new infrastructure – the expected lifetime of new construction before major capital rehabilitation or new facility must be built
- Potable distribution system data including
  - Initial cost for surveying the distribution system for leaks and repairing to the maximum percent feasible
  - O&M costs representing annual costs for maintaining repairs made to the distribution system

- o Maximum percent of distribution system leaks that can be fixed – this value may be less than 100% due to practical limitations of many miles of pipes

If no water treatment plant exists in your study area (i.e., all water is from interbasin transfer), then enter “0” for maximum capacities and remaining lifetimes. However, still enter the price that is charged for customers for water services. To exclude the option to increase facility capacity, enter “-9” in the “Exclude New/Additional” field for the appropriate facility.

Users can obtain data on the facility costs and capacities from the facility managers (likely the public works utility or water district). Data inputs may be derived from utility budgets or facility usage reports. If the cost data are not available, users can utilize the data from example case studies of WMOST as cost estimates, but these values should be used with caution and analyzed using sensitivity analyses.

Water services	Value	Units	To exclude new and additional capacity for enter -9 in the corresponding blue box.
Consumer's price for potable water: Fixed fee	84,942	\$/month	
Consumer's price for potable water: Variable, volume-based fee	4.56	\$/HCF	
			<b>Exclude New/Additional Capacity</b>
<b>Groundwater (Gw) Pumping</b>			-9
Capital cost for additional capacity	5,787,037	\$/MGD	
Operation & Maintenance (O&M) costs	670.02	\$/MG	
Existing maximum capacity	5.45	MGD	
Lifetime remaining on existing infrastructure	25	yrs	
Lifetime of new construction	25	yrs	
			<b>Exclude New/Additional</b>
<b>Surface Water (Sw) Pumping</b>			-9
Capital cost for additional capacity	467,621	\$/MGD	
O&M costs	184.95	\$/MG	
Existing maximum capacity	6.00	MGD	
Lifetime remaining on existing infrastructure	25	yrs	
Lifetime of new construction	25	yrs	
			<b>Exclude New/Additional</b>
<b>Water Treatment Plant (WTP)</b>			-9
Capital cost for additional capacity	6,229,186	\$/MGD	
O&M costs	0.00	\$/MG	
Existing maximum capacity	7.16	MGD	
Lifetime remaining on existing infrastructure	25	yrs	
Lifetime of new construction	25	yrs	
<b>Unaccounted-for-Water/ Potable water distribution system leak</b>			
Initial cost for survey & repair	455,000	\$	
O&M costs for maintaining reduction in UAW	45,500	\$/yr	
Maximum percent UAW that can be fixed	0.00	%	

Users modeling water quality need to enter additional data inputs within input table set 2 (see screenshot to the right). Of

Water Treatment Plant (WTP) Loadings	Value	Units
Maximum daily influent concentration	-9	mg/L
Average daily effluent concentration	0.1	mg/L

the additional data inputs, only one, the average daily effluent concentration, is required. If your plant has a maximum daily influent concentration, you can enter the concentration as a treatment facility constraint. If there is no maximum daily influent concentration, enter “-9”.

Users also have the option of upgrading the level of treatment in the water treatment plant. If selected, this management option partitions flows within the water treatment plant, such that a portion of the flows receives the upgraded level of treatment and the remaining flows receive the current level of treatment.

This management option would be useful for meeting in-stream or reservoir target concentrations and maximum influent concentrations at the wastewater treatment plant. To consider a treatment upgrade, enter data (see screenshot below) related to the upgraded water treatment plant including:

- Capital cost – cost for new capacity or cost for replacing existing capacity beyond the remaining lifetime
- Lifetime of new infrastructure – the expected lifetime of new construction or for replacing existing capacity beyond the remaining lifetime
- Average daily effluent concentration – the effluent concentration achieved by the upgraded treatment system. This concentration must be lower than the effluent concentration of the water treatment plant.

Upgraded Water Treatment Plant (WTP)	Units	Exclude New Treatment
Capital cost for additional treatment	500000 \$/MGD	
Lifetime of new construction	25 yrs	
<b>Upgraded Water Treatment Plant (WTP) Loadings Reduction</b>		
Average daily effluent concentration	0.05 mg/L	

The O&M costs and capacity that apply to the water treatment plant also apply to the upgraded water treatment plant. To exclude the option to upgrade treatment capacity, enter “-9” in the “Exclude New Treatment” input field for the upgraded water treatment plant.

In input table set 3, enter similar data for wastewater services as for water services including consumer’s price, capital and O&M costs, lifetime of new and existing infrastructure, and repair of infiltration into collection system. Two additional types of information are requested:

- “Are wastewater fees charged based on metered water or wastewater?” – Most wastewater utilities in the U.S. charge for wastewater services based on metered potable water delivered to a customer. However, the option is provided to charge based on metered wastewater to determine the effect of separating metering.
- “Existing Gw infiltration into collection system” – Specify the percent of wastewater inflow to the wastewater treatment plant that represents groundwater infiltration (infiltration/inflow).

Wastewater Treatment Plant (WWTP)	Value	Units	Exclude New/Additional
Consumer's price for wastewater services: Fixed fee	262,918	\$/month	-9
Consumer's price for wastewater services: Variable, volume-based fee	6.30	\$/HCF	
Are wastewater fees charged based on metered water or wastewater?	water	water or wastewater	
Capital cost for additional capacity	16,266,488.00	\$/MGD	
O&M costs	946.38	\$/MG	
Existing maximum capacity	3.14	MGD	
Lifetime remaining on existing infrastructure	25	years	
Lifetime of new construction	25	years	
<b>Infiltration into wastewater collection system</b>			
Existing Gw infiltration into collection system	0	% of WW Inflow	
Initial cost for survey & repair	0	\$	
O&M costs for maintaining reduction in infiltration	0	\$/yr	
Maximum percent of infiltration that can be fixed	0.00	%	

To exclude the option to increase wastewater treatment plant capacity, enter “-9” in the “Exclude New/Additional” input field.



Users modeling water quality need to enter additional data inputs in input table set 3 (see screenshot to the right). Of the additional data inputs, only one, the average daily effluent concentration, is required. If your plant has a maximum daily influent concentration, you can enter the concentration as a treatment facility constraint. If there is no maximum daily influent concentration, enter “-9”.

Wastewater Treatment Plant (WWTP) Loadings	Value	Units
Maximum daily influent concentration of Cons1	-9	mg/L
Average daily effluent concentration	3.4	mg/L

Like the upgraded water treatment plant option, users can consider a wastewater treatment plant upgrade that will treat a portion of the flows through the wastewater treatment plant to a higher treatment level.

Upgraded Wastewater Treatment Plant (WWTP)	Value	Units	Exclude New Treatment
Capital cost for additional treatment	1200000	\$/MGD	
Lifetime of new construction	25	yrs	
<b>Upgraded Wastewater Treatment Plant (WWTP) Loadings Reduction</b>			
Average daily effluent concentration	1.8	mg/L	

This option would be useful for meeting in-stream or reservoir target concentrations. In addition, if your watershed experiences combined sewer overflow (CSO) events, this management option could be used to meet the minimum level of treatment that is presumed to meet water quality-based standards. Enter similar data (screenshot to the right) for the upgraded wastewater treatment plant as for the upgraded water treatment plant, including:

- Capital cost – cost for new capacity or cost for replacing existing capacity beyond the remaining lifetime
- Lifetime of new infrastructure – the expected lifetime of new construction or for replacing existing capacity beyond the remaining lifetime
- Average daily effluent concentration – the effluent concentration achieved by the upgraded treatment system. This concentration must be lower than the effluent concentration of the water treatment plant.

To exclude the option to upgrade treatment capacity, enter “-9” in the “Exclude New Treatment” input field for the upgraded wastewater treatment plant.

In input table set 4, enter data for a water reuse facility (WRF) similar to water and wastewater facilities including the ability to exclude new and additional capacity.

Water Reuse Facility (WRF)	Value	Units	Exclude New/Additional
Capital cost for additional/ new capacity	18,644,791	\$/MGD	-9
O&M costs	1,305,135.00	\$/MG	
Existing maximum capacity	0.00	MGD	
Lifetime remaining on existing infrastructure	0	yrs	
Lifetime of new construction	35	yrs	

If no water reuse facility exists in your study area, then enter “0” for maximum capacities and remaining lifetimes. If you want to model the addition a new water reuse facility, enter the associated capital and O&M costs. To exclude the option to increase facility capacity, enter “-9” in the “Exclude New/Additional” input field.

Users modeling water quality need to enter an additional data input in

Water Reuse Facility (WRF) Loadings	Value	Units
Average daily effluent concentration	0	mg/L

input table set 4. Enter the daily effluent concentration achieved by the water reuse facility. As shown in the screenshot above, the user is not modeling a water reuse facility and, accordingly, set the average daily effluent concentration to 0 mg/L.

In input table set 5, enter data for a nonpotable water distribution system which are similar to the other facilities but, in addition, specify the price that would be charged to customers for the provision of nonpotable water.

Nonpotable Water Distribution System	Value	Units	Exclude New/Additional
Consumer's price for nonpotable water: Fixed fee	0	\$/month	-9
Consumer's price for nonpotable water: Variable, volume-based fee	3.11	\$/HCF	
Capital cost for additional capacity	12,529,440	\$/MGD	
O&M costs	1,768.00	\$/MG	
Existing maximum capacity	0.00	MGD	
Lifetime remaining on existing infrastructure	0	yrs	
Lifetime of new construction	35	yrs	

In input table set 6, enter data for an aquifer storage and recovery (ASR) facility similar to the other facilities.

Aquifer Storage and Recovery (ASR)	Value	Units	Exclude New/Additional
Capital cost for additional/new capacity	10,807,824	\$/MGD	-9
O&M costs	3,883.00	\$/MG	
Existing maximum capacity	0.00	MGD	
Lifetime remaining on existing infrastructure	0	yrs	
Lifetime of new construction	35	yrs	

Users modeling water quality need to enter an additional data input in input table set 6. If the ASR facility uses a treatment system, enter the average daily effluent concentration achieved by the ASR facility. The capital cost and lifetime of existing or new construction for the ASR facility will apply to both flows and loadings, similar to the O&M costs and capacities. To exclude the option to model water quality, enter “-9” in the “Exclude Treatment” input field.

Aquifer Storage and Recovery (ASR) Loadings	Value	Units	Exclude Treatment
Average daily effluent concentration	0	mg/L	-9

Select Return to Input and check the box next to Infrastructure when this section is complete.

**Surface Water & Streamflow Targets**
 **Groundwater**
 **Interbasin Transfer**
 **Infrastructure**

### 3.6 CSO Module

To apply management options that minimize the number of combined sewer overflow (CSO) events, press CSO Module<sup>48</sup> to navigate to the **CSO page**, which includes three steps.

<sup>48</sup> The CSO Module button is only visible when modeling hydrology only.

5. **CSO Module.** If you wish to model the application of combined sewer overflow (CSO) management, proceed to the CSO module.

CSO Module

In **CSO page** Step 1 (see screenshot on left), you must first indicate the maximum allowable number of CSO events. Then, you must define the conditions that define a CSO event. CSO events, within WMOST, are instances where: 1) the runoff fraction routed to the combined sewer exceeds the specified hydraulic capacity of the combined sewer, or 2)

**1. Combined Sewer Overflow Events**  
 Enter the hydraulic capacity of runoff and the hydraulic capacity of sewage flows through the combined sewer and the number of times those hydraulic capacities can be exceeded annually.

Enter the maximum number of CSO events.  event(s)/yr

Enter the hydraulic capacity for runoff routed through the combined sewer.  MGD

Enter the hydraulic capacity for sewage flows to the wastewater treatment plant.  MGD

the sum of the runoff fraction, flows from potable and nonpotable water users intended for the wastewater treatment plant, and groundwater infiltration exceeds the specified hydraulic capacity of the interceptor sewer that flows to the WWTP. In order to determine whether a CSO event occurs, enter the hydraulic capacity of the combined sewer and the hydraulic capacity of the wastewater treatment plant.

**2. CSO Management Options**

Enter the specifications for the management options available for minimizing the annual number of CSO events.

**2A. Offline Storage**

Enter the O&M cost per MG and the maximum capacity of the offline storage.

O&M cost for offline storage	20000	\$/MG
Maximum offline storage	10	MGD

**Exclude Offline Storage**

To exclude offline storage as a management option, enter -9.

**2B. Sewer Separation**

Enter the capital cost for sewer separation and the lifetime of the new construction.

Capital cost for sewer separation	5000	\$/MGD
Lifetime of new construction	35	yrs

**Exclude Sewer Separation**

To exclude sewer separation as a management option, enter -9.

In **CSO page** Step 2, you can specify whether or not offline storage or sewer separation are available management options for minimizing CSO events. If offline storage is an available management option, you must enter the O&M cost of using the offline storage and its maximum capacity in **CSO page** Step 2A. Similarly, if sewer separation is an available management option, you must enter the capital cost for sewer separation and the lifetime of that new construction in **CSO page** Step 2B. Costs related to offline storage management or sewer separation may be found in project-specific feasibility or evaluation reports (such as Washington State’s King County Comprehensive CSO Control Program Review [2011] or the CSO Control Program Reevaluation by the Narragansett Bay Commission [2017]) or in guidance from the EPA (such as the Impacts and Control of CSOs and Sanitary Sewer Overflows [SSOs] Report to Congress (2004) or CSO Management Fact Sheets [1999]).

If either offline storage or sewer separation are not available management options, you must enter “-9” in the appropriate exclusion input field. Other management options that are not present on the **CSO page** include stormwater management BMPs (land use “managed” sets) and additional capacity at the WWTP (**Infrastructure page**).

Capacity of the combined sewer	9	MGD
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Finally, in **CSO page** Step 3, you must define the combined sewer system (CSS) by its capacity (screenshot below) and the HRU areas that are serviced by the CSS (screenshot on next page of the user guide). The areas specified for each HRU must not exceed the baseline HRU area. Additionally, since the CSS routes flows from potable and nonpotable users to the WWTP, the CSS capacity should not exceed the WWTP capacity.

HRU Area Serviced by Combined Sewer System		
HRU ID	HRU Name	Area serviced by combined sewer system [acres]
HRU1B	Forest, Sand & Gravel & Gravel	39.08
HRU2B	Open/non-residential, Sand & Gravel & Gravel	1.34
HRU3B	Medium-low density, Sand & Gravel	42.80
HRU4B	Medium-high density, Sand & Gravel	0.00
HRU5B	Commercial-industrial, Sand & Gravel	0.00
HRU6B	Agriculture, Sand & Gravel	0.00
HRU7B	Forest, Till & Fine-Grained Deposits	6.08
HRU8B	Open/non-residential, Till & Fine-Grained Deposits	1.09
HRU9B	Medium-low density, Till & Fine-Grained Deposits	12.32
HRU10B	Medium-high density, Till & Fine-Grained Deposits	0.00
HRU11B	Commercial-industrial, Till & Fine-Grained Deposits	1.20
HRU12B	Agriculture, Till & Fine-Grained Deposits	0.00
HRU13B	Cranberry Bog	0.00
HRU14B	Forested Wetland	0.00
HRU15B	Nonforested Wetland	0.00
HRU16B	Water	0.00

Select Return to Input and check the box next to CSO Module when this section is complete.

### 3.7 Flood Module

To include flood damage costs in the optimization of management costs, select Flood Module to navigate to the **Flood page**. The Flood Module requires at least three sets of data for average daily streamflow, return period, and flood damage. If you do not have these data, refer to Section 5 for information on existing flood damage studies and conducting your own flood damage modeling using publicly available data and software. Note that engaging the Flood Module creates substantially larger optimization problems resulting in significantly longer model solve times.

6. Flood module. If you wish to consider the cost of flood damages in the total annual management costs, proceed to the flood module.

Flood Module

### 3.8 Measured Streamflow and In-stream Concentrations

Press the Measured Data button to navigate to the **Measured Data page**. These data are used to create an output graph showing both measured and modeled in-stream flow and concentration to assess the accuracy of the model in reproducing measured flows and constituent concentrations. These data may be

#### 7. Measured data.

If available, enter measured streamflow and water quality data.

Measured Data

acquired from the U.S. Geological Survey<sup>49</sup> or from the model from which you may have obtained baseline hydrology data.

Date (mm/dd/yyyy)	Measured In-Stream Flow (cfs)	Measured Concentration of TN (mg/L)
1/1/2002	45	1.60
1/2/2002	42	1.71
1/3/2002	40	1.79
1/4/2002	37	1.94
1/5/2002	36	1.99
1/6/2002	37	1.94
1/7/2002	56	1.28
1/8/2002	68	1.06
1/9/2002	67	1.07
1/10/2002	64	1.12

Select Return to Input and check the box next to Measured Data when this section is complete.

**Measured Data**

---

<sup>49</sup> <http://waterdata.usgs.gov/nwis> for streamflow data; <https://water.usgs.gov/nawqa/sparrow/> for water quality data

## 4. Optimization and Results

Unlike WMOST v2, which used a linear programming solver, WMOST v3 uses a mixed integer nonlinear programming (MINLP) solver to find the least-cost solution to the optimization problem in WMOST. The consideration of both water quantity and quality necessitated the switch from a linear solver to a nonlinear solver to accommodate the increased complexity. In order to solve the optimization problem, WMOST users can access the BONMIN (Basic Open-source Nonlinear Mixed INteger programming) (Bonami et al. 2008) solver via the online NEOS server<sup>50</sup> (Czyzyk et al. 1997; Dolan 2001; Gropp and More 1997). This section first describes how to use the NEOS Server to run the optimization and retrieve your results, and then it describes how to process and evaluate your results, including model calibration.

### 4.1 Running Optimization

Once all sections discussed in Section 3 are complete, you may run the optimization model by returning to the **Intro page** and pressing the red **Optimize** button. This will initiate the writing of the optimization file to your project folder. Before using the **Optimize** button, you may enter a “Scenario Name” to help you identify the scenario that is stored in the WMOST file. You also must select the solver algorithm you would like to use. The algorithm “Hybrid (B-Hyb)” is the default. Refer to the Theoretical Documentation for guidance on selecting the proper solver algorithm. For the majority of users, the default algorithm is preferred. The **Intro page** will display again once the optimization files have been written.

When you press the **Optimize** button, three optimization files are written by WMOST and saved to the WMOST project folder:

- Wmodel.mod – model file with variable definitions and constraints
- Wdata.dat – data file with parameter values
- Wcommand.amp – command file defining optimization specifications

After locating the optimization files, navigate to the NEOS Server BONMIN site<sup>51</sup>. On this site, you will see four buttons for uploading the model optimization files. Upload the three files created by the

#### Additional Settings

- Dry run: generate job XML instead of submitting it to NEOS
- Short Priority: submit to higher priority queue with maximum CPU time of 5 minutes
- E-Mail address:

model in its corresponding location. There is no need to upload an “Options File”.

Next, input your e-mail address to receive

<sup>50</sup> The NEOS Server is hosted by the University of Wisconsin–Madison and provides access to over 60 different solvers for numerical optimization problems. Access to the all of the available solvers on the NEOS server can be found at <https://neos-server.org/neos/solvers/index.html>.

<sup>51</sup> <https://neos-server.org/neos/solvers/minco:Bonmin/AMPL.html>

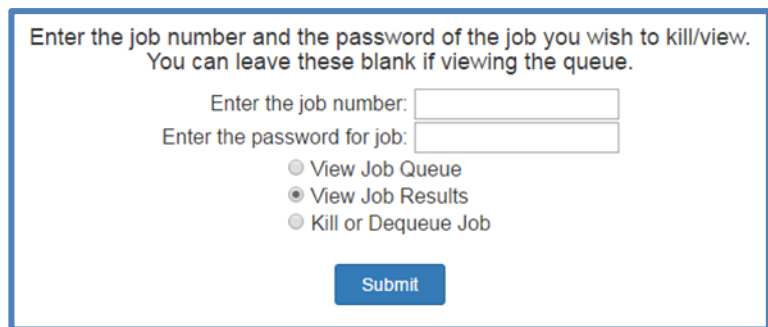


an update when your model run is complete (screenshot on left). If you do not include your email, you can instead access your results using the job number and password provided by NEOS when the model optimization run is submitted. Note that there is an option to run your model as “Short Priority” or “Dry run”. Users should not select these options because they provide results that cannot be processed by the Results Module. After the optimization files have been selected, press *Submit to NEOS* to initiate your model run. Most model runs take about 10-15 minutes to solve, but some model runs may take up to eight hours. The optimization time will depend on the complexity of the model and the model time period. The NEOS Server imposes a limit of eight hours on solve times so results will not be provided if the model takes longer than eight hours to solve.

After you submit the model run, the NEOS page will reload and provide you with a job number, password, and the job queue. The job number and password can be used to view the job queue, view job results (after optimization is complete), or kill/dequeue a job<sup>52</sup>. The current page may reload again after a few minutes without the job queue displayed. You can either keep this page open or close out as you wait for the solver to finish.

Once you receive an email indicating your model run has completed, you can view the optimization results in the following ways:

1. If you’ve kept the job number and password page up, you can refresh this page.
2. You can input the job number and password on the NEOS Admin site<sup>52</sup>, which is also provided in the results email. Select “View Job Results” to view the optimization results.



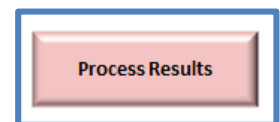
The screenshot shows a web form with the following elements:

- Header text: "Enter the job number and the password of the job you wish to kill/view. You can leave these blank if viewing the queue."
- Input fields: "Enter the job number:" and "Enter the password for job:"
- Radio buttons for actions: "View Job Queue", "View Job Results" (selected), and "Kill or Dequeue Job".
- A blue "Submit" button.

To run the Results Module in WMOST, you must copy the optimization results into a new text file. First, open a text editor, such as Notepad. Next, use CTRL+A to select all of the optimization results text on the web page. Finally, copy the selected text and paste it into the text editor. Save the file with a name that will help you identify the scenario and save it to your WMOST project folder.

## 4.2 Evaluating Results

After you save your optimization results, you can now run the Results Module to process and display results in WMOST. Navigate to the **Intro page**, and press the red Process Results button. This button will display a File Explorer dialog box. Navigate to your optimization results file and select it to initiate the Results Module. The Results Module may take 1 – 15 minutes to run depending on the length of your time period. Users should refrain from using their computer’s copy function while the Results Module is processing because it is used by the Results Module macros and may affect the results outputs.



<sup>52</sup> Users can enter the job number and password on the NEOS Server at <https://neos-server.org/neos/admin.html>



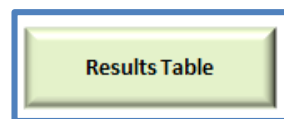
After running the Results Module, WMOST provides four outputs:

- A summary table of management practices and associated costs that met specified goals (e.g., minimum demand, minimum in-stream flow) with the least cost on the **Results page**
- A time series table of flow, loadings, and concentrations variables on the **Adv\_Results page**
- Scenario log file containing the scenario input data and results for analysis in ScenCompare<sup>53</sup>
- Four graphs displaying modeled and measured in-stream flow data, including:
  - Modeled in-stream flow and baseflow compared with user-specified measured in-stream flow
  - Modeled in-stream flow and baseflow and user-specified minimum and/or maximum in-stream flow targets (if applicable)
  - Modeled in-stream concentration compared with user-specified measured in-stream concentration
  - Modeled surface water or reservoir concentrations or loadings and user-specified minimum and/or maximum surface water or reservoir concentrations or loadings targets (if applicable)

Results represent estimated conditions at the end of the planning horizon if all management practices were implemented. For example, the modeled in-stream flow and baseflow are estimated to occur if recommended management practices are implemented and human demand is at the projected rate input by the user with the expected weather patterns (i.e., the user-input runoff and recharge rates). The flows over the modeling period represent estimated flows over a variety of potential weather conditions represented by the years in the modeling period. The length of the modeling period and the variety of climate scenarios it represents determine the robustness and sustainability of the solutions recommended by the model.

Results are most meaningful if compared relative to results from a simulation run (Section 2.1) and other optimization scenarios. In addition, *performing sensitivity analyses is highly recommended* especially for input data with least certainty to further determine the robustness of results (Section 6). By varying the input data, you can determine the robustness of results over a variety of potential climate and development scenarios that may occur by the end of planning period.

To view the summary table of results, press the **Results Table** button on the **Intro page** to display the management decisions and associated costs. Capital and O&M costs are presented separately in WMOST v3. Some facilities or management practice may only have a capital cost or only have O&M costs due to the nature of the selected management practice(s).

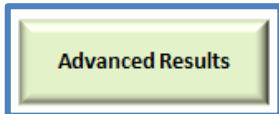


Excerpts from the summary table of results are as follows:

<sup>53</sup> WMOST ScenCompare is an external MS-Excel application designed to view and compare WMOST scenario results. The tool and instructions for its use are available from the WMOST website. Refer to the tool's instructions and Section 6 of this document for more information about the tool's use and its capabilities.

RESULTS			
Due to solver precision, there may be negligible changes in HRU areas that round to zero displayed as 0 or (0).			
<b>ANNUALIZED COSTS</b>		<b>(million \$/yr)</b>	
All Management Practices (including penalty and flood)		\$0.7	
<b>ANNUALIZED REVENUES</b>		<b>(million \$/yr)</b>	
Water Revenue		\$8.9	
Wastewater Revenue		\$14.0	
<a href="#">Return to Intro</a>			
<b>MANAGEMENT PRACTICES</b>		<b>Quantity</b>	<b>Units</b>
<b>Demand Management</b>			
Consumer Rate Change	0	%	\$0
Direct Demand Reduction	0.00	MGD	\$0
<b>Land Conservation</b>		0	Acres
			\$0
<b>Infrastructure</b>		<b>New Construction Costs (add on or new facility)</b>	
	<b>Quantity</b>	<b>Units</b>	<b>Annual Sub-Costs (\$/yr)</b>
SW Pumping	0.00	MGD	\$0
GW Pumping	0.00	MGD	\$0
Reservoir / Surface Water Storage	0.00	MGD	\$0
Water Treatment Plant	0.00	MGD	\$0
Potable Distribution System Repair	0	% Leaks Fixed	\$0
Wastewater Treatment Plant	0.00	MGD	\$0
Infiltration Repair	0	% Leaks Fixed	\$0
Interbasin Transfer of Water	0.00	MGD	\$0
Interbasin Transfer of Wastewater	0.00	MGD	\$0
<b>Operations and Maintenance Costs</b>		<b>Quantity</b>	<b>Units</b>
	<b>Annual Sub-Costs (\$/yr)</b>		
	7,198.53	MG	\$266,274
	0.00	MG	\$0
	NA	MG	\$0
	7,198.53	MG	\$0
	NA	-	NA
	1,045.19	MG	\$197,830
	NA	-	NA
	0.00	MG	\$0
	1,059.08	MG	\$200,378
<b>Total Costs</b>		<b>Annual Cost (\$/yr)</b>	
		\$266,274	
		\$0	
		\$0	
		\$0	
		\$197,830	
		\$0	
		\$0	
		\$200,378	

To view the time series table of advanced results, select the [Advanced Results](#) button on the **Intro** page to display the flow, loadings, and concentration time series. The Advanced Results table provides time series of the model decision variables. Refer to the theoretical documentation for variable definitions.



An excerpt from the hydrology and water quality sections of the advanced table of results are below:

All flows are MG/time step. All volumes are MG at that time step.															Runoff Total	SW Balance Error
Date (mm/dd/yyyy)	QRu	QRuStS	QRuCS	QRu_Total	QStSSw	QExtSw	QPtSw	QGwSw	QWwtpSw	QWrfSw	QSwRes	DQSwWtp	DQSwAsr	QSwPt	SW_Balance	
				7,614.86											0.000	
1/1/2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.780	1.202	0.000	13.982	0.000	0.000	0.000	0.000	
1/2/2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.667	1.202	0.000	13.869	0.000	0.000	0.000	(0.000)	
1/3/2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.375	1.202	0.000	13.577	0.000	0.000	0.000	(0.000)	
1/4/2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	11.974	1.202	0.000	13.176	0.000	0.000	0.000	(0.000)	
1/5/2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	11.538	1.202	0.000	12.740	0.000	0.000	0.000	(0.000)	
1/6/2002	0.185	0.000	0.000	0.185	0.000	0.000	0.000	10.979	1.202	0.000	12.181	0.000	0.000	0.000	(0.000)	
1/7/2002	29.070	0.000	0.127	29.197	0.000	0.000	0.000	10.327	1.328	0.000	11.656	0.000	0.000	0.000	0.000	
1/8/2002	0.488	0.000	0.002	0.490	0.000	0.000	0.000	19.215	1.204	0.000	20.418	0.000	0.000	0.000	(0.000)	
1/9/2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	24.490	1.202	0.000	25.692	0.000	0.000	0.000	(0.000)	
1/10/2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	26.240	1.202	0.000	27.441	0.000	0.000	0.000	(0.000)	

All loadings are lbs/time step (denoted by an "L"). All concentrations are mg/L at that time step (denoted by an "X").										SW Loads Balance Error
Water Quality Variables										0.000
LRu1	LUseNpSewer1	LStSSw1	LExtSw1	LPtSw1	LGwSw1	LWwtpSw1	LWrfSw1	LSw1	LSw_Balance	
0.000	0.000	0.000	0.000	3.302	0.000	12.112	0.000	15.413	(0.000)	
0.000	0.000	0.000	0.000	3.302	62.013	12.112	0.000	77.426	(0.000)	
0.000	0.000	0.000	0.000	3.302	87.517	12.112	0.000	102.930	0.000	
0.000	0.000	0.000	0.000	3.302	110.643	12.112	0.000	126.056	(0.000)	
0.000	0.000	0.000	0.000	3.302	131.906	12.112	0.000	147.320	0.000	
0.000	0.000	0.000	0.000	3.302	151.278	12.112	0.000	166.692	(0.000)	

Select the Compare to Measured & Target Flows button on the **Intro page** to display the two hydrologic flows graphs:

- Graph comparing measured in-stream flow to modeled in-stream flow and baseflow
- Graph comparing modeled in-stream flow and external outflow to the corresponding streamflow targets. If you did not set any streamflow targets, this target graph is not created; and thus is not displayed.



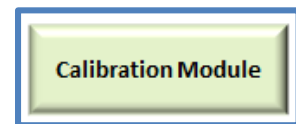
Select the Compare to Measured & Target Water Quality button on the **Intro page** to display the two water quality graphs:

- Graph comparing modeled in-stream concentrations to user-specified in-stream concentrations
- Graph comparing the water quality targets to their corresponding water quality flows. If you did not set any water quality targets, this target graph is not created; and thus is not displayed.

Results may be either printed from the Excel interface with the same options as any Excel file or copied and pasted into Word or other text editing applications.

### 4.3 Calibration Module

If you are in the process of calibrating your WMOST model, you may want to employ the Calibration Module to help analyze your simulation results and compute statistics for goodness-of-fit between measured and modeled in-stream flow and concentrations. To use this module, press Calibration Module on the **Intro page** to navigate to the **Calibration page**.



At the top of this page, you will see two options for running the Calibration Module:

- Process calibration statistics **before** processing the results –before using the Results Module by pressing the Process Calibration button
- Process calibration statistics **after** processing the results<sup>54</sup>—after using the Results Module by pressing the Calibration Statistics button.

Therefore, if you already ran the Results Module with your simulation results, you can quickly compute calibration statistics using Calibration Statistics under option B. If you are analyzing multiple calibration runs and do not care to have the full suite of results viewing options, you can use Process Calibration under option A to import a new results file and compute relevant statistics. This option will only run the results routines that are necessary for producing calibration statistics, thus expediting the calibration process.

<sup>54</sup> Calibration statistics are not automatically processed by the Results Module.

Return to Input

## Hydrology and Loadings Calibration Module

Clear Calibration Runs

Follow the step-by-step directions to process goodness-of-fit statistics for a calibration run.

**A. Process Calibration Statistics *Before* Process Results**

This procedure runs the processes that are necessary for calculating statistics (without running the full routine).

Process Calibration

**B. Process Calibration Statistics *After* Process Results**

This procedure calculates the model statistics for the results that were last processed with the results routine.

Calibration Statistics

After you use one of the calibration processing options, the Calibration Module copies your measured and modeled in-stream flow and concentration time series data to the time series table on the **Calibration**

Hydrology Calibration				
Date	Measured In-Stream Flow (cfs)	In-Stream Flow, Run#1	In-Stream Flow, Run#2	In-Stream Flow, Run#3
1/1/2002	45	142.421	141.8139546	141.795
1/2/2002	42	133.760	132.6519386	133.140
1/3/2002	40	125.308	124.1613666	124.725
1/4/2002	37	117.228	116.0527518	116.675
1/5/2002	36	109.673	108.474354	109.134
1/6/2002	37	102.889	101.6748454	102.354
1/7/2002	56	201.719	200.5256586	201.214
1/8/2002	68	118.296	117.0773799	117.798
1/9/2002	67	127.371	126.1318069	126.900

**page.** With each additional calibration run, the module will insert new columns containing your modeled in-stream flow or concentration in the time series tables and new rows containing computed goodness-of-fit statistics in the statistics summary tables.

The screenshot to the left shows the time series table after three calibration runs have been processed by the module. You can use these tables to compare your in-stream flow and concentration results on this page or construct a graph that compares measured data to multiple modeled results run at once (as compared to the Measured Flows graphs, which only compare measured data to a single results run).

In the statistics summary table (see above), you can see five different goodness-of-fit statistics computed based on your measured and modeled flows. These statistics include:

Hydrology Calibration								
Run ID	Run Name	Objective Cost	Average Measured Flow	NSE Value	R <sup>2</sup> Value	Relative Percent Error	Average Bias	Median Bias
1	Flow Run#1	664804.62	155.5283759	0.41521788	0.536199378	68.76265836	38.21449443	24.57075386
2	Flow Run#2	664481.66	155.5283759	0.417517021	0.536255051	67.69767941	37.56779065	24.15494307
3	Flow Run#3	664481.66	155.5283759	0.415974096	0.536214412	68.86602764	38.07161803	24.4788887

- Nash-Sutcliffe Efficiency (NSE), a statistic used to assess the predictive power of hydrological models (NSE values range between negative infinity and 1. An NSE value of 1 corresponds to a perfect match and a negative NSE value indicates that the measured average is a better predictor than the model results.)
- R<sup>2</sup>, a statistic used to measure how close the data are to the fitted regression line (R<sup>2</sup> values range between 0 and 1. An R<sup>2</sup> value of 1 corresponds to a perfect match.)
- Relative Percent Error, a statistic used to analyze the precision of the data

- Average Bias and Median Bias, statistics used to evaluate the difference between the modeled values and the measured values (average bias computes the average difference between modeled and measured data, while median bias computes the median of the same calculation)

In addition to comparing measured streamflow and concentrations to the WMOST results, users should also compare the costs generated by the simulation run. The costs related to operating the system during the baseline period should accurately reflect the costs borne by the utility during the same period. For example, if WMOST estimates WTP costs of \$250,000 per year, then the user should verify that the utility spent an equivalent amount on WTP operation. If that is not the case, the unit costs for operation of the WTP may be inaccurate.

## 5. Flood Damage Modeling with HAZUS<sup>55</sup>

HAZUS-MH is used to generate the flooding cost curve data which are entered into the WMOST v3 Flood Module table. HAZUS-MH is a multi-hazard loss estimation tool developed by the Federal Emergency Management Agency (FEMA) which provides a nationally applicable and standardized methodology for estimating flood (and earthquake) losses on a regional scale. HAZUS is designed to run with ESRI's ArcMap GIS. The Flood Model is designed with three levels of analysis, from Level I using the default HAZUS-supplied building stock and flood modeling procedures to Level III which requires extensive hydraulic modeling and high quality building data<sup>56</sup>. The following steps will guide the user through methodology to determine the 100-year flood depth grid using data from the FEMA National Flood Hazard Layer and to create 10, 50 and 500-year grids. Additionally, this guide will assist users in creating a user-defined building inventory from the available data to improve upon existing default settings in HAZUS and perform a Level II analysis. By running several flood levels, the user is then able to create a flood depth (return interval)-damage curve for use as input into the WMOST tool.

*Note: This example uses data for Plymouth County in Massachusetts. Some data sources may not be available in other states or regions.*

### 5.1 Data Needed

- FEMA National Flood Hazard Layer (NFHL) data
  - Data can be downloaded for the entire state (where available) or by county. (<https://msc.fema.gov/portal/advanceSearch>)
- Elevation data—Accuracy of solutions may vary with resolution of input data. HAZUS can be run either with 10- or 30-meter resolution data from USGS or with finer resolution LIDAR data if available for the area of interest.
  - National Elevation Data can be obtained at the National Elevation Dataset from the National Map (<http://viewer.nationalmap.gov/viewer/>).
  - LiDar data can be found and downloaded from NOAA Digital Coast website (<http://coast.noaa.gov/digitalcoast/data/coastallidar>) or from state specific GIS websites where available.

*It is important that the ground elevation grid and the FEMA flood elevations are in the same vertical projection (NAV88).*

The generalized method to creating a flood depth grid for any region is to create a flooding surface using available information and subtract the ground elevation. Areas where the flood surface minus the ground elevation is positive represent flooded regions. Areas where the flood surface minus the ground elevation is negative represent non-flooded areas.

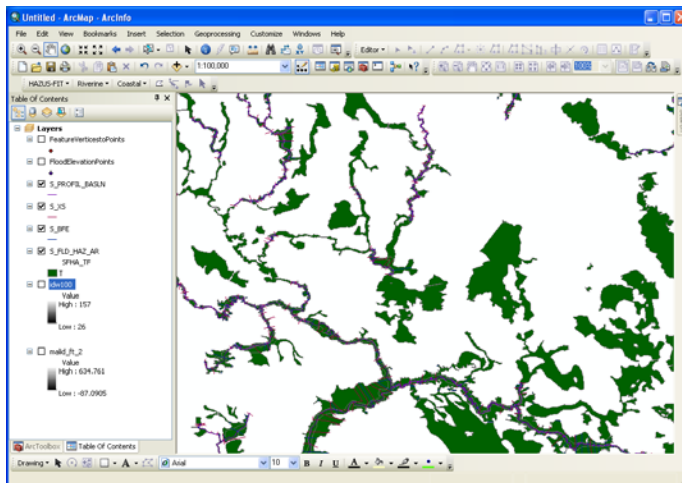
<sup>55</sup> HAZUS Level 2 Site Specific Flood Model: FEMA Region VIII Standard Operating Procedure for Riverine Flood Hazard and Site Specific Loss Analysis, prepared by Jesse Rozelle, Austen Cutrell, Doug Bausch, and H.E. Longenecker.

<sup>56</sup> Multi-hazard Loss Estimation Methodology Flood Model HAZUS-MH, Users Manual, FEMA ([www.fema.gov/plan/prevent/hazus](http://www.fema.gov/plan/prevent/hazus)).

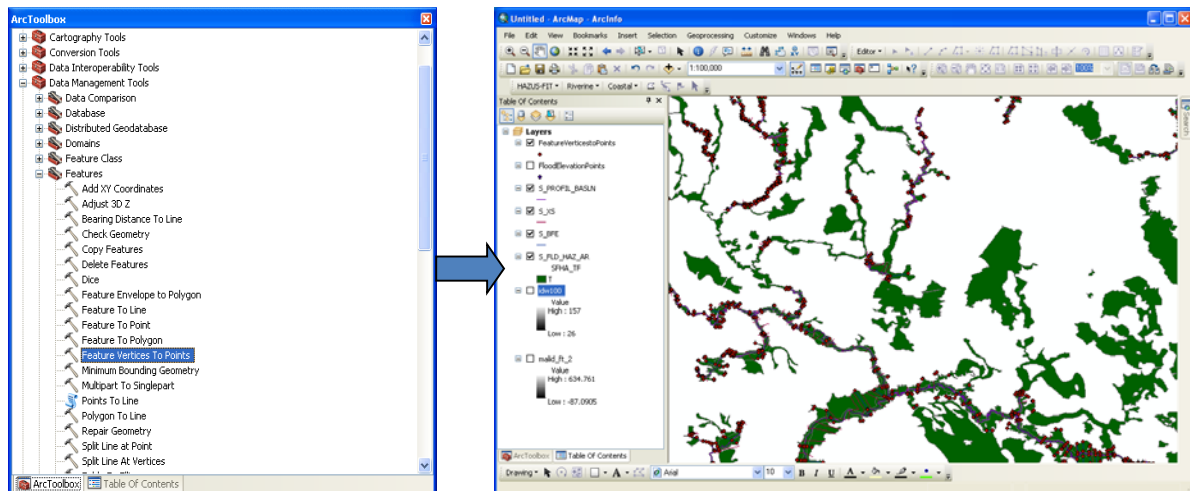
## 5.2 Creating the 100-Year Flood Depth Grid from FEMA NFHL Data

These preprocessing methods require the use of ArcMap to maintain compatibility with FEMA's HAZUS tool.

1. Open ArcMap.
2. Add the Base Flood Elevation (BFE) shapefile (S\_BFE.shp) from the NFHL dataset to the map. The shapefile has an attribute "ELEV" which is the Base Flood Elevation (BFE) at each section.
3. Add the Stream Profile Centerline and the Flood Hazard Area shapefiles from the NFHL(S\_PROFIL\_BASLN.shp and S\_FLD\_HAZ\_AR.shp).

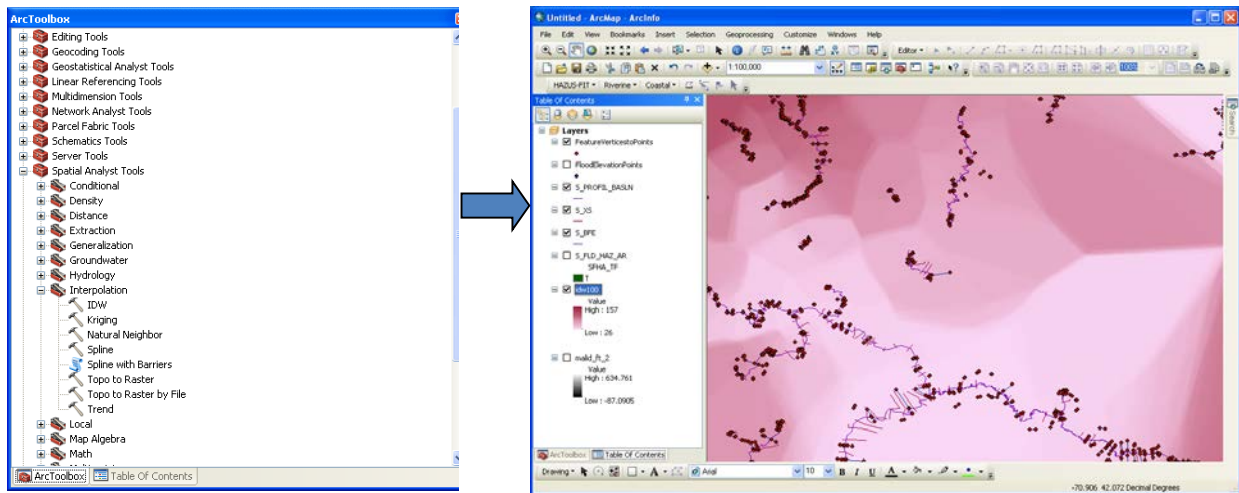


4. Create points at each vertex of the BFE lines (Data Management Tools>>Feature>>Feature Vertices to Points).

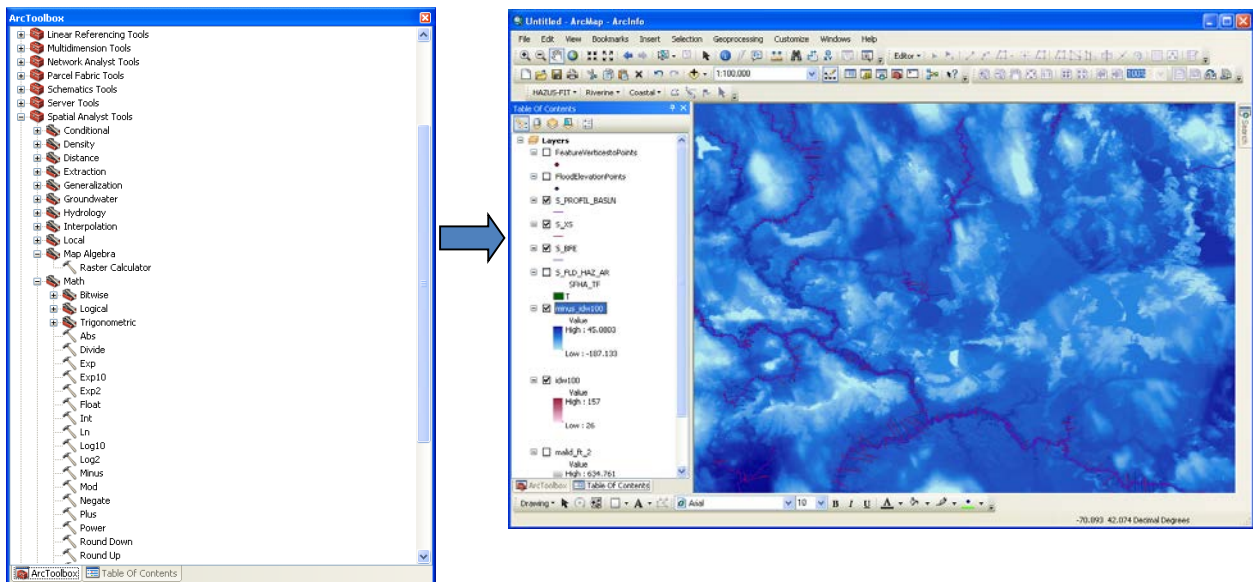




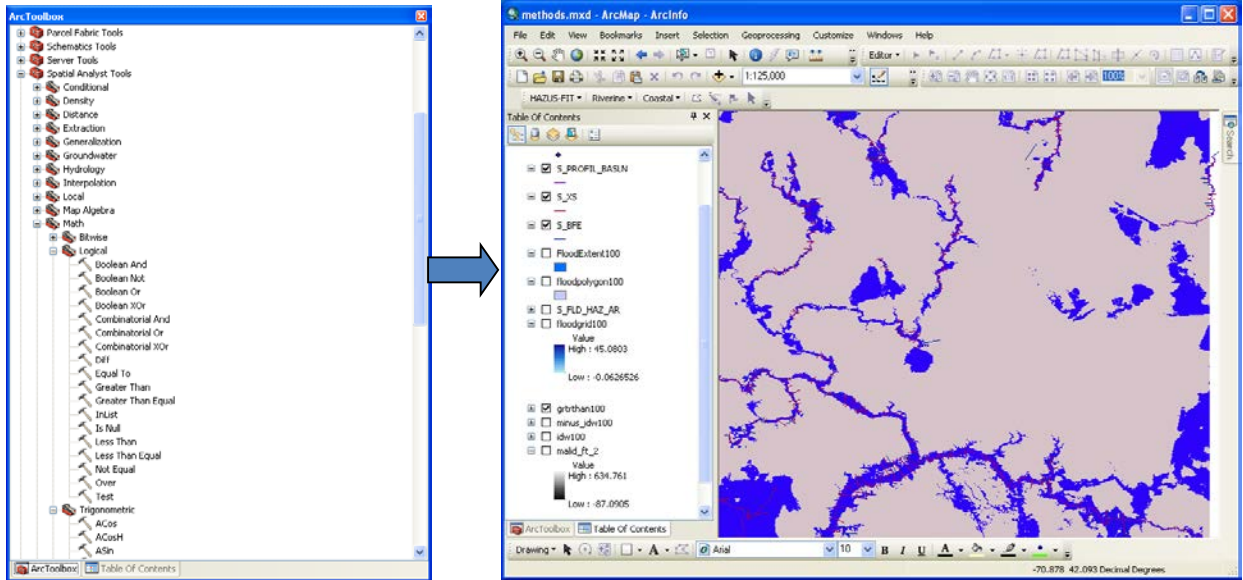
- Using the point feature generated in Step 4, create the 100-year flood surface by inverse distance weighting using the ELEV attribute (Spatial Analyst>>Interpolation>>IDW).



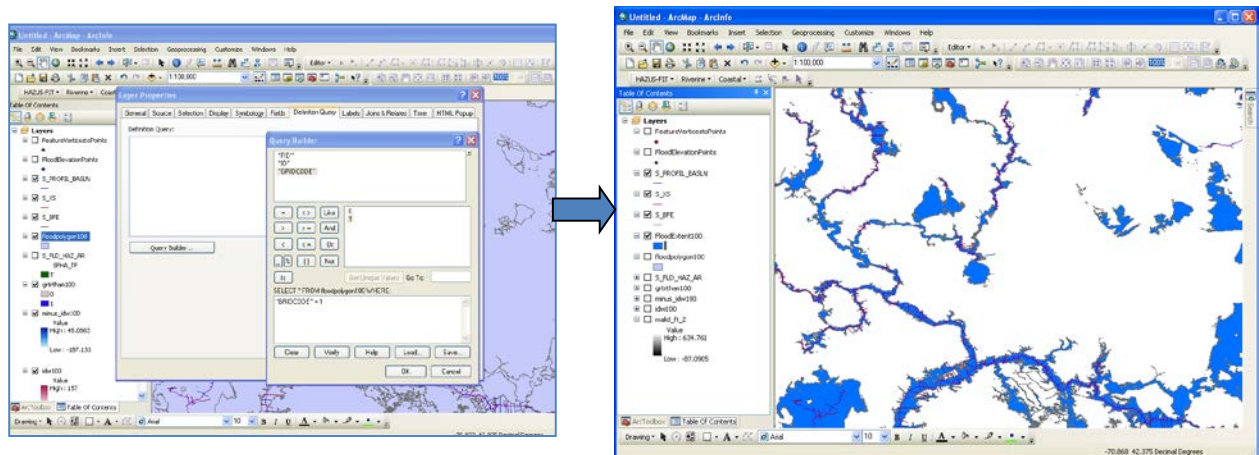
- Subtract the ground surface elevations from the flood surface layer created in Step 5 (Map Algebra>>Raster Calculator or Math>>Minus) to determine a water depth grid. The resulting layer will have negative values where the ground surface is above the flooded elevation (areas of no flooding) and positive values in flooded areas.



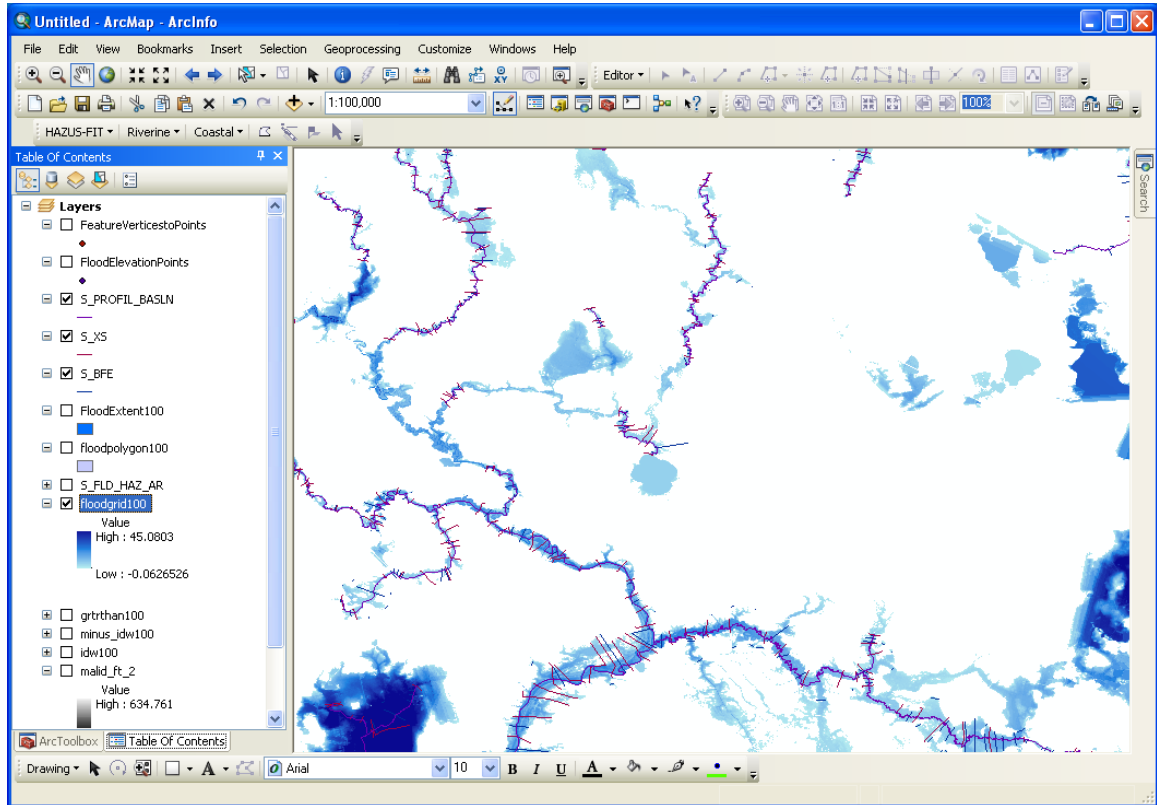
- Eliminate negative values using a conditional statement (SpatialAnalyst>>Math>>Logical >>Greater than Equal). Setting the flood elevation grid greater than zero will result in a true/false condition where positive values will have a grid code of 1 and negative values will have a grid code of 0.



- Determine the flood extent boundary polygon by first converting the conditional raster created in Step 7 to a polygon. Then, export polygons with a GRIDCODE=1 to a new data layer delineating the flood extent boundary.



- Mask the water depth grid (Step 6) by the flood extent boundary (Step 8) to create a flood depth grid.



10. Import this flood depth grid into HAZUS as a user-defined depth grid.

### 5.3 Creating the Flood Depth Grid from Lake Elevation Flooding

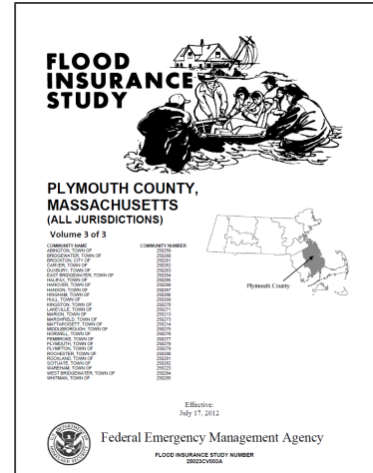
Creating a flood depth grid for possible lake flooding follows a similar approach

1. Determine the watershed draining to the lake and clip the digital elevation model (DEM) to the watershed boundary. This will be the study area of interest.
2. Beginning at Step 6, subtract the ground surface elevations from the lake flood elevation (Map Algebra>>Raster Calculator or Math>>Minus) to determine a water depth grid. Instead of a raster layer as in the riverine example above, this will now be a constant value representing the lake elevation during flood events. The resulting layer will have negative values where the ground surface is above the flooded elevation (areas of no flooding) and positive values in flooded areas.
3. Continue with Steps 7 through 10.
4. Repeat these steps for various lake flooding elevations.

## 5.4 Creating Flood Depth Grids for the 10, 50 and 500-Year Events

The next set of steps demonstrate how to create a flood depth grid from the 10, 50 and 500-year data in the published Flood Insurance Study books.

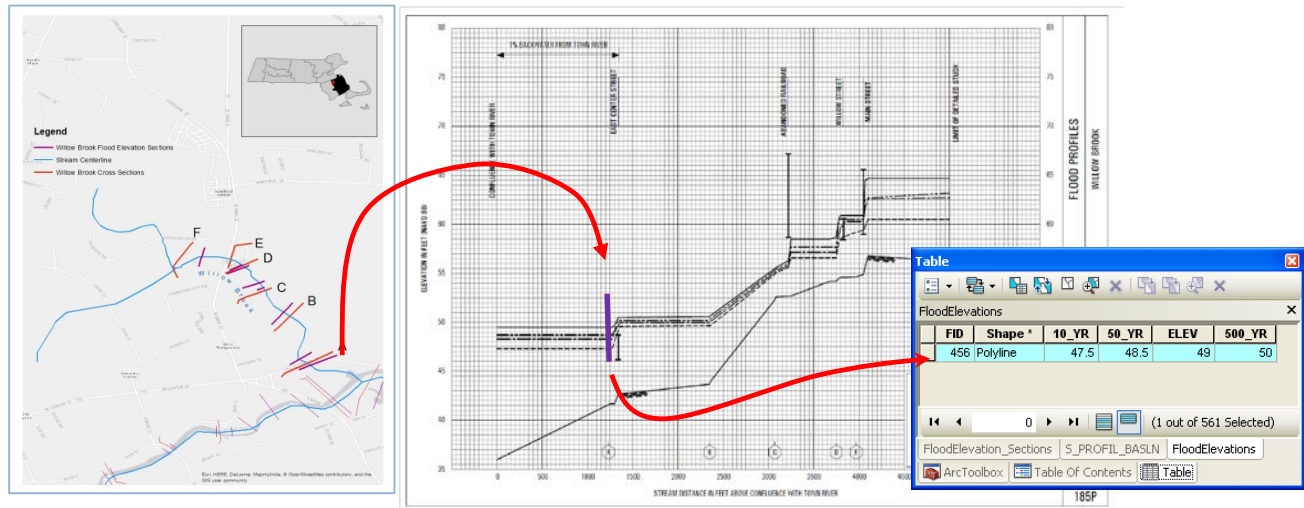
1. FEMA Flood Insurance Studies (FIS) are county-specific and can be obtained from the FEMA Map Service Center ([www.msc.fema.gov](http://www.msc.fema.gov)). The flood profile graphs show flood elevations along the centerline of the stream (S\_PROFIL\_BASLN.shp). The profiles show the elevation of the 100-year flood as well as the 10, 50, and 500-year floods. The profiles also show locations of streets, elevation of the streambed and other hydraulic structures.
2. For each stream in the study area, locate the profile plot in the FIS along with the corresponding stream in ArcMap. Each stream has both cross-section locations (S\_XS.shp) and Base Flood Sections locations (S\_BFE.shp).
3. In the S\_BFE the existing attribute ELEV represents the 100-year base flood elevation. Add attribute fields to S\_BFE.shp representing the 10, 50 and 500-year flood. The attribute labeled ELEV is the BFE. **Although the S\_BFE.shp file is easily replaced, it is a good idea to make a copy of this file to use as a working platform.**



SOURCE_CIT	500_YR	ELEV	50_YR	10_YR
25023C_FIS1	0	77	0	0
25023C_FIS1	0	69	0	0
25023C_FIS1	0	64	0	0
25023C_FIS1	0	79	0	0
25023C_FIS1	0	40	0	0
25023C_FIS1	0	82	0	0
25023C_FIS1	0	84	0	0
25023C_FIS1	0	47	0	0
25023C_FIS1	0	27	0	0
25023C_FIS1	0	31	0	0
25023C_FIS1	0	42	0	0
25023C_FIS1	0	16	0	0



- For each BFE line, locate the corresponding location on the profile plot and transfer these elevations to the appropriate attribute field. The cross-section labels on the map correspond to the cross-section labels across the bottom of the profile plot. Although the BFE lines are not shown on the profile plot, their location can be easily estimated. Cross-section locations are NOT the same as BFE locations



- Repeat this procedure for all section lines.
- Once all elevations are determined, the methodology to create the 100-year flood grid can be utilized to create flood depth grids for the 10, 50 and 500-year intervals.

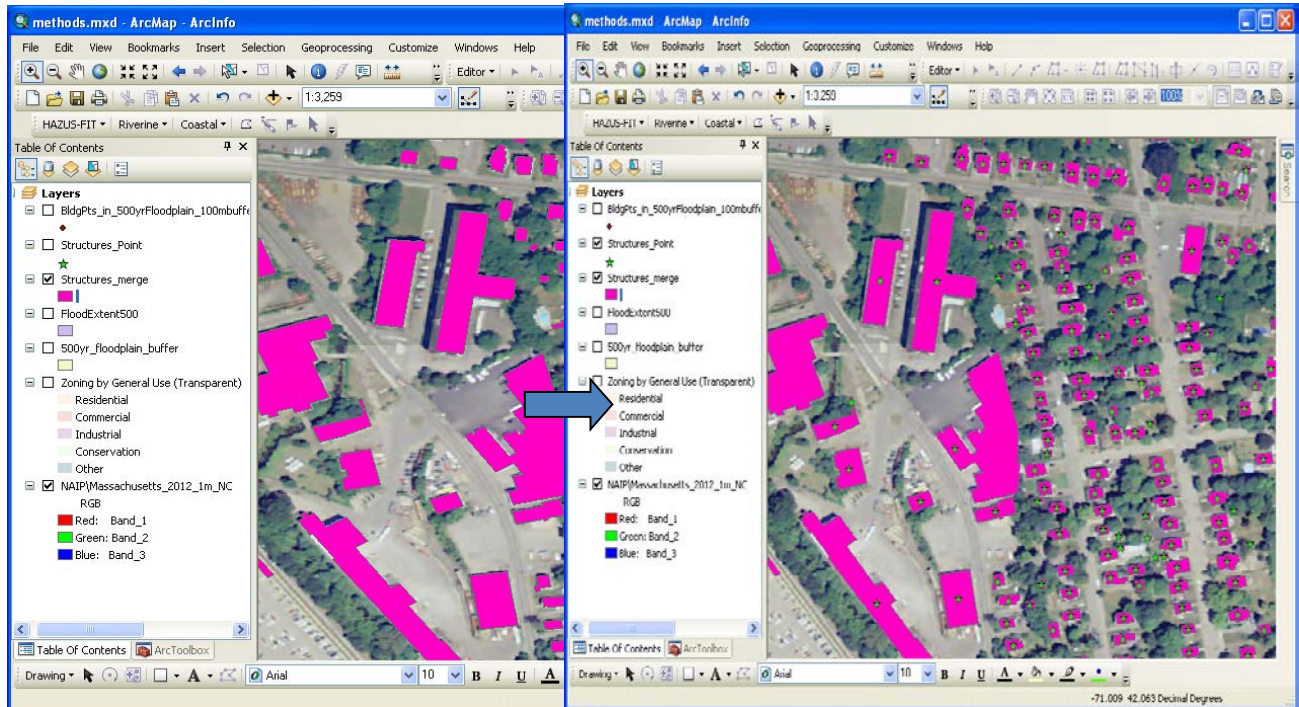
## 5.5 Creating a Site Specific Building Inventory

To determine flood damage, HAZUS assumes that all buildings are distributed evenly throughout a census tract. In order to get a more accurate assessment of the potential damage, it is helpful to build a user-defined building inventory. To create a detailed building inventory, the following information is necessary: structure location, foundation type, first floor height, building value, contents value, occupancy type, design level and number of stories.

- Create point locations of buildings within the floodplain. This can be accomplished in several ways, depending on the type of available data and the amount of time and effort available to spend on this step. The best data source is a shapefile of building footprints. If there is not a field labeled Area, add a field and calculate the area of each building. If the building footprint data are not available, parcel data can be used as well. For parcel data, the centroid of the parcel can be used as a substitute for building location. If neither of these is available, it is possible to manually locate each building from available orthoimagery. Only primary structures are necessary. Structures such as garages, sheds and small out-buildings should be excluded from the dataset. Buildings smaller than 400 square feet are often accessory structures. Aerial photographs such as the NAIP 1-meter imagery can be helpful in determining building use.<sup>57</sup> One can also perform a spatial join with the building points and the parcel layer to determine parcels with more than one building to help locate secondary, accessory structures on a property.

<sup>57</sup> Available from <https://gdg.sc.egov.usda.gov/>.

## 5. Flood Damage Modeling with HAZUS



- HAZUS needs several attributes for each building: occupancy class, first floor height above ground level, design level, number of stories, building value and foundation type. These can be obtained from a number of sources, such as tax assessor databases and zoning information.

BLD_AREA	RES_AREA	STYLE	STORIES	OCC_Class	FFH	Foundation	NUM_ROOMS	E
2396	1804	Two Family	2	RES3A	2	4	11	1
6214	3532	Two Family	2	RES3A	2	4	9	95.4
6458	3351	Conventional	1.75	RES1	2	4	9	98.6
2231	836	Ranch	1	RES1	2	4	4	1
3078	3078	Clubs/Lodges	1	COM1	2	7	0	87.9
2522	1530	Conventional	1.75	RES1	2	4	8	1
1976	973	Ranch	1	RES1	2	4	5	1
2630	1383	Conventional	1.75	RES1	2	4	6	1
2780	1008	Ranch	1	RES1	2	4	5	1
6010	3301	Apart OS	2	RES3C	2	4	17	1
6356	2128	Clubs/Lodges	2	COM1	2	7	0	94.7
2559	1280	Conventional	1.5	RES1	2	4	6	1
2314	1276	Colonial	1.75	RES1	2	4	6	1
2350	1160	Raised Ranch	1	RES1	2	4	7	1
3592	2357	Raised Ranch	1	RES1	2	4	7	1
3583	1945	Cape Cod	1.75	RES1	2	4	4	1

Fields should be created in the attribute table for each of these necessary attributes.

- HAZUS has specific values for occupancy class and foundation type and these must correspond exactly in order to map correctly. The HAZUS Technical Manual<sup>58</sup> has various default values to aid in assigning these attributes. In New England, 81% of residential structures have basements, so all residential structures were assumed to have a basement type foundation with the first floor height 4 feet above the existing ground. Commercial and industrial structures were assumed to have a slab type foundation with first floor height one foot above existing ground. Once completed, this attribute table should be exported to a database table and properly formatted for use in HAZUS. The HAZUS Users Manual gives detailed instructions to import the user-specified inventory.

Field Name	Data Type	Description
ID	Text	Field Size: 8
Name	Text	Field Size: 40
Address	Text	Field Size: 40
City	Text	Field Size: 40
State	Text	Field Size: 2
ZipCode	Text	Field Size: 10
Contact	Text	Field Size: 40
Phone	Text	Field Size: 14
Occupancy	Text	Field Size: 5
BldgType	Text	Field Size: 15
Cost	Currency	Field Size:
YearBuilt	Number	Field Size: Integer
Area	Number	Field Size: Single
NumStories	Number	Field Size: Byte
DesignLevel	Text	Field Size: 1
FoundationType	Text	Field Size: 1
FirstFloorHt	Number	Field Size: Double
ContentCost	Currency	Field Size:
BldgDamageFnId	Text	Field Size: 10
ContDamageFnId	Text	Field Size: 10
InvdamageFnId	Text	Field Size: 10
FloodProtection	Number	Field Size: Long Integer
ShelterCapacity	Number	Field Size: Integer
BUPower	Yes/No	Field Size:
Longitude	Number	Field Size: Decimal (11,6)
Latitude	Number	Field Size: Decimal (11,6)
County	Text	Field Size: 40
Comment	Text	Field Size: 40

Proper formatting schema for database table in Access

The following figure shows typical output from HAZUS for user-defined facilities. Damages are listed by occupancy type, damage percentage, building loss cost, content damage percentage and content loss cost. The figure shows only building-related damages but the user may wish to include estimates of other flood-related damages from HAZUS output as well.

<sup>58</sup> HAZUS MR4 Technical Manual, Department of Homeland Security, Federal Emergency Management Agency, Mitigation Division, Washington, D.C. (<http://www.fema.gov/plan/prevent/hazus/>)



OccupancyC	Controllin	BldgDmgPct	BldgLossUS	ContDmgPct	ContentLos	InventoryL	AnalysisOp
RES1	R	66.358566	92039.331042	60	41610	0	0
RES1	R	69.112408	102493.701064	60	44490	0	0
RES1	R	69.945282	106946.336178	60	45870	0	0
RES1	R	44.59601	84821.61102	42.39734	40319.87034	0	0
RES1	R	15.103155	18667.49958	9.765048	6034.799664	0	0
RES1	R	50	60200	49.759718	29955.350236	0	0
RES1	R	33.106655	53103.07462	26.927986	21596.244772	0	0
RES1	R	56.994598	0	54.991897	0	0	0
RES1	R	20.483168	28041.456992	19.483168	13336.228496	0	0
RES1	R	57.004348	68918.256732	55.006522	33251.442549	0	0
RES1	R	16.967435	39262.64459	12.747896	14749.315672	0	0
RES1	R	36.476012	59091.13944	31.095015	25186.96215	0	0
RES1	R	41.96305	63951.6882	37.75566	28769.81292	0	0
COM2	R	17.798485	49853.556485	60.59697	169732.11297	186538.11297	0
RES1	R	19.404114	27223.971942	16.404114	11507.485971	0	0
IND2	R	45.388669	196169.827418	73.796223	478420.913709	336235.275806	0
RES1	R	56.545074	105286.927788	54.317611	50569.695841	0	0

Typical output from HAZUS for user-defined facilities (buildings).

For each HAZUS flood depth grid corresponding to a unique flood recurrence interval, the user will need to sum the flood-related damages and enter these into the flood cost table on the **Flood page**.

Average Daily Streamflow (cfs)	Return Period (years)	Flood Related Damages (\$)

Flood cost curve in WMOST Flood Module

## 6. User Tips

The following tips are provided for troubleshooting, interpreting results and modeling specific situations or scenarios.

- If the objective cost section of the results does not contain feasible results, the Results Module informs you that there was an optimization error and what type of error was reported by the NEOS Server. *This means the scenario run was infeasible*, and that the specified management goals and/or continuity constraints could not be met with the user-provided input data. Refer to the Theoretical Documentation for constraints that are defined in the optimization model. You may need to adjust your management goals or identify erroneous input data. Future versions of the model will support identifying constraints and data that contribute to infeasible solutions.
- If you want to test the effect of a management option but the model is not selecting it, you can enter “0” for cost. You can also adjust the cost of a management practice to see the cost at which that practice is selected by the model and, therefore, assessed as cost effective.
- To exclude replacement costs for existing infrastructure, set the remaining lifetime to be greater than the planning period. This tells the model that the infrastructure does not need replacement within the planning period and the model will not calculate replacement costs. It will only calculate capital costs for new or additional capacity of infrastructure and O&M costs.
- A “calibration run” is advised before optimization runs to determine the accuracy of WMOST in modeling in-stream flow relative to measured data or data from the detailed watershed simulation model from which RRRs may have been acquired. Calibration runs can be used to ensure that the WMOST model closely matches the hydrologic and water quality conditions of your watershed. They can also be used to error check constraint and target values to ensure that they are feasible. Case study applications in the WMOST User Guide for Versions 1 and 2 describe the process for performing a “simulation run” with WMOST.
- If your model runs are infeasible, review all constraints, targets, and initial values. The constraints or targets may be too limiting and preventing the optimization from finding a solution. Furthermore, if initial concentrations or volumes differ in orders of magnitude from the average concentrations of volumes calculated by the model, the initial values should be adjusted so that the optimization solution is running the optimization from a reasonable starting point.
- Avoid groundwater volumes near zero as this can lead to infeasible model runs. In calibration, set the initial groundwater volume near the maximum in wet years in order to get a reasonable low volume estimate. Low flow accuracy is critical for effluent dominated streams, especially when applying loading or concentration targets, so consider potential influence of groundwater volume on concentrations during low flow periods.
- If your model cannot meet the maximum daily load target specified, consider the maximum loads during the times of greatest biological activity. Separate out non-point source loadings from point source loadings to determine the contribution of point source loadings to total stream loads and to

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determine what level of nonpoint source pollutant load reduction is likely to be feasible based on application of BMPs.

- Sensitivity analyses should be performed with the most uncertain input data. For example, if the price elasticity for industrial water use is most uncertain, then the model should be run multiple times over a range of potential values as follows:
  1. Starting with the best estimated value, determine the range of potential values e.g., -0.5 with a potential range of -0.2 to -0.7.
  2. Run the model with the same input data varying only the price elasticity for industrial water use. For example, run the model five times with values of -0.2, -0.3, -0.5, -0.6, and -0.7.
  3. Save the results of each run, that is, either use the “save as” function in Excel to save a different version of the file/model with each run or copy and paste the results tables into a separate Excel file.
  4. Determine the effect of the price elasticity on results. Does it change whether demand management via pricing is implemented? Does it change the mix of other management options? How does it change the total annual cost?

Ideally, change only one of the input data values at a time at first so that you can determine the individual effect of each variable. Once you know the individual effects and you have more than one uncertain input data value, you may want to run the model varying more than one data value at a time to determine their combined effects. You may consider “worst” and “best” case scenarios. For example, vary all uncertain data in the direction of higher costs to determine the worst case scenario for total cost if all uncertain data were to be truly in the higher cost direction. Alternatively, run the highest cost for a specific management practice to determine the whether it is still a cost effective practice that is chosen by the model and, therefore, a “no regrets” option. For more guidance, please refer to EPA’s “Sensitivity and Uncertainty Analyses” website<sup>59</sup>. You may also employ WMOST ScenCompare to facilitate sensitivity analyses using the scenario log file produced by the Results Module. Refer to the ScenCompare User Guide for detailed instructions regarding the use and capabilities of ScenCompare.

- Trade-off analyses are similar to sensitivity analyses but with a different purpose. With trade-off analyses the question may be “How does cost change with increasing in-stream flow? Is it linear? Are there points at which the increasing investment in management practices (i.e., total cost) results in less increase in in-stream flow than the first \$X?” To answer these questions, follow the same steps as for the sensitivity analysis. For the in-stream flow example, increase the minimum in-stream flow requirement with each run and record the results. Then, examine the effect of this increase on the combination of management practices that are suggested and the total costs and revenues. A trade-off curve may be created by plotting total cost versus percent of in-stream flow requirement to create a visual understanding of the trade-off and results. An example of the process is shown in the case study of Danvers and Middleton, MA.

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<sup>59</sup> <https://www.epa.gov/modeling/sensitivity-and-uncertainty-analyses-training-module>

## 7. References for Watershed Simulation Models Incorporated into WMOST Hydrology and Loadings Databases

- AQUA TERRA Consultants, and HydroQual, Inc. 2001. Modeling Nutrient Loads to Long Island Sound from Connecticut Watersheds, and Impacts of Future Buildout and Management Scenarios. Prepared for CT Department of Environmental Protection. Hartford, CT. 138 pg, plus CD.
- Barbaro, J.R. 2007. Simulation of the Effects of Water Withdrawals, Wastewater-return Flows, and Land-use Change on Streamflow in the Blackstone River Basin, Massachusetts and Rhode Island: U.S. Geological Survey Scientific Investigations Report 2007–5183, 98 p.
- Barbaro, J.R., and Sorenson, J.R. 2013. Nutrient and Sediment Concentrations, Yields, and Loads in Impaired Streams and Rivers in the Taunton River Basin, Massachusetts, 1997–2008: U.S. Geological Survey Scientific Investigations Report 2012–5277, 89 p., available at <http://pubs.usgs.gov/sir/2012/5277/>.
- Barbaro, J.R., and Zarriello, P.J. 2006. A Precipitation-runoff Model for the Blackstone River Basin, Massachusetts and Rhode Island: U.S. Geological Survey Scientific Investigations Report 2006–5213, 85 p.
- Bent, G.C., Zarriello, P.J., Granato, G.E., Masterson, J.P., Walter, D.A., Waite, A.M., and Church, P.E. 2011. Simulated Effects of Water Withdrawals and Land-use Changes on Streamflows and Groundwater Levels in the Pawcatuck River Basin, Southwestern Rhode Island and Southeastern Connecticut: U.S. Geological Survey Scientific Investigations Report 2009–5127, 254 p., available at <http://pubs.usgs.gov/sir/2009/5127>.
- Charles River Watershed Association and Numeric Environmental Services. 2011. Total Maximum Daily Load for Nutrients in the Upper/Middle Charles River, Massachusetts. Massachusetts Department of Environmental Protection, Division of Watershed Management, Worcester, MA. Report Number MA-CN 272.0.
- Donigian, Jr., A.S., and J.T. Love. 2002. The Connecticut Watershed Model - Tool for BMP Impact Assessment in Connecticut. Presented at WEF-Watershed 2002, February 23-27, 2002. Ft. Lauderdale, FL.
- U.S. EPA. 2013. Watershed Modeling to Assess the Sensitivity of Streamflow, Nutrient, and Sediment Loads to Potential Climate Change and Urban Development in 20 U.S. Watersheds (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-12/058F, 2013.
- U.S. EPA. 2017. Opti-Tool Version 2. U.S. Environmental Protection Agency, Region 1, 2017.
- Zarriello, P.J. and K.G. Ries, III. 2000. A Precipitation-Runoff Model for Analysis of the Effects of Water Withdrawals on Streamflow, Ipswich River Basin, Massachusetts. U.S. Geological Survey Water Resources Investigations Report 00-4029.
- Zarriello, P.J., Parker, G.W., Armstrong, D.S., and Carlson, C.S. 2010. Effects of Water Use and Land-use on Streamflow and Aquatic Habitat in the Sudbury and Assabet River Basins, Massachusetts. U.S. Geological Survey Scientific Investigations Report 2010–5042, 160 p.

## 8. User Guide References

- American Rivers. 2010. Putting Green to Work: Economic Recovery Investments for Clean and Reliable Water. American Rivers, Washington, D.C.
- American Water Resources Association (AWRA). 2012. Case Studies in Integrated Water Resources Management: From Local Stewardship to National Vision. American Water Resources Association Policy Committee, Middleburg, VA.
- Bonami, P., Biegler, L.T., Conn, A.R., Cornuejols, G., Grossman, I.E., Laird, C.D., Lee, J., Lodi, A., Margot, F., and Waechter, A. 2008. An Algorithmic Framework for Convex Mixed Integer Nonlinear Programs. *Discrete Optimization* 5(2), 186–204.
- Czyzyk, J., Mesnier, M.P., and Moré, J.J. 1998. The NEOS Server. *IEEE Journal on Computational Science and Engineering* 5(3), 68–75.
- Dolan, E. 2001. The NEOS Server 4.0 Administrative Guide. Technical Memorandum ANL/MCS-TM-250, Mathematics and Computer Science Division, Argonne National Laboratory.
- Gropp, W. and Moré, J.J. 1997. Optimization Environments and the NEOS Server. Approximation Theory and Optimization, M.D. Buhmann and A. Iserles, eds., Cambridge University Press, p 167–182.
- King County Department of Natural Resources and Parks. 2011. Comprehensive Combined Sewer Overflow Control Program Review: Cost Estimating Methodology for CSO Control Facilities. Water Treatment Division, Technical Memorandum 620.
- MA EAA. 2012. Massachusetts Sustainable Water Management Initiative Framework Summary (December 21, 2015); <http://www.mass.gov/eea/agencies/massdep/water/watersheds/sustainable-water-management-initiative-swmi.html>.
- Maurer, E.P., G.M. O'Donnell, D.P. Lettenmaier, and J.O. Roads, 2001: Evaluation of the Land Surface Water Budget in NCEP/NCAR and NCEP/DOE Reanalyses using an Off-line Hydrologic Model. *J. Geophys. Res.*, 106(D16), 17,841–17,862.
- NACWA, WERF, and WEF. 2013. The Water Resources Utility of the Future: A Blueprint for Action. National Association of Clean Water Agencies (NACWA), Water Environment Research Foundation (WERF) and Water Environment Federation (WEF), Washington, D.C.
- Narragansett Bay Commission. 2017. CSO Control Facilities Phase III Amended Reevaluation Report Volume 1. Prepared by MWH and Pare Corporation.
- United Nations Environmental Programme (UNEP)-DHI Centre for Water and Environment. 2009. Integrated Water Resources Management in Action. WWAP, DHI Water Policy, UNEP-DHI Centre for Water and Environment.
- United States Environmental Protection Agency (EPA). 1999. Combined Sewer Overflow Management Fact Sheet: Sewer Separation. EPA Office of Water. Report No. 832-F-99-041.
- United States Environmental Protection Agency. 2004. Reprt to Congress: Impacts and Control of CSOs and SSOs. EPA Office of Water. Report No. 833-R-04-001.
- Zoltay, V.I. 2007. Integrated watershed management modeling: Optimal decision making for natural and human components. M.S. Thesis, Tufts Univ., Medford, MA.
- Zoltay, V.I., R.M. Vogel, P.H. Kirshen, and K.S. Westphal. 2010. Integrated watershed management modeling: Generic optimization model applied to the Ipswich River Basin. *Journal of Water Resources Planning and Management*. 136:566–575.

## Appendix A – Module and Page Summary

Page Names	Associated Module
Intro	
Hydro	Baseline Hydrology and Loadings Module
Precipitation	
Runoff <sup>1</sup>	
Recharge <sup>1</sup>	
Runoff_L <sup>1</sup>	
Recharge_L <sup>1</sup>	
Land Use <sup>1</sup>	
Stormwater	
Stormwater-Data	
WQ BMPs	Water Quality Module
Riparian Buffers	
Potable Demand	
Nonpotable Demand	
Demand Mgmt	
Septic_Sewer	
Surface Water	
Groundwater	
Interbasin	
Infrastructure	
CSO	CSO Module
Flood	Flood Damage Module
Measured Data	
Results	Results Module
Adv_Results	
Calibration	Calibration Module
<sup>1</sup> These pages also apply to the Stormwater Hydrology and Loadings Module	