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WATERSHED MANAGEMENT OPTIMIZATION SUPPORT TOOL (WMOST) v2

User Guide

Office of Research and Development
National Health and Environmental Effects Research Laboratory

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User Guide

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Notice

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Abstract

The Watershed Management Optimization Support Tool (WMOST) is a decision support tool that evaluates the relative cost-effectiveness of management practices at the local or watershed scale. WMOST models the environmental effects and costs of management decisions in a watershed context, which is, accounting for the direct and indirect effects of decisions. At this time, the model considers water flows and does not consider water quality. It is spatially lumped with options for a daily or monthly modeling time step. The optimization of management options is solved using linear programming. WMOST is intended to be a screening tool used as part of 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 does require MS Office Excel, but the accompanying linear optimization program and EPA SUSTAIN tool are free of charge.) Practices that can be evaluated include projects related to stormwater (including green infrastructure [GI]), 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 State Revolving Funds (SRF). In addition, the tool can enable assessing the trade-offs and co-benefits of various practices. In WMOST v2, the Baseline Hydrology and Stormwater Hydrology modules assist users with input data acquisition and pre-processing. In addition, 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"[1]. IWRM has been promoted as an integral part of the "Water Utility of the Future"[2] 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.[3] The U.S. Environmental Protection Agency (EPA) has also endorsed the concept of IWRM, focusing on coordinated implementation of stormwater and wastewater management.[4]

Several states and river basin commissions have started to implement IWRM.[5] For example, in the arid West, both Oregon and California have incorporated integrated water resources management into their planning strategies.[6] 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.[7] WMOST has been applied in pilot projects funded by the state of Massachusetts to apply IWRM in the permit planning process.[8]

Stormwater and land use management are two aspects of IWRM which include practices such as green infrastructure (GI, both natural GI and constructed stormwater BMPs), low-impact development (LID) and land conservation. In recent years, the EPA SRF funding guidelines have been broadened to include support for green infrastructure at local scales–e.g., stormwater best management practices (BMPs) to reduce runoff and increase infiltration–and watershed scales–e.g., conservation planning for source water protection. Despite this development, few applicants

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1 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.

2 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.

3 http://www.awra.org/policy/policy-statements--water-vision.html, January 22, 2011.

4 Nancy Stoner memo: www3.epa.gov/npdes/pubs/memointegratedmunicipalplans.pdf, October 27, 2011.

5 AWRA. 2012. Case Studies in Integrated Water Resources Management: From Local Stewardship to National Vision. American Water Resources Association Policy Committee, Middleburg, VA.

6 http://www.oregon.gov/owrd/pages/law/integrated_water_supply_strategy.aspx, http://www.water.ca.gov/irwm/, accessed November 2015.

7 MA EAA. 2012. Massachusetts Sustainable Water Management Initiative Framework Summary (November 28, 2012); http://www.mass.gov/eea/agencies/massdep/water/watersheds/sustainable-water-management-initiative-swmi.html

8 See examples at http://www.abtassociates.com/wma.

have taken advantage of these opportunities to try nontraditional approaches to water quality improvement.[9] 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.[10]

Beginning with the American Recovery and Reinvestment Act (ARRA) and continued with 2010 Appropriations language, Congress mandated a 20% set-aside of SRF funding for a “Green Project Reserve (GPR)”, which includes green infrastructure and land conservation measures as eligible projects in meeting water quality goals. The utilization of the GPR for green infrastructure projects has been relatively limited, and responses have varied widely across states. According to a survey of 19 state allocations of Green Project Reserve funds, only 18% of funds were dedicated to green infrastructure projects, and none of these projects were categorized as conservation planning to promote source water protection.[8] The state of Virginia passed regulations banning the use of ARRA funds for green infrastructure projects until wastewater treatment projects had been funded.[8] In New England, states exceeded the 20% GPR mandate and used 30% of their ARRA funds for the GPR but directed most of the funds (76%) to energy efficiency and renewables; other uses of ARRA funds included 12% for water efficiency, 9% for green infrastructure, and 3% for environmentally innovative projects.

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 Version 1 of the Watershed Management Optimization Support Tool (WMOST). Version 2 of WMOST has been developed with support from a RARE grant to EPA Region 1 and ORD collaborators, supplemented with funding from US EPA ORD’s Green Infrastructure Initiative research program. Enhancements to WMOST included in Version 2 include Baseline Hydrology and Stormwater Hydrology modules to facilitate populating WMOST with the necessary hydrologic input data pre- and post- stormwater BMP implementation and a Flood Damage module to allow inclusion of flood-related costs into the optimization analysis. The need to quantify the potential role of green infrastructure in flood reduction was identified as a high priority by EPA Region 1 in their call for RARE project proposals. The need to simplify and facilitate data entry requirements for WMOST was identified by stakeholders following presentations on WMOST v1.

WMOST is based on a recent 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.[11] This model includes evaluation of

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[9] American Rivers. 2010. Putting Green to Work: Economic Recovery Investments for Clean and Reliable Water. American Rivers, Washington, D.C

[10] http://www.crwa.org/blue.html, http://v3.mmsd.com/greenseamsvideo1.aspx

[11] 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.

conservation options for source water protection and infiltration of stormwater on forest lands, green infrastructure stormwater BMPs to increase infiltration, and other water-related management options. The current version of WMOST focuses on management options for water quantity endpoints. Additional functionality to address water quality issues is one of the high priority enhancements identified for future versions.

Development of each version of the WMOST tool was overseen by an EPA Planning Team. Priorities for update and refinement of the original model[11] were established following review by a Technical Advisory Group comprised of water resource managers and modelers. Case studies for two communities were developed to illustrate the application of IWRM using WMOST. These case studies (Upper Ipswich River, and Danvers/Middleton, MA) are available from the WMOST website. 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 Technical Advisory Group (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 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.

Acknowledgements

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[12] Versions 1 and 2

[13] Version 1

[14] Version 2

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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 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).

WMOST identifies the least-cost combination of management practices to meet the user specified management goals. Management goals may include meeting projected water supply demand, minimum and maximum in-stream flow targets, and reducing damages associated with flooding. The tool considers a range of management practices related to water supply, wastewater, nonpotable water reuse, aquifer storage and recharge, 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.

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. For example, results may demonstrate the potential cost-savings of coordinating or integrating the management of water supply, wastewater and stormwater. In addition, the tool may facilitate the evaluation of LID and green infrastructure as alternative or complementary management options in projects proposed for State Revolving Funds (SRF). As of October 2010, SRF Sustainability Policy calls for integrated planning in the use of SRF resources as a means of improving the sustainability of infrastructure projects and the communities they serve. In addition, Congress mandated a 20% set-aside of SRF funding for a “Green Project Reserve” which includes green infrastructure and land conservation measures as eligible projects in meeting water quality goals.

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 versions 1 and 2 is shown in Figure 1. The figure shows the *possible* watershed system components and *potential* water flows among them.

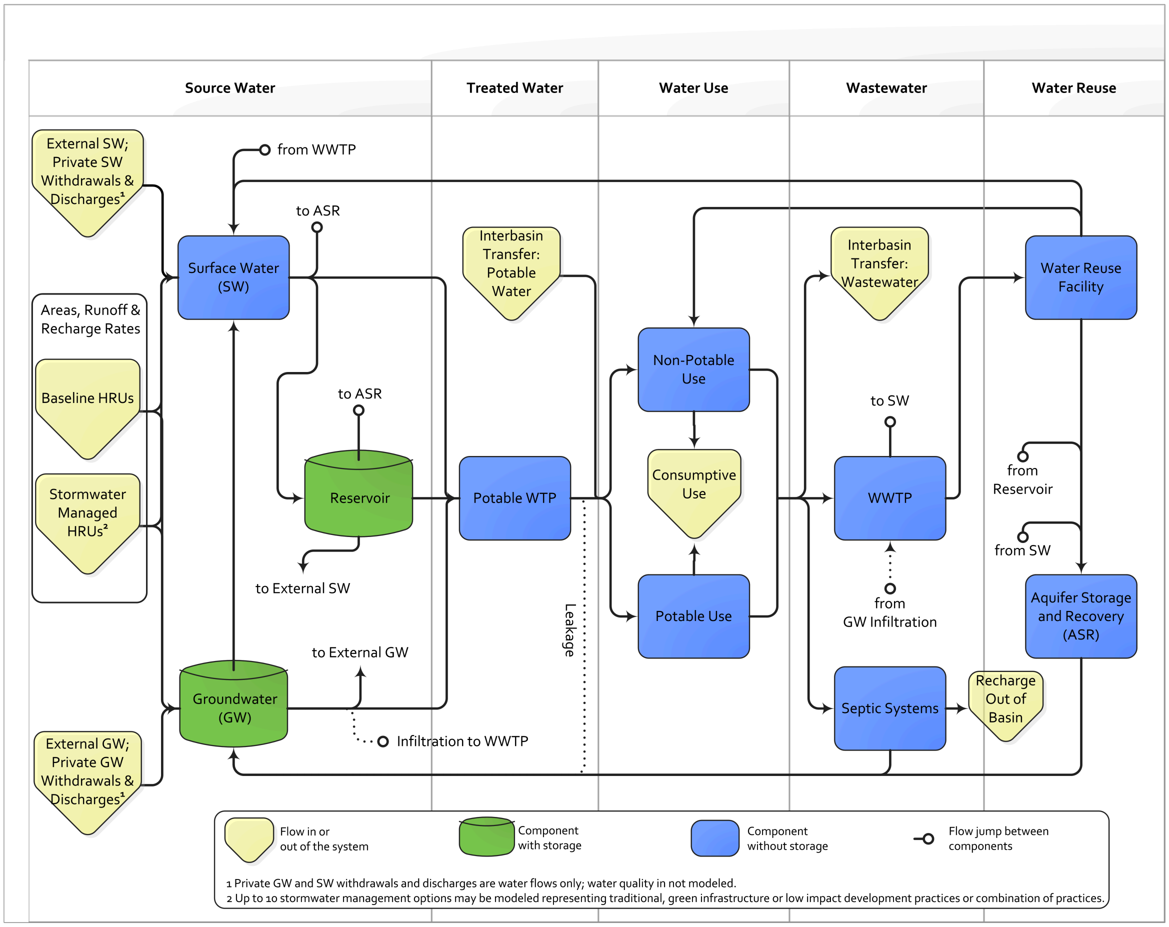


Figure 1. Schematic of Potential Water Flows in the WMOST. SW = surface water, GW = groundwater, HRU = hydrologic response unit, WTP = water treatment plant, WWTP = wastewater treatment plant, ASR = aquifer storage and recharge

The principal characteristics of WMOST include:

- Implementation in Microsoft Excel 2010© which is linked seamlessly with Visual Basic for Applications (VBA) and a free, linear programming (LP) optimization solver, 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 Lp solve 5.5, a LP optimization solver, to determine the least-cost combination of practices that achieves the user-specified management goals (See *Section 3* in the Theoretical Documentation report for WMOST for details on Lp solve 5.5, LP optimization, and the software configuration);
- Spatially lumped calculations modeling one basin and one reach but with flexibility in the number of hydrologic response units (HRUs),[15] 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;[16]
- 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 or LID practices;
- A sustainability constraint that forces the groundwater and reservoir volumes at the start and end of the modeling period to be equal;
- Enforcement of physical constraints, such as the conservation of mass (i.e., water), within the watershed; and
- Consideration of water flows only (i.e., no water quality modeling yet).

The rest of this document is organized as follows. *Section* 2 provides considerations in model definition and setup and directions for computer and software preparation. *Section* 3 leads the user through model setup with screenshots as well as the steps for performing and trade-off analyses. *Section 4* provides directions for performing flood damage modeling to derive input data for the Flood Damage module. *Section 5* summarizes tips for the user in performing model runs and analyzing results, including conduct of sensitivity analyses. A case study for Halifax, MA, is described in Appendix A, with input data sources listed in Appendix B.

[15] 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.

[16] While the number of HRUs and modeling period are not limited, solution times are significantly affected by these model specifications.

A *separate* Theoretical Documentation report provides a detailed description of WMOST including a mathematical description and the 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.

Table 1-1. Summary of Management Goals and Management Practices[17].
MGD = million gallons per day

Management Practice	Action[18]	Model Component Affected	Impact
Land conservation	Increase area of land use type specified as 'conservable'	Land area allocation	Preserve runoff & recharge quantity & quality
Stormwater management via traditional, 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, treatment
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
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 maximum treatment capacity	Potable water treatment plant	Treatment to standards, meet potable human demand
Leak repair in potable distribution system	Decrease % of leaks	Potable water treatment plant and associated distribution system	Reduce demand for water quantity
Wastewater treatment capacity	Increase MGD	Wastewater treatment plant	Maintain water quality of receiving water (or improve if sewer overflow events)
Infiltration repair in wastewater collection system	Decrease % of leaks	Wastewater treatment plant and associated distribution system	Reduce demand for wastewater treatment capacity

[17] 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.

[18] Please refer to the separate Theoretical Documentation for the specific effect of each management practice.

Table 1-1 (continued)

Management Practice	Action[19]	Model Component Affected	Impact
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
Minimum human water demand	MGD	Groundwater and surface water pumping and/or interbasin transfer	Meet human water needs
Minimum in-stream flow	ft^3/sec	Surface water	Meet in-stream flow standards, improve ecosystem health and services, improve recreational opportunities
Maximum in-stream flow	ft^3/sec	Surface water	Meet in-stream flow standards, improve ecosystem health and services by reducing scouring, channel and habitat degradation, and decrease loss of public and private assets due to flooding

[19] 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 of the envisioned applications 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 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 and suggestions are provided throughout the User Guide and in the case studies[20] for how to specify input data appropriately. As such, the model does not provide an annual implementation plan or specifics on operations of systems. Rather it provides the management practices and associated costs that meet management goals at least cost and the state of the watershed and human system at the end of the planning period if the management practices have been implemented.

2.1 Preparing for a Model Run

This section describes model specifications the user must consider prior to applying WMOST v2. Data sources used in the case studies are detailed in their respective appendices. Some of those data sources, especially for environmental data, are state or national level and may serve as a source for your project. Most data related to the human water system is anticipated to be available to the municipality (ies) from their own internal sources.

Defining Hydrologic Response Units

A main input data requirement is time series of both runoff and recharge rates (RRR) for hydrologic response units (HRUs)[21] in the study area and the corresponding area for each HRU. The time series are not volumetric but rates that must be input as depth per unit area (e.g., inches per day). The Baseline Hydrology module in WMOST v2 assists users in obtaining and pre-processing the time series data. If watersheds in the hydrology runoff and recharge time series databases are not similar to the study area's watershed, the user may derive these data from a calibrated/validated simulation model such as Hydrological Simulation Program Fortran (HSPF)[22], Soil Water and Assessment Tool (SWAT)[23]) and/or Storm Water Management Model(SWMM)[24]. Several post-processors such as GenScn and WDMutil in EPA BASINS[25] are available to facilitate extraction of hydrology time series from HSPF model output

[20] Case study documents are available on the WMOST website.

[21] 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.

[22] http://water.usgs.gov/software/HSPF/

[23] http://swat.tamu.edu/

[24] http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/

[25] http://water.epa.gov/scitech/datait/models/basins/framework.cfm#tools

WDM files. SWAT model output files are in ASCII format so should not require conversion prior to input. 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 available from state or regional studies. Such 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.

In addition to a baseline set of HRUs, up to ten "sets" of "managed" HRUs may be specified with corresponding areas, RRRs 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 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 may be used to represent any change in land use or land 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. 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 v2, 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 may be derived using SWMM or other stormwater management models outside of WMOST then manually input to WMOST. For agricultural HRUs, the "managed set" may reflect RRRs resulting from implementation of edge of site or riparian buffers.

For each set, you can specify the area of each HRU on which the management practice may be implemented. Therefore, for the stormwater managed set, you may restrict available area to urban HRUs only. In addition, if stormwater management exists in part of the watershed, urban 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, urban HRUs and excluded for managed, urban 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 is modeled at the subbasin or watershed level[26] while management practices are limited to those areas within the

[26] In cases where groundwater flows cross the watershed divide, the user can specify groundwater imports and exports beyond the watershed boundary.

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 Ipswich 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[27].

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 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, 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, time series that are input (e.g., RRRs, 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. This may be accomplished, for example, by adjusting historical conditions for projected climate change. The EPA website “Climate Change Impacts and Adapting to Change” describes projected changes by region[28]. EPA’s Climate Resilience Evaluation and Awareness Tool provides projected changes in temperature and precipitation for climate stations throughout the United States[29]. These values may be used to adjust the detailed watershed simulation model from which watershed time series data is obtained for WMOST (e.g., see Soil and Water Assessment Tool climate change function) and to adjust the traditional methodology used for projecting human demand. The next version of WMOST will provide a library of time series based on down-scaled climate projections for specific models.

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**

[27] 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 an input into the downstream study area. WMOST v2 does not output this time series in table form (only as a graph) but this functionality is listed for future development. In addition, 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.

[28] http://www.epa.gov/climatechange/impacts-adaptation/

[29] http://water.epa.gov/infrastructure/watersecurity/climate/creat.cfm

data with least certainty to determine the robustness of the solution. *Section 5* briefly describes the process for performing sensitivity analyses.

Performing a Simulation Run for Validation

A simulation run is advised before optimization runs to determine the accuracy of WMOST and the input data in reproducing streamflow. 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 different from an optimization setup which is described in the rest of this document. The case study of Danvers and Middleton, MA, in the User Guide for Version 1 and the case study for Halifax, MA, in Appendix A to this volume describe the process for performing a "simulation" run. The "simulated" streamflow may be compared to measured data or modeled data from the detailed watershed simulation model.

2.2 System Requirements

To open and run WMOST, you will need Microsoft Excel version 2010 installed on your computer. The WMOST Excel file and the file for the solver, *lpsolve55.dll*, must be placed in the same folder. After opening WMOST, choose 'Enable content' or 'Enable macros' if these prompts are displayed.

To run the Baseline Hydrology module of WMOST, you will need to download the WMOST support files. (If you have data from a calibrated/validated model already, these data can be used without relying on the support files supplied.) The SupportFiles folder should be placed in the same directory as the WMOST spreadsheet and solver files. The support files include: 1) WatershedInfo.xlsm with a map of the available watersheds and metadata on each of the watersheds, 2) time series database (e.g., Taunton_Timeseries.csv), and 3) HRU characteristics database (e.g., Taunton_Characteristics.csv). You will only need to download the two database files for the watershed that overlaps with or is most similar to your study area with respect to land-use/soil type combinations and climate.

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[30]. SUSTAIN is available in two versions: non-GIS and ArcGIS 9.3. Both versions are compatible with the Stormwater Hydrology module. To prevent errors, do not move SUSTAIN files automatically created during installation from their default location.

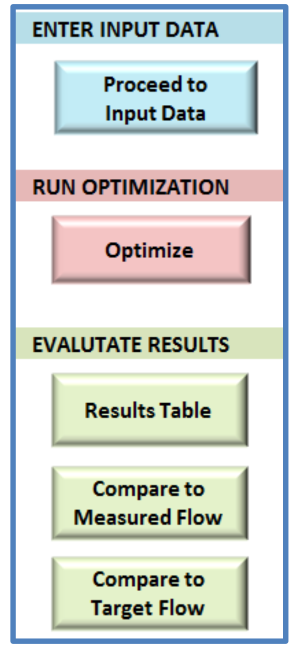
When using WMOST, you may save various versions that are set up for different scenarios. You cannot run multiple scenarios at the same time from the same folder. However, you may save a different scenario along with the *lpsolve55.dll* file in a different folder in order to run multiple scenarios at once. Depending on your computer's specifications, this may increase the run time for each model. 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.

[30] http://www2.epa.gov/water-research/system-urban-stormwater-treatment-and-analysis-integration-sustain

If other Excel files are open while running WMOST, the Results table will have the correct values but may not be formatted properly. Therefore, it is recommended that you do not have other Excel files open and run model scenarios one at a time.

Finally, if you encounter software errors, please email Naomi Detenbeck at 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”.

3. Model Setup and Runs



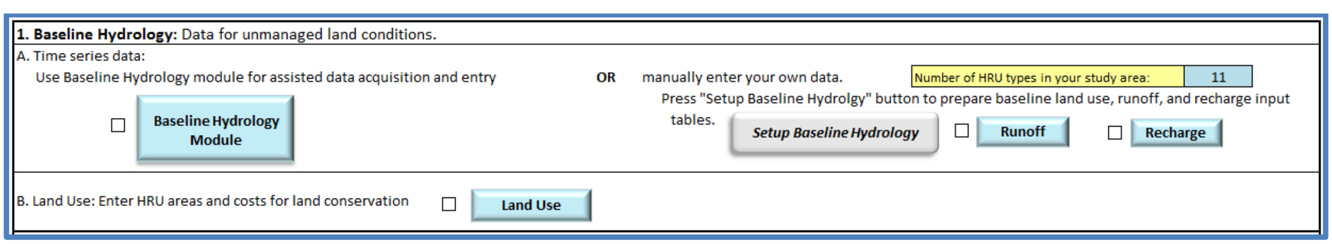
When you open WMOST you will see the familiar Excel interface with one worksheet active called "Intro". On the introduction page, you can navigate to input data page using the blue button, run the optimization tool using the red button, and view the result table and figures using the green buttons found on this screen. To begin entering data for your study area, navigate to "Input" page and use the blue buttons to complete all the input tables linked to this worksheet. In general, input fields requiring selection or date input are shaded in blue.

Please note that example screenshots and values displayed in them are from the Danvers-Middleton 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, 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. *Section 10.1* in the Theoretical Documentation provides additional details on input data checks and user support.

3.1

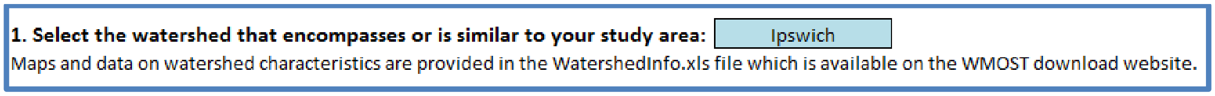
Step 1. Baseline Hydrology and HRU Areas

HRUs are areas of similar hydrology based on similarity of characteristics such as land use, soil and/or slope. The number of HRUs will likely be determined by the diversity of these land characteristics in your study area and your source of runoff and recharge rates. For example, a detailed simulation model that may be available for your study area may have predefined HRUs. For part 1A, use the Baseline Hydrology Module button to get assistance inputting hydrology data or manually enter the data using the buttons on the right half of the box for part 1A.

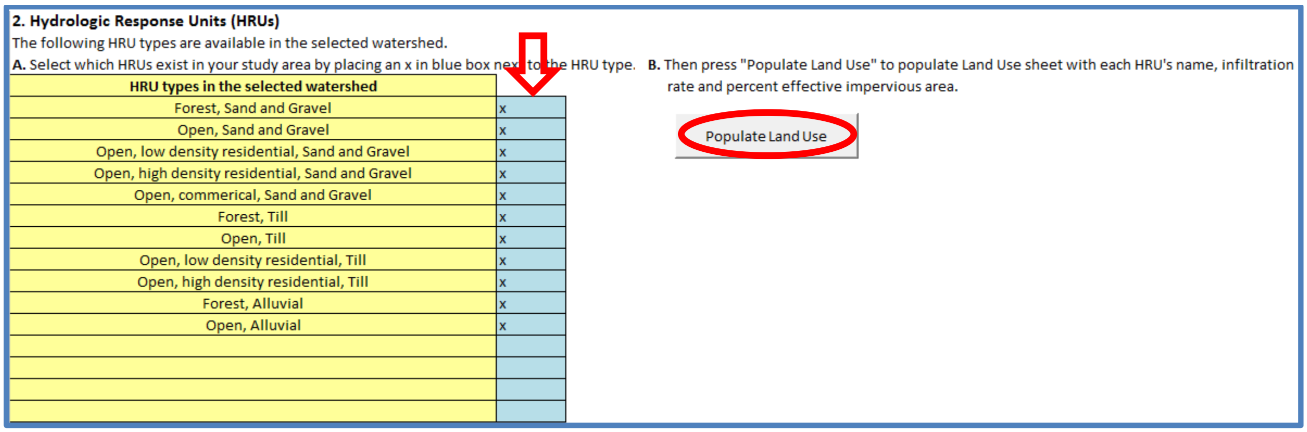


Step 1A Assisted – Baseline Hydrology Module

Five steps comprise the Baseline Hydrology Module. First, select one of the six watersheds[31] from the drop-down menu that is most hydrologically similar to your study area. The Watershed Info file provides data on each of the watersheds to help you compare them to your study area.



Once you select the watershed, the table in part 2 will automatically populate the HRUs 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 HRU names. You will need to use a GIS to calculate the area of each land-use/soil type combination for your subwatershed of interest. Then, press *Populate Land Use* to automatically set up appropriately sized input tables (i.e., Baseline Land Use table and Baseline Runoff and Recharge tables on “Land Use”, “Runoff”, and “Recharge”).

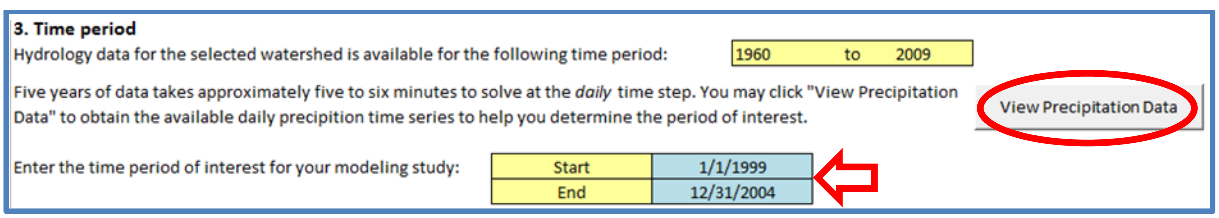


Once the table setups are complete, you will be taken to the “Land Use” page showing the percent effective impervious area and infiltration rate for each HRU. These values were automatically populated based on the selected watershed model. Review the value for these HRU characteristics to make sure that 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, only HRUs with non-zero EIA will be utilized in the module to create stormwater-managed hydrology time series. However, you can edit any Percent Effective Impervious value in the HRU series to be a minimal amount of impervious area (e.g., 0.001%) so that the desired zero EIA HRU is modeled in the Stormwater Hydrology Module.

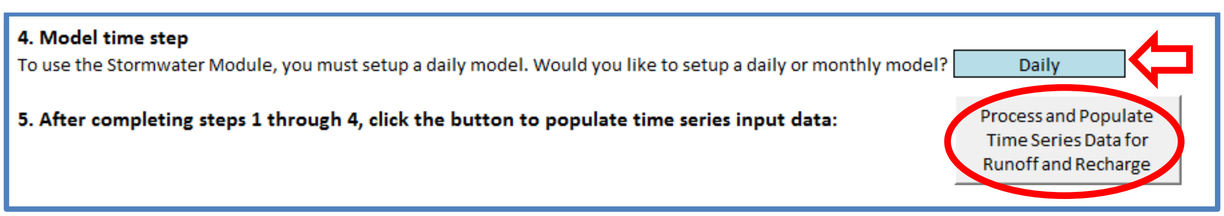
[31] HSPF model development for each of these watersheds is described in the reports listed in Section 6 References.

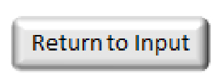
Baseline HRU Characteristics				
HRU ID	*HRU Name	Baseline Area [acre]	*Percent Effective Impervious	*Infiltration Rate [in/hr]
HRU1B	Forest, Sand and Gravel		0.0%	0.572
HRU2B	Open, Sand and Gravel		0.0%	0.574
HRU3B	Open, low density residential, Sand and Gravel		2.5%	0.484
HRU4B	Open, high density residential, Sand and Gravel		13.7%	0.424
HRU5B	Open, commerical, Sand and Gravel		63.4%	0.16
HRU6B	Forest, Till		0.0%	0.076
HRU7B	Open, Till		0.0%	0.076
HRU8B	Open, low density residential, Till		2.5%	0.056
HRU9B	Open, high density residential, Till		13.7%	0.044
HRU10B	Forest, Alluvial		0.0%	0.19
HRU11B	Open, Alluvial		0.0%	0.184

Next, return to the "Baseline Hydrology Module" and continue with part 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. This may help in selecting wet, dry or average precipitation time periods. Five years of daily modeling takes approximately six minutes to optimize. We do not recommend longer time periods but rather suggest running scenarios with five-year periods of wet, dry and average conditions. Enter the desired start and end of the modeling time period in the appropriate blue input boxes.

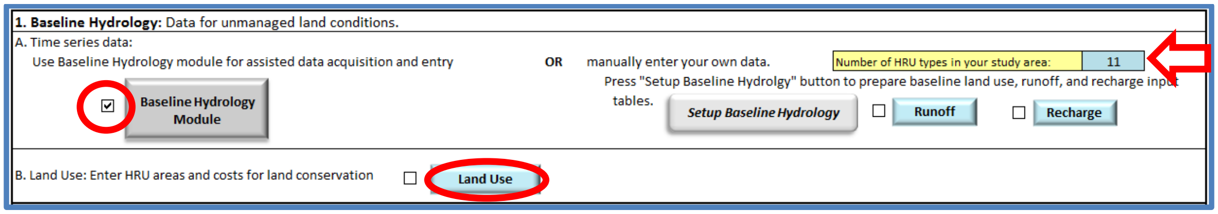


In part 4, use the drop-down box to indicate whether you will run a daily or a monthly model. If you intend to use the Stormwater Hydrology Module or include flood damage costs in modeling, you must run a daily model. Finally, in part 5, press *Process and Populate Time Series Data for Runoff and Recharge* to pre-process and populate the runoff and recharge data for your study area.





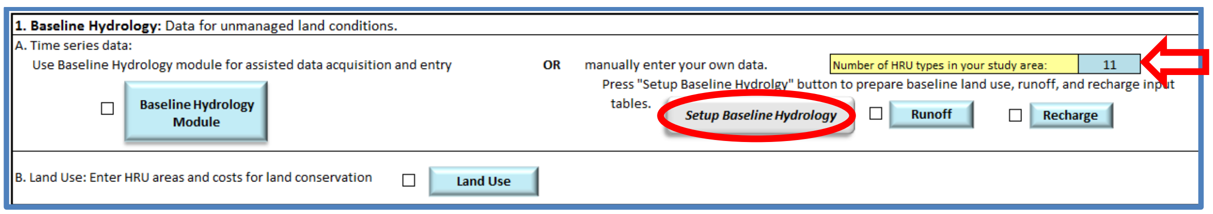
Once the processing is complete, you can view the baseline runoff and recharge time series on "Runoff" and "Recharge" pages. Navigate back to input data worksheet using the *Return to Input* button. Enter the number of HRUs you modeled with the *Baseline Hydrology Module* into the blue box. Check the box next to *Baseline Hydrology Module* to indicate that the data input is complete. This will help track all completed input pages. Continue with data entry and model setup under Step 1B.



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 press the *Setup Baseline Hydrology* 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.*

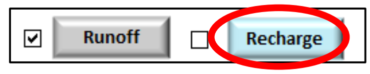


Next, select the *Runoff* button to navigate to the input table and enter time series data of runoff rate for each HRU for the modeling time period. The runoff rate must be input per unit time (e.g., inches per day). Values can be cut and pasted from another file or imported using Data – (Get External Data) From Text options in Excel to add contents of a comma-delimited file.

	Units: inches/time step										
Date	Baseline HRU Set										
(mm/dd/yyyy)	HRU1	HRU2	HRU3	HRU4	HRU5	HRU6	HRU7	HRU8	HRU9	HRU10	HRU11
1/1/1989	7.62E-06	1.39E-03	6.54E-05	8.05E-05	2.91E-03	1.78E-03	1.19E-02	7.29E-03	9.47E-03	1.43E-04	4.26E-03
1/2/1989	6.86E-06	1.25E-03	5.76E-05	6.93E-05	2.38E-03	1.60E-03	1.07E-02	6.42E-03	8.15E-03	1.28E-04	3.83E-03
1/3/1989	6.19E-06	1.13E-03	5.07E-05	5.96E-05	1.95E-03	1.44E-03	9.65E-03	5.65E-03	7.01E-03	1.15E-04	3.45E-03
1/4/1989	5.58E-06	1.02E-03	4.47E-05	5.12E-05	1.60E-03	1.29E-03	8.68E-03	4.97E-03	6.03E-03	1.04E-04	3.10E-03
1/5/1989	5.04E-06	9.15E-04	3.93E-05	4.41E-05	1.31E-03	1.16E-03	7.81E-03	4.37E-03	5.18E-03	9.35E-05	2.79E-03
1/6/1989	4.54E-06	8.23E-04	3.46E-05	3.80E-05	1.08E-03	1.05E-03	7.03E-03	3.85E-03	4.46E-03	8.42E-05	2.51E-03
1/7/1989	4.11E-06	7.41E-04	3.05E-05	3.27E-05	8.84E-04	9.44E-04	6.35E-03	3.40E-03	3.86E-03	7.58E-05	2.26E-03
1/8/1989	3.69E-06	6.67E-04	2.68E-05	2.81E-05	7.25E-04	8.49E-04	5.72E-03	3.00E-03	3.33E-03	6.82E-05	2.04E-03
1/9/1989	3.36E-06	6.00E-04	2.36E-05	2.42E-05	5.94E-04	7.65E-04	5.15E-03	2.64E-03	2.86E-03	6.14E-05	1.84E-03
1/10/1989	3.01E-06	5.40E-04	2.08E-05	2.08E-05	4.87E-04	6.88E-04	4.63E-03	2.32E-03	2.46E-03	5.53E-05	1.65E-03
1/11/1989	2.73E-06	4.86E-04	1.83E-05	1.79E-05	4.00E-04	6.19E-04	4.17E-03	2.04E-03	2.12E-03	4.98E-05	1.49E-03

This table requires a time series of runoff rates for baseline and 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. The dates entered on sheet will populate the dates in all other input tables that require 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 discussion about data sources for runoff and recharge rates.

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.



Date (mm/dd/yyyy)	Baseline HRU Set (HRU) HRU1	HRU2	HRU3	HRU4	HRU5	HRU6	HRU7	HRU8	HRU9	HRU10	HRU11
1/1/1989	2.2E-02	5.2E-02	3.4E-02	3.4E-02	3.2E-02	1.2E-02	2.8E-02	2.1E-02	1.9E-02	1.6E-02	3.8E-02
1/2/1989	2.2E-02	5.1E-02	3.4E-02	3.3E-02	3.1E-02	1.2E-02	2.8E-02	2.0E-02	1.8E-02	1.5E-02	3.6E-02
1/3/1989	2.2E-02	5.0E-02	3.3E-02	3.2E-02	3.0E-02	1.2E-02	2.7E-02	2.0E-02	1.8E-02	1.5E-02	3.5E-02
1/4/1989	2.1E-02	4.9E-02	3.2E-02	3.1E-02	2.9E-02	1.2E-02	2.7E-02	1.9E-02	1.8E-02	1.5E-02	3.4E-02
1/5/1989	2.1E-02	4.8E-02	3.1E-02	3.0E-02	2.8E-02	1.2E-02	2.6E-02	1.9E-02	1.7E-02	1.4E-02	3.3E-02
1/6/1989	2.1E-02	4.7E-02	3.1E-02	3.0E-02	2.7E-02	1.1E-02	2.6E-02	1.9E-02	1.7E-02	1.4E-02	3.2E-02
1/7/1989	2.1E-02	4.6E-02	3.0E-02	2.9E-02	2.6E-02	1.1E-02	2.5E-02	1.8E-02	1.7E-02	1.4E-02	3.1E-02
1/8/1989	2.1E-02	4.5E-02	3.0E-02	2.8E-02	2.6E-02	1.1E-02	2.5E-02	1.8E-02	1.6E-02	1.4E-02	3.1E-02
1/9/1989	2.0E-02	4.5E-02	2.9E-02	2.8E-02	2.5E-02	1.1E-02	2.5E-02	1.8E-02	1.6E-02	1.3E-02	3.0E-02
1/10/1989	2.0E-02	4.4E-02	2.9E-02	2.7E-02	2.4E-02	1.1E-02	2.4E-02	1.7E-02	1.6E-02	1.3E-02	2.9E-02
1/11/1989	2.0E-02	4.3E-02	2.8E-02	2.7E-02	2.3E-02	1.1E-02	2.3E-02	1.7E-02	1.5E-02	1.3E-02	2.8E-02

Similar to the runoff input table, the recharge input table also requires a time series of recharge rates for baseline and land use at the daily or monthly time step. Similarly, it should be consecutive and complete. Select *Return to Input* and check the "Recharge" box. This completes Step 1A manual entry. Continue to Step 1B.

Step 1B – Land Use and Its Management

Select *Land Use* button to navigate to the *Land Use and Its Management page*. On this page you must enter HRU areas for baseline conditions and may enter information for considering land conservation as a management practice. The Baseline HRU Characteristics part of the 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 in Step 1A, then you must enter information on the percent effective impervious area and infiltration rate for each HRU.

Baseline HRU Characteristics				
HRU ID	*HRU Name	Baseline Area [acre]	*Percent Effective Impervious	*Infiltration Rate [in/hr]
HRU1B	Forest, Sand and Gravel	1,681	0.0%	0.572
HRU2B	Open, Sand and Gravel	437	0.0%	0.574
HRU3B	Open, low density residential, Sand and Gravel	3,099	2.5%	0.484
HRU4B	Open, high density residential, Sand and Gravel	1,274	13.7%	0.424
HRU5B	Open, commerical, Sand and Gravel	1,255	63.4%	0.16
HRU6B	Forest, Till	6,660	0.0%	0.076
HRU7B	Open, Till	519	0.0%	0.076
HRU8B	Open, low density residential, Till	7,005	2.5%	0.056
HRU9B	Open, high density residential, Till	1,616	13.7%	0.044
HRU10B	Forest, Alluvial	110	0.0%	0.19
HRU11B	Open, Alluvial	153	0.0%	0.184

For the Land Conservation part of the table, the following examples are provided to help guide inputting appropriate values:

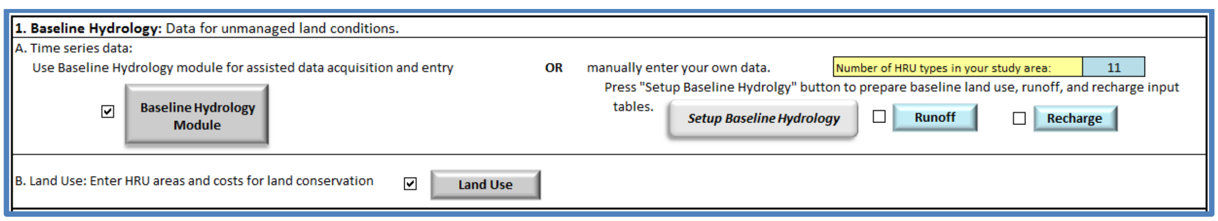
- "Minimum" areas for each HRU – For urban HRUs this may be the existing area of urban HRUs given that these areas are not expected to be reforested or otherwise be "undeveloped". For forest lands, it may be the area of conserved/protected forest lands which must exist in the future due to their protected 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 – For example, it may be 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.

Data for Land Conservation Option

Minimum Area [acre]	Maximum Area [acre]	Initial Cost to Conserve [$/acre]	O&M Cost [$/acre/yr]
1,681	2,760	187,408	1,874
437	774	187,408	1,874
3,099	3,099	-9	(9)
1,274	1,274	-9	-9
1,255	1,255	-9	-9
6,660	9,371	187,408	1,874
519	600	187,408	1,874
7,005	7,005	-9	-9
1,616	1,616	-9	-9
110	148	187,408	1,874
153	237	187,408	874

If land conservation is not possible or desirable for a HRU, then enter "-9" for initial and O&M costs. In the above screenshot example, forest land is possible to conserve at an initial cost of $187,408 per acre and $1,874 annual O&M costs.

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

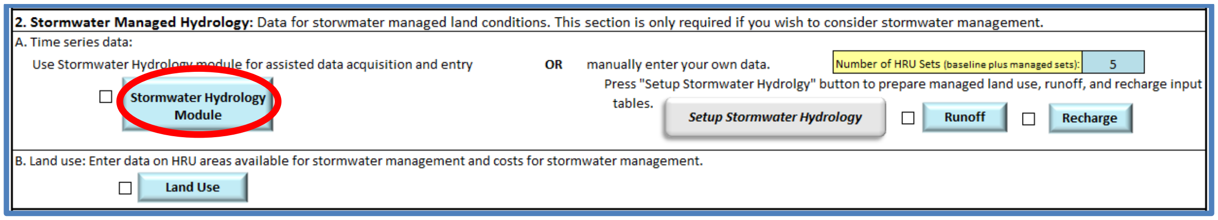


Step 2. Managed Hydrology and HRU Areas/Stormwater Management

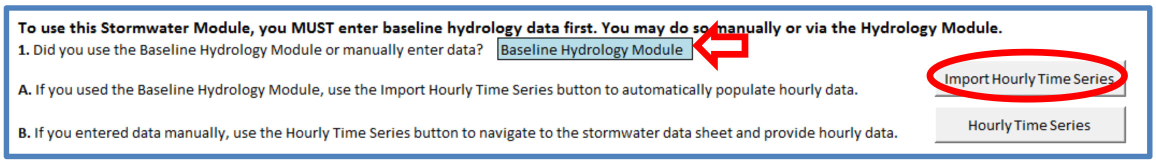
To include stormwater best management practices (BMPs) in the cost-effectiveness assessment, you must complete this step.

Step 2A Assisted – Stormwater Hydrology Module

Navigate to the Stormwater Hydrology Module to get assistance with deriving and populating stormwater management related inputs. To enter your own stormwater hydrology data, proceed to the next section – Step 2A Manual.

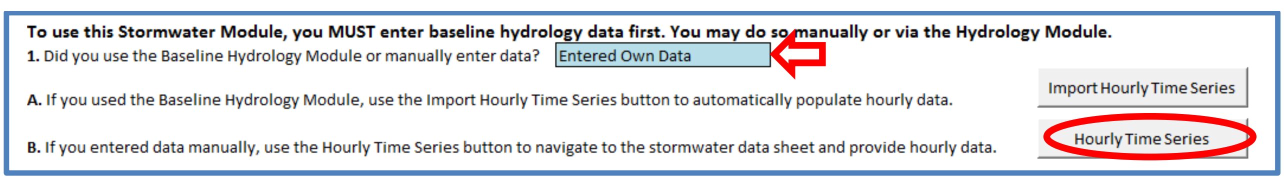


Four parts comprise the Stormwater Hydrology Module. In part 1, use the drop-down menu to indicate whether you used *Baseline Hydrology Module* or manually entered your own data. If you used Baseline Hydrology Module, choose the "Baseline Hydrology Module" and press *Import Hourly Time Series*. If you manually entered your own data, choose the "Entered Own Data" and press *Hourly Time Series* where you will be asked for additional information.

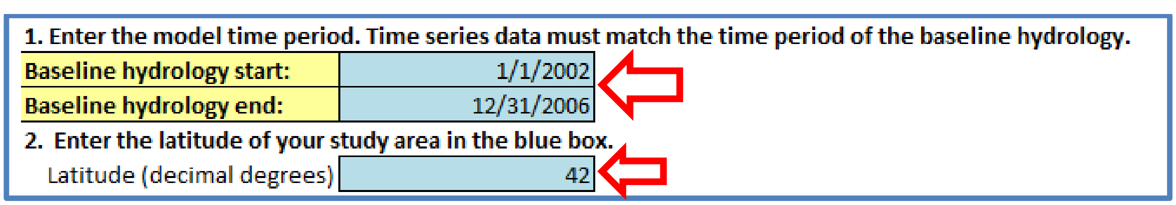


Additional Stormwater Data: Three types of additional data are required if you entered your own baseline hydrology: 1) latitude of your study area, 2) hourly temperature time series for your study area, and 3) hourly runoff time series for developed HRUs (HRUs with percent effective impervious value greater than 0). The time series data must match the modeling time period. More detailed guidance is below.

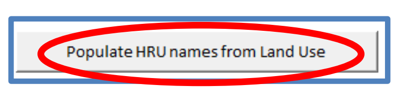
If you used Baseline Hydrology Module, the *Import Hourly Time Series* button will populate all additional stormwater data based on your model setup in Step 1. If you entered your own data in Step 1, you must provide the additional data requirements. Press *Hourly Time Series* to navigate to "Stormwater-Data" and enter the data.



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.



Next, enter the hourly temperature time series that best suits your study area and spans the entire modeling time period. 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. Finally, enter hourly runoff data for all developed HRUs. Press *Populate HRU Names from Land Use* to prepare the input table for the runoff data. This will create time series columns for all developed HRUs. The Stormwater Hydrology Module only simulates stormwater management for developed HRUs (i.e., HRUs with percent EIA=0 are ignored) so you do not need to provide hourly runoff time series for HRUs with 0 EIA.

Date/Time		Date/Time	Runoff (in/hr)							
Date/Time (dd-mm-yyyy hh)	Temperature (deg F)	(dd-mm-yyyy hh)	Open nonresidential, Sand and Gravel	Medium to low density residential, Sand and Gravel	High-density residential, Sand and Gravel	Commercial-industrial-transportation, Sand and Gravel	Open nonresidential, Till & fine-grained deposits	Medium to low density residential, Till & fine-grained	High-density residential, Till & fine-grained deposits	Commercial-industrial-transportation, Till & fine-
1/1/1989 1:00 AM	29	1/1/1989 1:00 AM	0	0	0	0	0	0	0	0
1/1/1989 2:00 AM	28	1/1/1989 2:00 AM	0	0	0	0	0	0	0	0
1/1/1989 3:00 AM	28	1/1/1989 3:00 AM	0	0	0	0	0	0	0	0
1/1/1989 4:00 AM	27	1/1/1989 4:00 AM	0	0	0	0	0	0	0	0
1/1/1989 5:00 AM	24	1/1/1989 5:00 AM	0	0	0	0	0	0	0	0
1/1/1989 6:00 AM	23	1/1/1989 6:00 AM	0	0	0	0	0	0	0	0
1/1/1989 7:00 AM	24	1/1/1989 7:00 AM	0	0	0	0	0	0	0	0
1/1/1989 8:00 AM	24	1/1/1989 8:00 AM	0	0	0	0	0	0	0	0
1/1/1989 9:00 AM	25	1/1/1989 9:00 AM	0	0	0	0	0	0	0	0
1/1/1989 10:00 AM	27	1/1/1989 10:00 AM	0	0	0	0	0	0	0	0
1/1/1989 11:00 AM	29	1/1/1989 11:00 AM	0	0	0	0	0	0	0	0
1/1/1989 12:00 PM	29	1/1/1989 12:00 PM	0	0	0	0	0	0	0	0
1/1/1989 1:00 PM	29	1/1/1989 1:00 PM	0	0	0	0	0	0	0	0
1/1/1989 2:00 PM	33	1/1/1989 2:00 PM	0	0	0	0	0	0	0	0
1/1/1989 3:00 PM	34	1/1/1989 3:00 PM	0	0	0	0	0	0	0	0
1/1/1989 4:00 PM	33	1/1/1989 4:00 PM	0	0	0	0	0	0	0	0

Use the *Return to Stormwater Hydrology Module* to navigate back. Confirm that you are using a daily timestep in part 2. If you will include flood damages in the optimization of costs, you must select to set up a daily model.

2. Model time step	You must set up a daily timestep model to use the Stormwater Module.	Daily

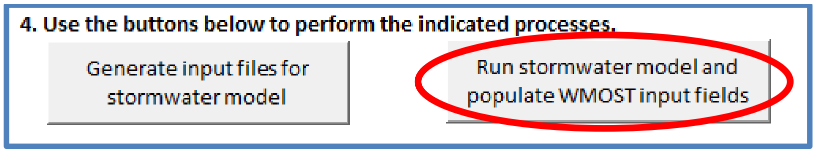
In part 3, select the stormwater BMP types and sizes that you would like to model. You can select up to 10 combinations of BMP type and runoff design depth. This limitation is imposed to ensure manageable processing time and completion. For each combination, the Stormwater Hydrology Module will calculate the appropriate BMP design parameters, run a simulation for all the developed HRUs, calculate the final "managed" runoff and recharge time series and populate the appropriate WMOST input table. In order for the Stormwater Hydrology Module to run, the WMOST file must be saved in a folder location with no spaces in the file path.

BMP Type	Design Depth For BMP (in)
Biorentention with UD	0.6
Biorentention with UD	2
Infiltration trench	0.8
Infiltration trench	1.4
Detention pond	4.5
Detention pond	6

After entering the BMP management combinations, press *Generate input files for stormwater model*. This button creates three input files for the stormwater simulation: 1) the main input file (Input.inp), 2) a climate time series file (Climate.swm), and 3) 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.

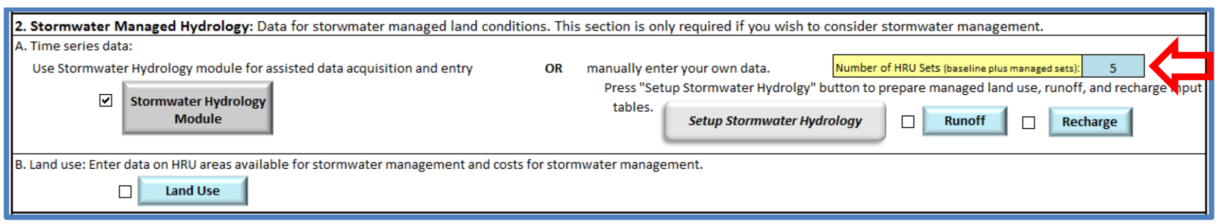
4. Use the buttons below to perform the indicated processes.	
Generate input files for stormwater model	Run stormwater model and populate WMOST input fields

The generated input files are saved to a folder titled “Input” in same location as the WMOST Excel file. Next, press *Run stormwater model and populate WMOST input fields*.



The stormwater simulation determines how much of the runoff is infiltrated or detained by a BMP and the remaining runoff due to surface discharge and/or overflow. Simulation outputs are automatically processed and the appropriate input tables for Managed HRU Sets are populated on the “Runoff” and “Recharge” pages.

Once the module completes processing, select *Return to Input* and check the box for *Stormwater Hydrology Module* to indicate that the module and data entry is complete. Enter the number of HRU sets created by the *Baseline Hydrology Module* (always one) and the *Stormwater Hydrology Module* (depends on the number of HRUs and BMP types entered onto the *Stormwater* tab. Proceed to Step 2B.

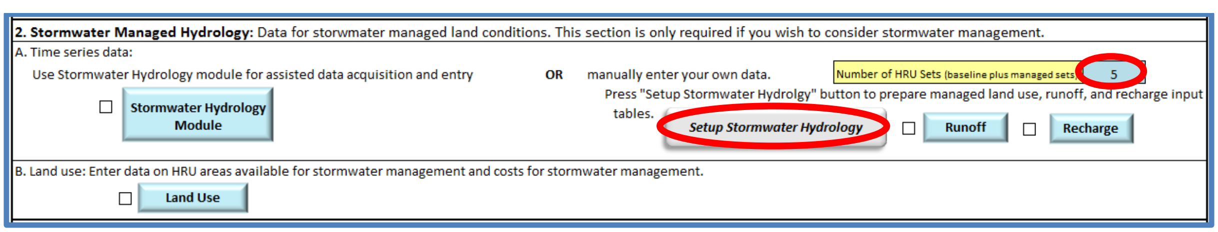


Step 2A Manual – Stormwater Hydrology

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. Each BMP setup is assessed for all developed HRUs, that is, HRUs with effective impervious areas greater than zero. The runoff and recharge time series associated with one BMP setup for all developed 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).



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.

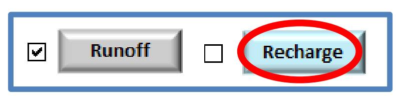
Next, select “Runoff” to navigate to the input table and enter time series data of runoff rate for each developed HRU.

Managed HRU Set (HRUM1)										
HRU1M1	HRU2M1	HRU3M1	HRU4M1	HRU5M1	HRU6M1	HRU7M1	HRU8M1	HRU9M1	HRU10M1	HRU11M1
7.62E-06	1.39E-03	6.38E-05	6.93E-05	1.07E-03	1.78E-03	1.19E-02	7.11E-03	8.15E-03	1.43E-04	4.26E-03
6.86E-06	1.25E-03	5.61E-05	5.96E-05	8.81E-04	1.60E-03	1.07E-02	6.26E-03	7.01E-03	1.28E-04	3.83E-03
6.19E-06	1.13E-03	4.94E-05	5.12E-05	7.23E-04	1.44E-03	9.65E-03	5.51E-03	6.03E-03	1.15E-04	3.45E-03
5.58E-06	1.02E-03	4.35E-05	4.41E-05	5.93E-04	1.29E-03	8.68E-03	4.85E-03	5.18E-03	1.04E-04	3.10E-03
5.04E-06	9.15E-04	3.84E-05	3.79E-05	4.86E-04	1.16E-03	7.81E-03	4.26E-03	4.46E-03	9.35E-05	2.79E-03
4.54E-06	8.23E-04	3.38E-05	3.26E-05	3.99E-04	1.05E-03	7.03E-03	3.75E-03	3.83E-03	8.42E-05	2.51E-03
4.11E-06	7.41E-04	2.97E-05	2.81E-05	3.27E-04	9.44E-04	6.35E-03	3.31E-03	3.32E-03	7.58E-05	2.26E-03
3.69E-06	6.67E-04	2.61E-05	2.42E-05	2.68E-04	8.49E-04	5.72E-03	2.92E-03	2.86E-03	6.82E-05	2.04E-03
3.36E-06	6.00E-04	2.30E-05	2.08E-05	2.20E-04	7.65E-04	5.15E-03	2.57E-03	2.46E-03	6.14E-05	1.84E-03
3.01E-06	5.40E-04	2.03E-05	1.79E-05	1.80E-04	6.88E-04	4.63E-03	2.26E-03	2.12E-03	5.53E-05	1.65E-03
2.73E-06	4.86E-04	1.79E-05	1.54E-05	1.48E-04	6.19E-04	4.17E-03	1.99E-03	1.82E-03	4.98E-05	1.49E-03

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. The dates entered on sheet will populate the dates in all other input tables that require time series. **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 discussion about data sources for runoff and recharge rates.

The time series are input vertically and HRUs and HRU sets horizontally. If an HRU is excluded from a “managed set” (i.e., HRUs without impervious areas), then the values specified for those HRUs are not consequential since the model will exclude those values. To the right of the Baseline HRU set, which was completed in Step 1, you will see the continuation of HRU columns for the managed sets.

Once you have entered these 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.



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).

Managed HRU Set (HRUM1)										
HRU1M1	HRU2M1	HRU3M1	HRU4M1	HRU5M1	HRU6M1	HRU7M1	HRU8M1	HRU9M1	HRU10M1	HRU11M1
2.2E-02	5.2E-02	3.4E-02	2.9E-02	1.2E-02	1.2E-02	2.8E-02	2.0E-02	1.6E-02	1.6E-02	3.8E-02
2.2E-02	5.1E-02	3.3E-02	2.8E-02	1.2E-02	1.2E-02	2.8E-02	2.0E-02	1.6E-02	1.5E-02	3.6E-02
2.2E-02	5.0E-02	3.2E-02	2.7E-02	1.1E-02	1.2E-02	2.7E-02	1.9E-02	1.6E-02	1.5E-02	3.5E-02
2.1E-02	4.9E-02	3.1E-02	2.7E-02	1.1E-02	1.2E-02	2.7E-02	1.9E-02	1.5E-02	1.5E-02	3.4E-02
2.1E-02	4.8E-02	3.1E-02	2.6E-02	1.0E-02	1.2E-02	2.6E-02	1.8E-02	1.5E-02	1.4E-02	3.3E-02
2.1E-02	4.7E-02	3.0E-02	2.5E-02	1.0E-02	1.1E-02	2.6E-02	1.8E-02	1.5E-02	1.4E-02	3.2E-02
2.1E-02	4.6E-02	3.0E-02	2.8E-02	2.2E-02	1.1E-02	2.5E-02	1.8E-02	1.7E-02	1.4E-02	3.1E-02
2.1E-02	4.5E-02	2.9E-02	2.6E-02	1.7E-02	1.1E-02	2.5E-02	1.8E-02	1.6E-02	1.4E-02	3.1E-02
2.0E-02	4.5E-02	2.8E-02	2.4E-02	9.3E-03	1.1E-02	2.5E-02	1.7E-02	1.4E-02	1.3E-02	3.0E-02
2.0E-02	4.4E-02	2.8E-02	2.3E-02	8.9E-03	1.1E-02	2.4E-02	1.7E-02	1.4E-02	1.3E-02	2.9E-02
2.0E-02	4.3E-02	2.7E-02	2.3E-02	8.6E-03	1.1E-02	2.3E-02	1.7E-02	1.3E-02	1.3E-02	2.8E-02

Select *Return to Input* and check the “Recharge” box indicating that this section is complete.

Step 2B – Land Use and Its Management

Select the *Land Use* button to navigate to the input page. Beneath the baseline HRU 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 (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 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 already managed by the specified 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.

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[32,33]. If a management practice is not applicable or desirable for an HRU, “-9” is entered for initial and O&M costs.

[32] U.S. Environmental Protection Agency (EPA). 2011. Memorandum to Project File: Methodology for developing cost estimates for structural stormwater controls for preliminary Residual Designation sites for Charles River watershed areas in the communities of Milford, Bellingham and Franklin, Massachusetts. August 9, 2011.

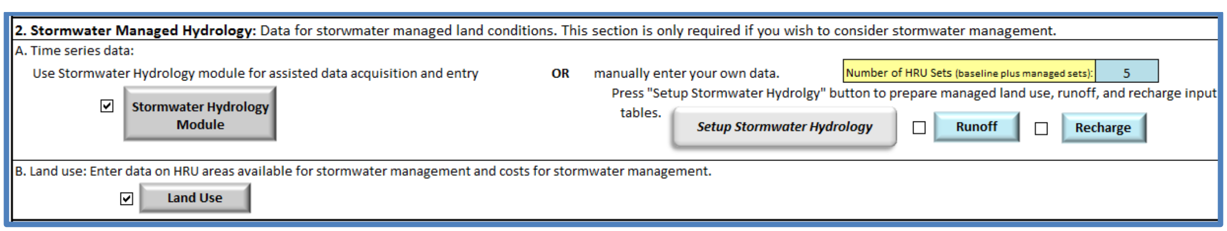
[33] U.S. Environmental Protection Agency (EPA) and Massachusetts Department of Environmental Protection (MassDEP). 2009. Optimal Stormwater Management Plan Alternatives: A Demonstration Project in Three Upper Charles River Communities.

First Set of Managed Land Uses and Their Limits				Bioretention basin, 0.6"		< Input name of management practice
HRU ID	Land Use Name	Minimum Area [acre]	Maximum Area [acre]	Initial Cost to Manage [$/acre]	O&M Cost [$/acre/yr]	
HRU1M1	Forest, sand & gravel	0	0	-9	-9	
HRU2M1	Open, sand & gravel	0	0	-9	-9	
HRU3M1	Low-resid, sand & gravel	0	3,099	3,833	38	
HRU4M1	High-resid, sand & gravel	0	1,274	5,685	57	
HRU5M1	Comm, sand & gravel	0	1,255	12,589	126	
HRU6M1	Forest, Till	0	0	-9	-9	
HRU7M1	Open, Till	0	0	-9	-9	
HRU8M1	Low-resid, Till	0	7,005	3,833	38	
HRU9M1	High-resid, Till	0	1,616	5,685	57	
HRU10M1	Forest, Fine deposition	0	0	-9	-9	
HRU11M1	Open, Fine deposition	0	0	-9	-9	

In the above screenshot, all urban HRUs receive bioretention basin 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 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 $3,833 and O&M cost of $38 for low density 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. 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 or LID practices or other land management practices that modify runoff and recharge may be specified. A managed set may include multiple practices that achieve some standard such as retaining a one inch storm event using rooftop disconnection, bioretention basins and swales.

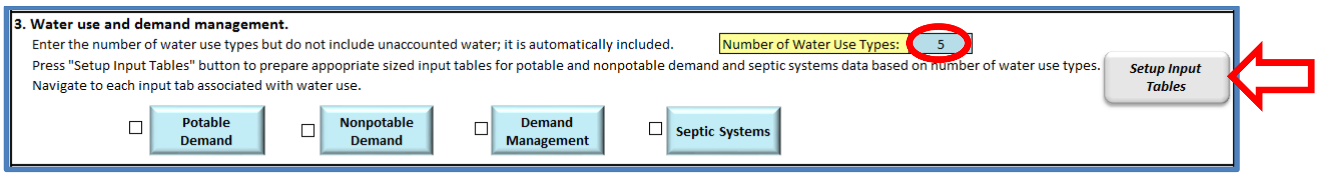
Once this section of “Land Use” is complete, navigate to the input screen by pressing *Return to Input*. Check the box next to *Land Use* to indicate that you have completed data entry for this category of input.



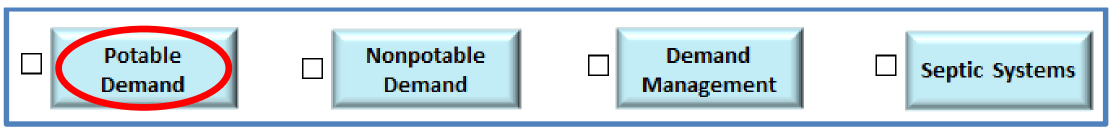
Step 3. Water Users, Water Demand, Demand Management and Septic System Use

On "Input", 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.**



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



Date	Total Water Demand [million gallons /time step]					
(mm/dd/yyyy)	Unaccounted	Residential	Commercial	Agricultural	Industrial	Municipal
1/1/1989	0.199	1.937	0.882	0.005	0.008	0.333
1/2/1989	0.199	1.937	0.882	0.005	0.008	0.333
1/3/1989	0.199	1.937	0.882	0.005	0.008	0.333
1/4/1989	0.199	1.937	0.882	0.005	0.008	0.333
1/5/1989	0.199	1.937	0.882	0.005	0.008	0.333
1/6/1989	0.199	1.937	0.882	0.005	0.008	0.333
1/7/1989	0.199	1.937	0.882	0.005	0.008	0.333
1/8/1989	0.199	1.937	0.882	0.005	0.008	0.333
1/9/1989	0.199	1.937	0.882	0.005	0.008	0.333
1/10/1989	0.199	1.937	0.882	0.005	0.008	0.333
1/11/1989	0.199	1.937	0.882	0.005	0.008	0.333

This table requires a time-series of the potable water demand for all users entered in 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.

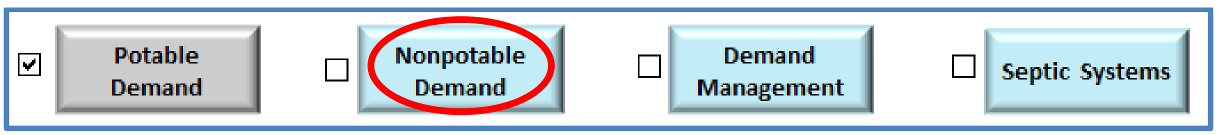
This section also includes an input table for the average percent consumptive water use by month. These values can reflect any seasonal changes in consumptive use over the year, such as increased outdoor watering in the summer, and among water user types.

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.

	Average Percent Consumptive Water Use (%)				
Month	Residential	Commerci	Agricultural	Industrial	Municipal
January	4	4	99	4	4
February	4	4	99	4	4
March	4	4	99	4	4
April	6	6	99	6	6
May	20	20	99	20	20
June	26	26	99	26	26
July	29	29	99	29	29
August	25	25	99	25	25
September	20	20	99	20	20
October	4	4	99	4	4
November	4	4	99	4	4
December	4	4	99	4	4

Note: None of these columns or rows need to add to 100%. Each value is the percent consumptive use for a user type for a month.

Select *Return to Input* and check the box next to “Potable” when this section is complete. Next, select Nonpotable demand to navigate to the input table.



Enter the percent nonpotable water use and percent consumptive use for nonpotable applications. The percent nonpotable water is the maximum amount of potable use that may 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.

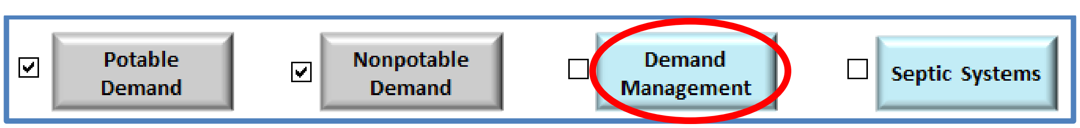
	Maximum Potential Nonpotable Water Use (%)				
Month	Residential	Commercial	Agricultural	Industrial	Municipal
January	45	90	90	99	90
February	45	90	90	99	90
March	45	90	90	99	90
April	45	90	90	99	90
May	45	90	90	99	90
June	45	90	90	99	90
July	45	90	90	99	90
August	45	90	90	99	90
September	45	90	90	99	90
October	45	90	90	99	90
November	45	90	90	99	90
December	45	90	90	99	90

Month	Average Percent Consumptive Nonpotable Water Use (%) Residential	Commercial	Agricultural	Industrial	Municipal
January	1	1	99	4	1
February	1	1	99	4	1
March	1	1	99	4	1
April	3	3	99	6	3
May	17	17	99	20	17
June	23	23	99	26	23
July	26	26	99	29	26
August	22	22	99	25	22
September	17	17	99	20	17
October	1	1	99	4	1
November	1	1	99	4	1
December	1	1	99	4	1

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 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" worksheet pre-calculates these adjusted values (see below). If any of the values are outside of the feasible range, they are highlighted red. In addition, the model will not run and the user is provided 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 red in the table shown below before proceeding.

Month	Adjusted Consumptive Potable Water Use (%) Residential	Commercial	Agricultural	Industrial	Municipal
January	6	31	99	4	31
February	6	31	99	4	31
March	6	31	99	4	31
April	8	33	99	6	33
May	22	47	99	20	47
June	28	53	99	26	53
July	31	56	99	29	56
August	27	52	99	25	52
September	22	47	99	20	47
October	6	31	99	4	31
November	6	31	99	4	31
December	6	31	99	4	31

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



The first option is reducing demand by increasing the price of water 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[34]. 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 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[35].

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

Initial cost	23,000	$
O&M cost	2,000	$/yr
Maximum price change	20	%

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 which may be achieved using rebates for water efficient appliances, 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 is overall demand.

Initial cost	3,186,600	$
O&M cost	0	$/yr
Total demand reduction	0.60	MGD

Total demand reduction value should equal the MGD reduction in demand across all user types achieved by all managemnet 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[36]. **When acquiring input data for these practices, the user must be aware of**

[34] For example, http://www.hks.harvard.edu/fs/rstavins/Monographs_&_Reports/Pioneer_Olmstead_Stavins_Water.pdf

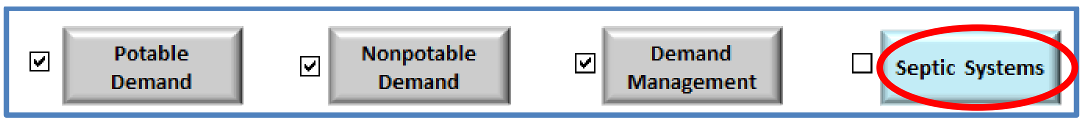
[35] The effect of price on water is assumed to be linear with WMOST v2 but nonlinear assumption may be implemented in future version.

[36] http://www.epa.gov/watersense/our_water/start_saving.html#tabs-3

the potential reduction in the individual effectiveness of demand management practices when multiple practices are implemented simultaneously[37].

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. Click on "Septic" to enter information about 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 input worksheets depending on their source and discharge of water (see Step 4 below for description of these input worksheets).



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

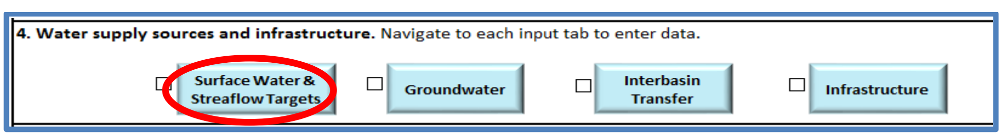
Customers with Public Water & Septic Systems Recharging Inside Study Area (%)				
Residential	Commercial	Agricultural	Industrial	Municipal
9.4	9.4	9.4	9.4	9.4

Customers with Public Water & Septic Systems Recharging Outside Study Area (%)				
Residential	Commercial	Agricultural	Industrial	Municipal
0	0	0	0	0

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

Step 4. Surface Water, Groundwater, Interbasin Transfer and Infrastructure

Select "Surface Water & Streamflow Targets" to navigate to three input tables.



In Part 1 of this section, 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 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

[37] 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.

due to the height of the storage outlet. Existing maximum volume is the total volume of existing storage. Initial costs should include the cost to plan, design and build additional surface storage volume. O&M costs should include the annual cost for maintaining surface storage capacity in operational condition.

Initial reservoir/surface storage volume	533	[MG]
Minimum target reservoir/storage volume	0.0	[MG]
Existing maximum reservoir/storage volume	710	[MG]
Initial construction cost	1,542,790	[$/MG]
O&M costs	0	[$/MG]

To exclude an increase in reservoir/surface storage volume as a management option, enter -9 in the input field shown below. In version 2 of WMOST, based on the next response supplied, reservoir outflow can either be entered as a data time series or included as a decision variable.

-9	**Exclude New/Additional** - to exclude new and additional capacity for a surface water storage, enter -9 in the corresponding blue box.
Yes	**Enter *Yes* to use Reservoir/Sw Outflow as data time series or *No* to allow it to be a decision.**

In Part 2 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 such as 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 informatioln 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.

These time-series must be at the 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 data you entered in the Runoff tab. As with other time series data, they must be complete and consecutive. For any of the three time series, if you do not have data or they do not exist, enter zero for all dates. Note that upstream inflow is critical, especially if you will be specifying any streamflow requirements.

Date (mm/dd/yyyy)	Other Sw Withdrawal [MG/time step]	Other Sw Discharge [MG/time step]	External Sw Inflow [cfs]	Reservoir Withdrawal [MG/time step]	Reservoir Discharge [MG/time step]	Reservoir Outlfow [MG/time step]
1/1/1989	0.00	0.00	19.91	1.02	0.36	5.00
1/2/1989	0.00	0.00	18.60	0.45	0.71	5.00
1/3/1989	0.00	0.00	17.80	1.00	0.41	5.00
1/4/1989	0.00	0.00	17.09	2.31	0.33	5.00
1/5/1989	0.00	0.00	16.23	1.88	0.50	5.00
1/6/1989	0.00	0.00	15.53	1.32	0.59	5.00
1/7/1989	0.00	0.00	14.92	1.42	0.72	5.00
1/8/1989	0.00	0.00	14.42	3.01	0.49	5.00
1/9/1989	0.00	0.00	13.92	0.00	0.10	5.00
1/10/1989	0.00	0.00	13.31	0.00	0.45	5.00
1/11/1989	0.00	0.00	12.60	0.00	0.23	5.00

In Part 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[38] and in Massachusetts there is a Sustainable Water Management Initiative Framework[39]. If any of these flow requirements do not exist in your study area, enter "-9" for each month of that set.

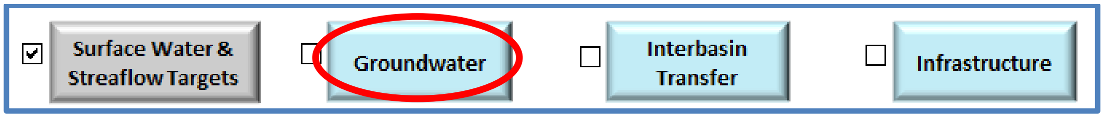
For minimum and maximum values, enter -9 and the model will not apply the constraint

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

Select *Return to Input* and check the box next to "Surface Water & Streamflow Targets" when this section is complete. Select "Groundwater" to navigate to three input tables.

[38] http://www.fws.gov/newengland/pdfs/Flowpolicy.pdf

[39] http://www.mass.gov/eea/docs/eea/water/swmi-framework-nov-2012.pdf



As on the “Surface Water & Streamflow Targets” page, the Groundwater input tables consist of three parts. The same state and regional data sources are recommended as for surface water data. In Part 1, enter information about groundwater storage characteristics will likely be derived from the same model that you obtain 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, and
- Maximum volume – this value represents the total storage capacity of the aquifer.

Groundwater recession coefficient	0.01	[1/time step]
Initial groundwater volume	1,134	[MG]
Minimum volume	706	[MG]
Maximum volume	2,838	[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 *Baseline Hydrology Module*, you may use *Calculate and Populate the Groundwater Recession Coefficient* to calculate this value.

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

Calculate and Populate the Groundwater Recession Coefficient

In Part 2, similar to “Surface Water & Streamflow Targets” sheet, you can enter time series data for other groundwater withdrawals, discharges and inflow into the study area.

Note: If you used the *Baseline Hydrology Module* to create your baseline recharge time series, a small part of the water balance is not yet present in the model. 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 were retained as positive values in the WMOST Support Files folder as “Watershed_RechargeAdjustment.csv”. Enter the sum of all the recharge values for your HRUs and time period into the model as part of the other groundwater withdrawals time series.

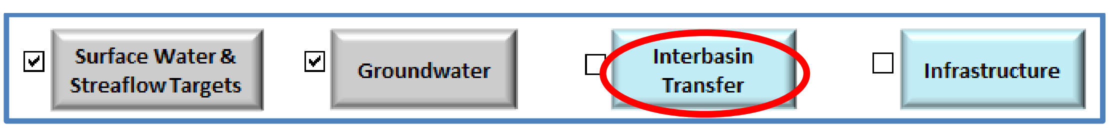
Date [mm/dd/yyyy]	Other Gw Withdrawal [MG/time step]	Other Gw Discharge [MG/time step]	External Gw Inflow [MG/time step]
1/1/1989	0.00	0.00	0.00
1/2/1989	0.00	0.00	0.00
1/3/1989	0.00	0.00	0.00
1/4/1989	0.00	0.00	0.00
1/5/1989	0.00	0.00	0.00
1/6/1989	0.00	0.00	0.00
1/7/1989	0.00	0.00	0.00
1/8/1989	0.00	0.00	0.00
1/9/1989	0.00	0.00	0.00
1/10/1989	0.00	0.00	0.00
1/11/1989	0.00	0.00	0.00

In Part 3, similar to "Surface Water & Streamflow Targets" sheet, you can enter requirements for groundwater flowing out of the basin. In most cases this 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.

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

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



In Part 1, you can enter data for:

- Costs to purchase water and wastewater from systems outside of your study area and
- Initial costs for water and wastewater rights in addition to any existing agreements including costs for any new infrastructure to utilize the additional rights [40].

If you do not want IBT as a management option, enter -9 for costs AND 0 for constraints.		
Purchase cost for potable water	3,803	[$/MG]
Purchase cost for wastewater	6,340	[$/MG]
Initial cost for new/increased IBT potable water limit	29,500,000	[$/MGD]
Initial cost for new/increased IBT wastewater limit	0	[$/MGD]

In Part 2, enter any existing monthly limits for interbasin transfer of water and wastewater in the left 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 a constraint does not exist, enter -9.

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

Existing Limits on IBT		
	Water	Wastewater
Daily [MGD]	-9.00	6.00
Annual [MG per year]	-9.00	-9.00

Additional Capacity Limits		
	Water	Wastewater
Daily [MGD]	0.27	-9.00

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

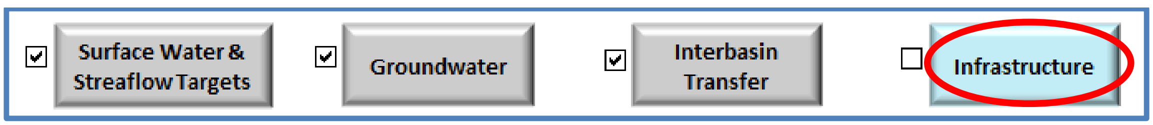
- **If you do not have interbasin transfer as an option, you must enter "0" for limits.** Entering "-9" will indicate no restriction, that is, unlimited interbasin transfer is available. As such if you enter -9 for daily, monthly or annual limits, then you must specify the initial cost for new/increased 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

[40] 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.

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 "Infrastructure" for input data tables related to wastewater treatment plant and aquifer and storage recharge facility.

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 parts.



In Part 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 2.1.1* in the separate Theoretical Documentation.

Planning horizon [years]	20
Interest rate [%]	5.00

In Part 2, you 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
  - o Capital costs – cost for increasing capacity or cost for replacing existing capacity beyond the remaining lifetime,
  - o O&M costs – cost for operating based on the size and flow through the facility,
  - o Existing maximum capacity of the facility,
  - o Lifetime remaining on existing infrastructure or the number of years expected to remain before major capital rehabilitation or new facility must be built, and
  - o 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

- o Initial cost for surveying the distribution system for leaks and repairing to the maximum percent feasible,
- o O&M costs representing annual costs for maintaining repairs made to the distribution system, and
- 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" for the appropriate facility.

Water services	Value	Units	Exclude New/Additional
Consumer's price for potable water: Fixed fee	0	$/month	
Consumer's price for potable water: Variable, volume-based fee	5.03	$/HCF	
Groundwater (Gw) Pumping			0
Capital cost for additional capacity	747,285	$/MGD	
Operation & Maintanance (O&M) costs	-	$/MG	
Existing maximum capacity	1.74	MGD	
Lifetime remaining on existing infrastructure	33	yrs	
Lifetime of new construction	35	yrs	
Surface Water (Sw) Pumping			0
Capital cost for additional capacity	453,885	$/MGD	
O&M costs	-	$/MG	
Existing maximum capacity	9.40	MGD	
Lifetime remaining on existing infrastructure	33	yrs	
Lifetime of new construction	35	yrs	
Water Treatment Plant (WTP)			0
Capital cost for additional capacity	2,022,884	$/MGD	
O&M costs	5,314	$/MG	
Existing maximum capacity	9.40	MGD	
Lifetime remaining on existing infrastructure	33	yrs	
Lifetime of new construction	35	yrs	
Unaccounted-for-Water/ Potable water distribution system leak			
Initial cost for survey & repair	774,368	$	
O&M costs for maintaining reduction in UAW	77,437	$/yr	
Maximum percent UAW that can be fixed	99	%	

In Part 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 is groundwater infiltration

Wastewater treatment plant (WWTP)	Value	Units	Exclude New/Additional
Consumer's price for wastewater services: Fixed fee	0.00	$/month	0
Consumer's price for wastewater services: Variable, volume-based fee	6.12	$/HCF	
Are wastewater fees charged based on metered water or wastewater?	water	water or wastewater	
Capital cost for additional capacity	15,788,674	$/MGD	
O&M costs	7,925	$/MG	
Existing maximum capacity	0.00	MGD	
Lifetime remaining on existing infrastructure	0	years	
Lifetime of new construction	40	years	
Infiltration into wastewater collection system			
Existing Gw infiltration into collection system	0	% of WW Inflow	
Initial cost for survey & repair	214,846	$	
O&M costs for maintaining reduction in infiltration	21,485	$/yr	
Maximum percent of infiltration that can be fixed	0	%	

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

In Part 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	10,402,467	$/MGD	0
O&M costs	2,850	$/MG	
Existing maximum capacity	0.00	MGD	
Lifetime remaining on existing infrastructure	0.00	yrs	
Lifetime of new construction	35	yrs	

In Part 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. See case study appendices for potential data sources.

Nonpotable Water Distribution System	Value	Units	Exclude New/Additional
Consumer's pricefor nonpotable water: Fixed fee	0	$/month	0
Consumer's pricefor nonpotable water: Variable, volume-based fee	3.02	$/HCF	
Capital cost for additional capacity	12,529,440	$/MGD	
O&M costs	1,716	$/MG	
Existing maximum capacity	0.00	MGD	
Lifetime remaining on existing infrastructure	0	yrs	
Lifetime of new construction	35	yrs	

In Part 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	0
O&M costs	3,769	$/MG	
Existing maximum capacity	0	MGD	
Lifetime remaining on existing infrastructure	0	yrs	
Lifetime of new construction	35	yrs	

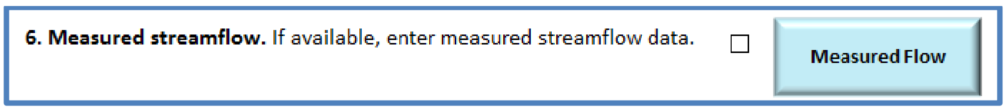
Select *Return to Input* and check the box next to "Infrastructure" when this section is complete.

Step 5. Flood Module

To include flood damage costs in the optimization of management costs, select *Flood Module* to navigate to the input 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 4* for information on existing flood damage studies and conducting your own flood damage modeling using publicly available data and software. Note: Engaging the flood module creates substantially larger optimization problems resulting in significantly longer solve times. A one-year, daily time step model may require less than 5 minutes to solve without the flood module and require approximately 30 minutes with the flood module.

Step 6. Measured Streamflow

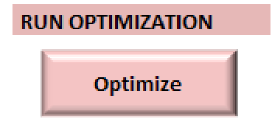
Click on "Measured Flow" to navigate to the next input table. These data are used to create an output graph showing both measured and modeled in-stream flow to assess the accuracy of the model in reproducing measured flows. These data may be acquired from the U.S. Geological Survey[41] or from the model from which you may have obtained baseline hydrology data.



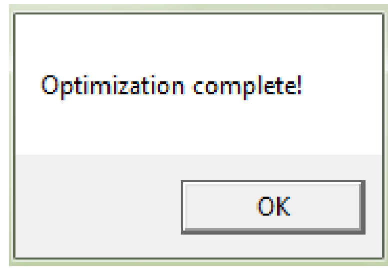
Date (mm/dd/yyyy)	Measured In-Stream Flow (cfs)
1/1/1989	25.66
1/2/1989	26.77
1/3/1989	26.27
1/4/1989	25.06
1/5/1989	23.90
1/6/1989	22.79
1/7/1989	21.63
1/8/1989	20.72
1/9/1989	19.91
1/10/1989	19.06
1/11/1989	18.10

41 http://waterdata.usgs.gov/nwis

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



Once all sections are complete, you may run the optimization model by returning to "Intro" and clicking the red *Optimize* button. This will initiate the optimization and processing of results.



After the optimization is finished, the model will display the message shown to the right. Click "OK" and wait for the model to process outputs and populate the Results tables. The "Intro" page will display again once the output processing is complete.

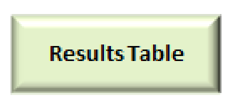
3.2 Evaluating Results

After optimization, WMOST provides three outputs:

1. Summary table of management practices and associated costs that met specified goals (e.g., minimum demand, minimum in-stream flow) at least cost,
2. Graph of modeled in-stream flow and baseflow compared with user-specified measured in-stream flow, and
3. Modeled in-stream flow and baseflow and user-specified minimum and/or maximum in-stream flow targets.

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., user input runoff and recharge rates). The flows over the modeling period represent estimated flow 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 conditions 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 5*). By varying the input data, you can determine the robustness of results over a variety of potential conditions that may occur by the end of planning period.



To view the summary table of results, select the "Results Table" button to display the management decisions and associated costs. Capital and O&M costs are presented as one total annualized cost in WMOST v2. This may lead to costs for an existing facility even if no additional capacity is selected as a management practice. For example, an existing water treatment plant may be able to meet projected demand without additional capacity but O&M costs are still incurred for operating the facility for the required demand. Therefore, when "number of units" is zero but there is still a cost, that cost represents O&M costs.

An excerpt from the summary table of results is below:

RESULTS

Due to solver precision, there may be neglible changes in HRU areas that round to zero displayed as 0 or (0).

Total Annual Cost	$13.5	million
Water Revenue	$10.2	million
Wastewater Revenue	$10.3	million

MANAGEMENT PRACTICES	UNITS	Number of Units	Total Annual Sub-Costs (incl. O&M)
Demand Management			
Consumer Rate Change	%	20	$3,846
Direct Demand Reduction	MGD	0.60	$255,701
Land Conservation			$0
Forest, sand & gravel	Acres	0	
Open, sand & gravel	Acres	0	
Low-resid, sand & gravel	Acres	(0)	
High-resid, sand & gravel	Acres	0	

Select “Compare to Measured Flow” to display a graph comparing measured in-stream flow to modeled in-stream flow and baseline.

Select “Compare to Target Flow” to display a graph comparing modeled flows to user-specified in-stream flow constraints.

Results may be printed from the Excel interface with the same options as any Excel file or copied and pasted into Word or another application.

4. Flood Damage Modeling with HAZUS[42]

HAZUS-MH is used to generate the flooding cost curve data which are entered into the WMOST v2 Flooding 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, with 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.[43] The following steps will guide the user on methodology to determine the 100-year flood depth grid using data from the FEMA National Flood Hazard Layer, as well as methodology to create 10, 50 and 500-year grids. Additionally, this guide will assist users to create 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.

4.1 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.

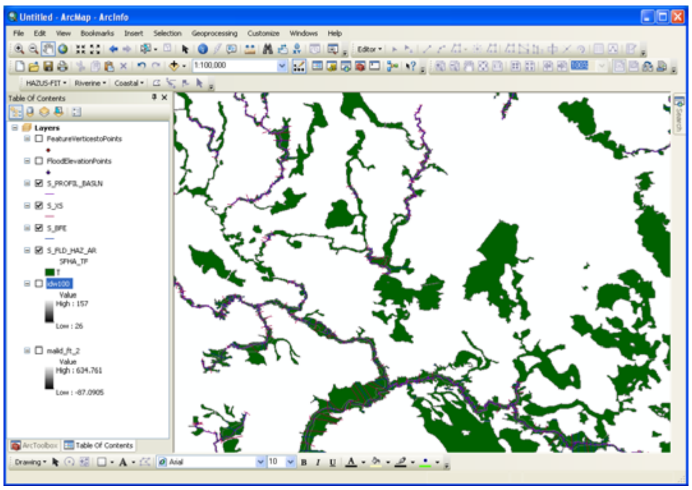
[42] HAZUS Level 2 Site Specific Flood Model: FEMA Region VIII Standard Operating Procedure for Riverine Flood Hazard and Site Specific Loss Analysis, prepared by Jesse Rozelle, Austen Cutrell, Doug Bausch, and H.E. Longenecker.

[43] Multi-hazard Loss Estimation Methodology Flood Model HAZUS-MH, Users Manual, FEMA (www.fema.gov/plan/prevent/hazus.)

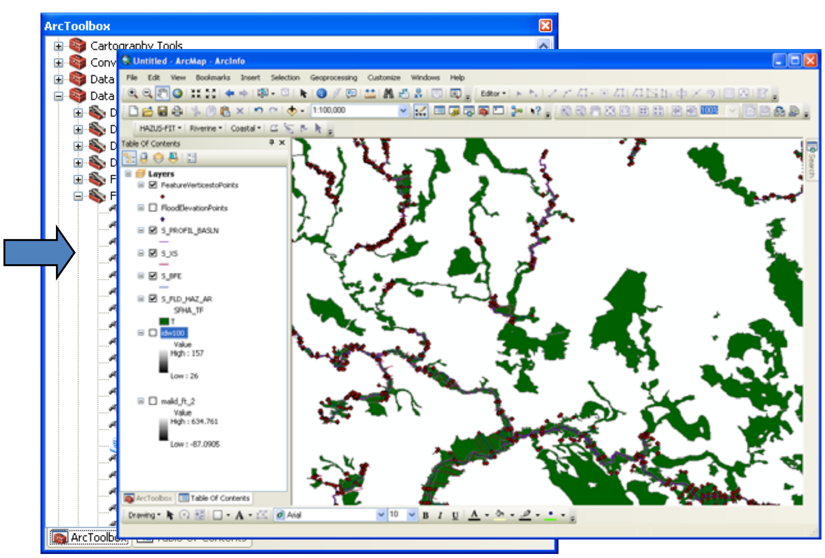
4.2 Creating the 100-Year Flood Depth Grid from FEMA NFHL Data

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

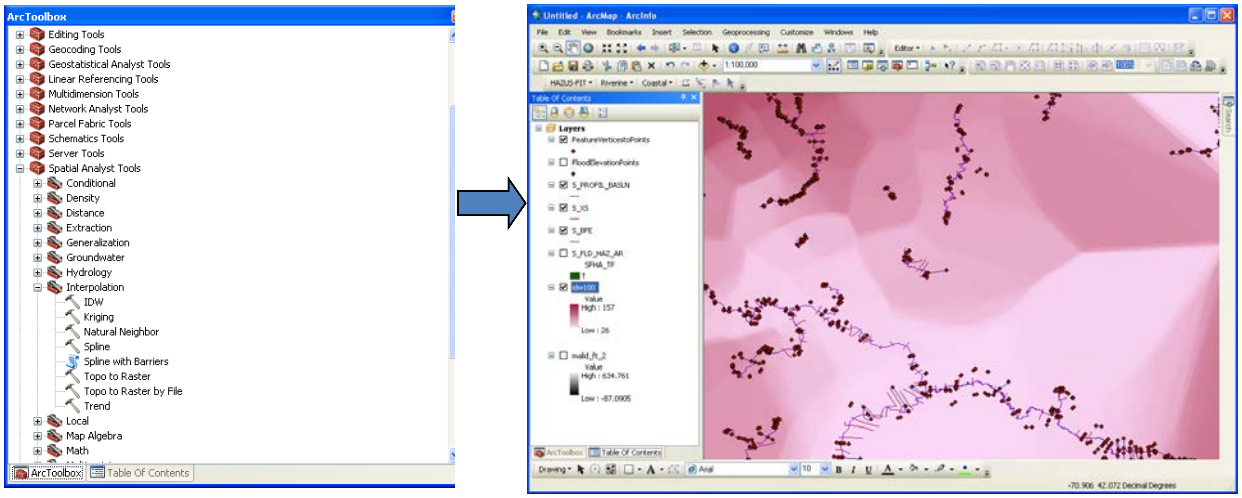
1. Open ArcMap.
2. Add the Base Flood Elevation (BFE) shapefile (S_BFE.shp) from the NFHL dataset to the map. The shapefile has an attribute "ELEV" which is the Base Flood Elevation (BFE) at each section.
3. Add the Stream Profile Centerline and the Flood Hazard Area shapefiles from the NFHL(S_PROFIL_BASLN.shp and S_FLD_HAZ_AR.shp).



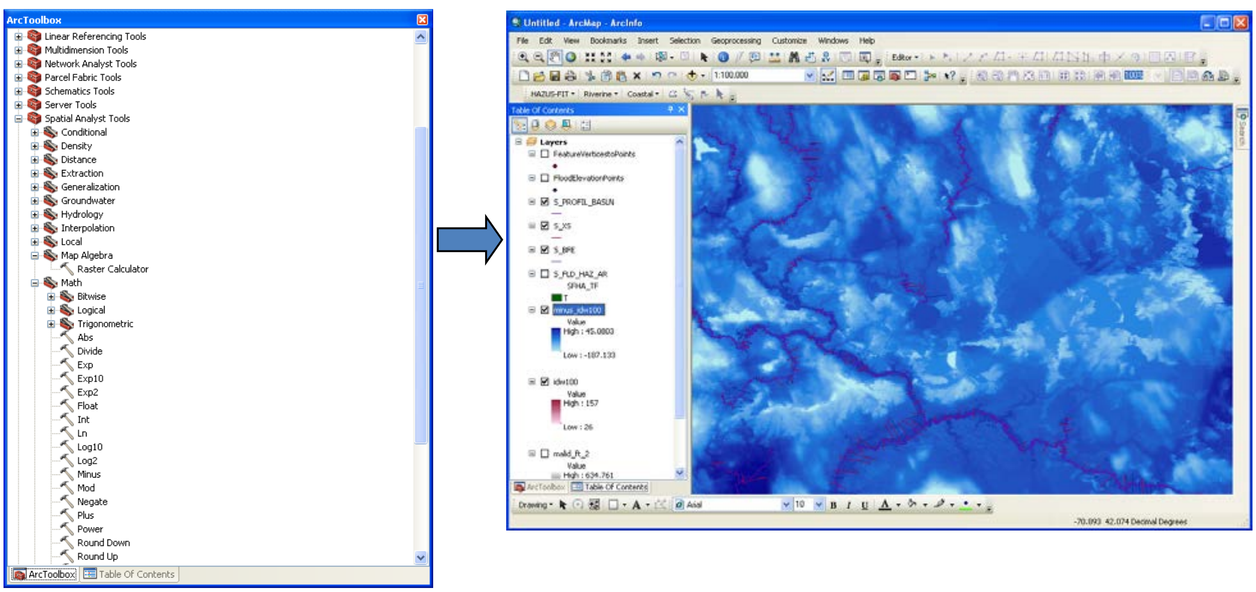
4. Create points at each vertex of the BFE lines (Data Management Tools>>Feature>>Feature Vertices to Points).

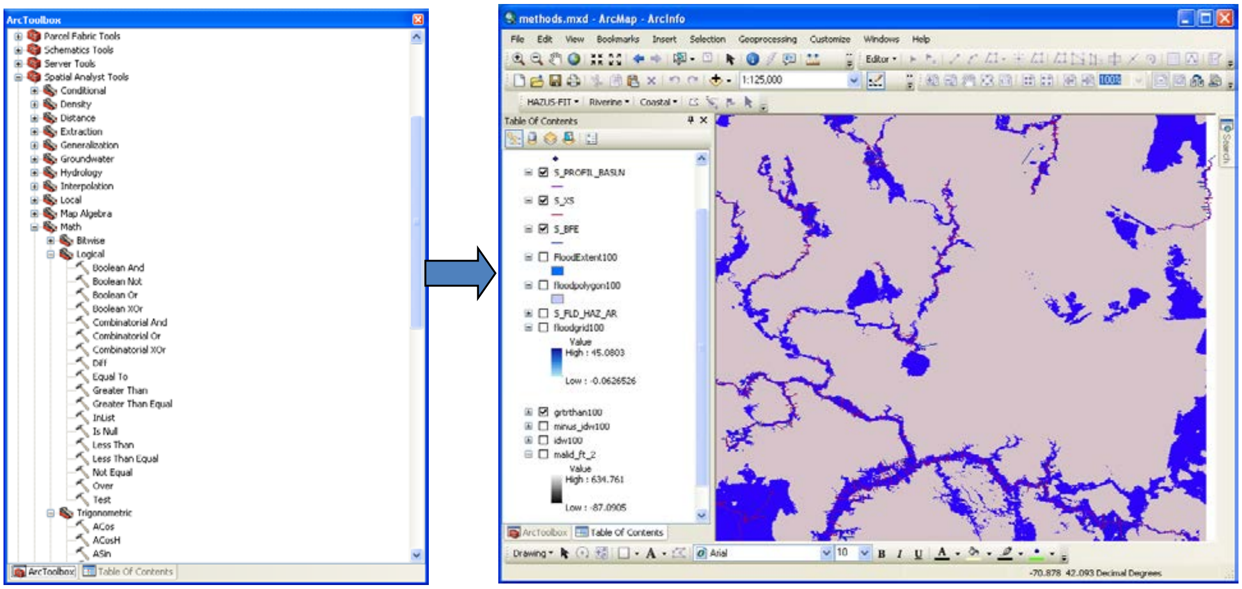


5. Using the point feature generated in Step 4, create the 100-year flood surface by inverse distance weighting using the ELEV attribute (Spatial Analyst>>Interpolation>>IDW).



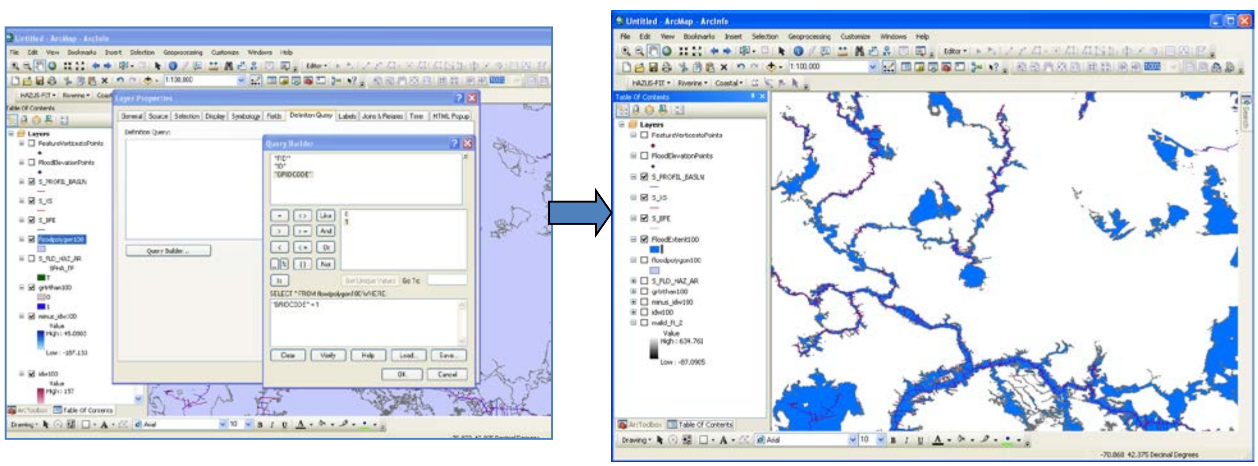
6. Subtract the ground surface elevations from the flood surface layer created in Step 5 (Map Algebra>>Raster Calculator or Math>>Minus) to determine a water depth grid. The resulting layer will have negative values where the ground surface is above the flooded elevation (areas of no flooding) and positive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





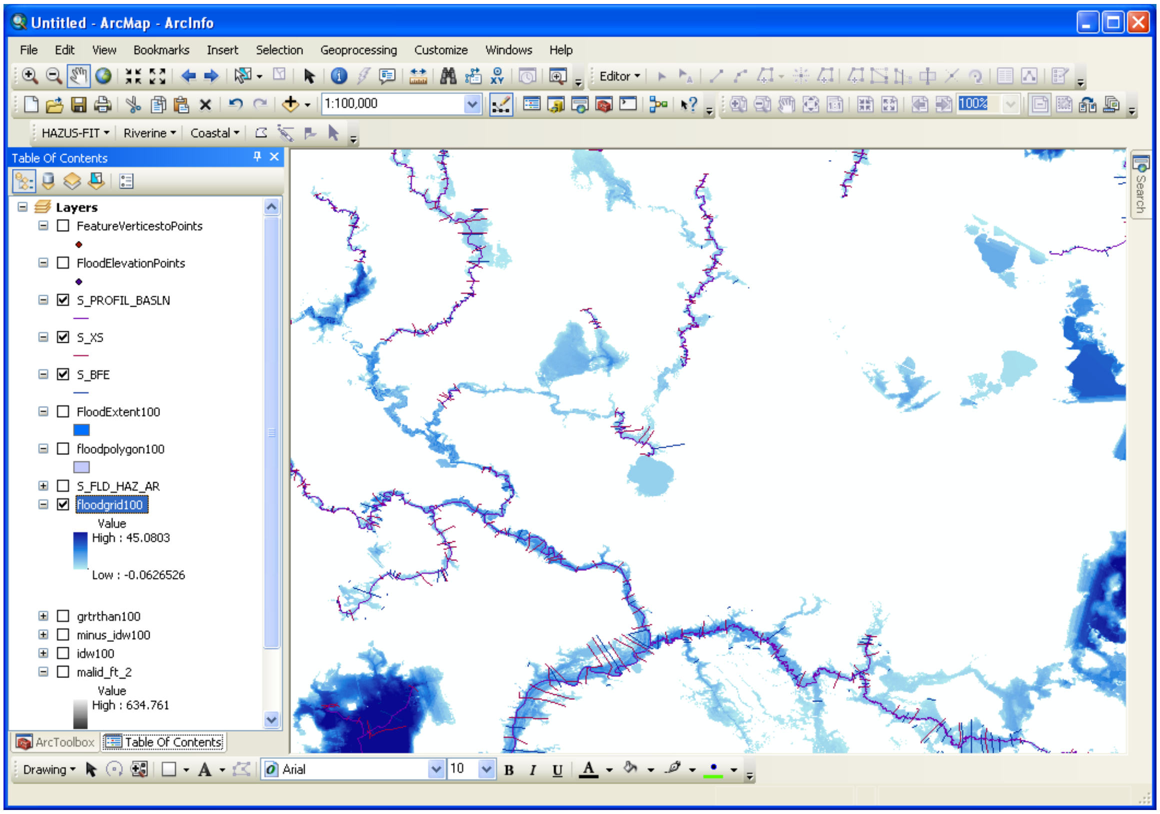
7. Eliminate negative values using a conditional statement (SpatialAnalyst>>Math>>Logical >>Greater than Equal). Setting the flood elevation grid greater than zero will result in a true/false condition where positive values will have a gridcode of 1 and negative values will have a grid code of 0.

8. 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.



9. 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.



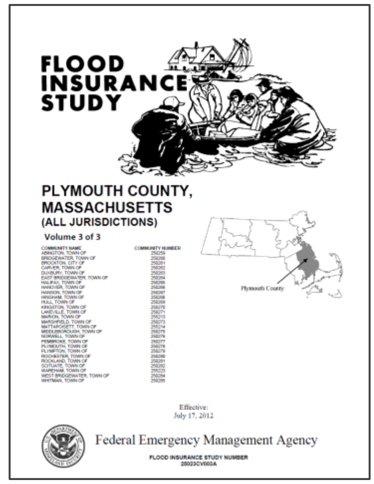
4.3 Creating the Flood Depth Grid from Lake Elevation Flooding

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

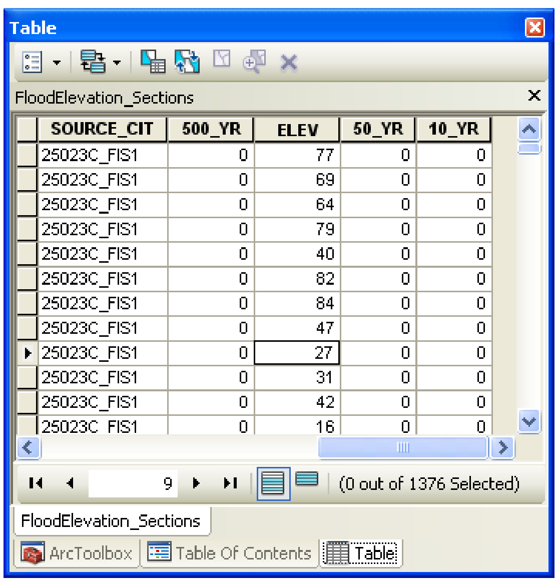
1. Determine the watershed draining to the lake and clip the digital elevation model (DEM) to the watershed boundary. This will be the study area of interest.
2. Beginning at Step 6, subtract the ground surface elevations from the lake flood elevation (Map Algebra>>Raster Calculator or Math>>Minus) to 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.

4.4 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.

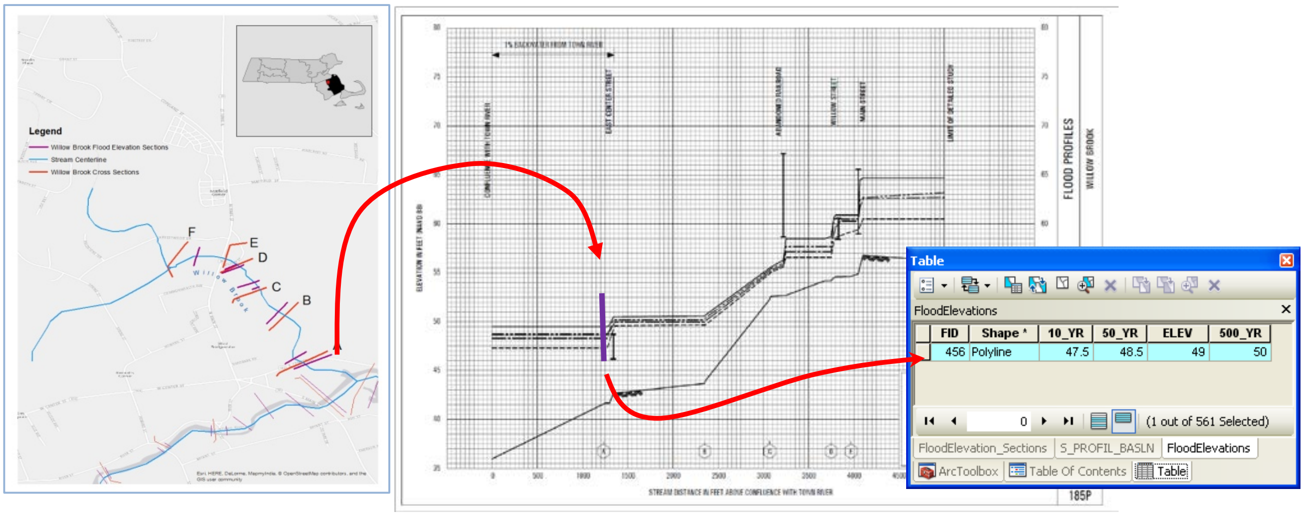


1. FEMA Flood Insurance Studies (FIS)are county-specific and can be obtained from the FEMA Map Service Center (www.msc.fema.gov). The flood profile graphs show flood elevations along the centerline of the stream (S_PROFIL_BASLN.shp). The profiles show the elevation of the 100-year flood as well as the 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_BFEhe 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

4. 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



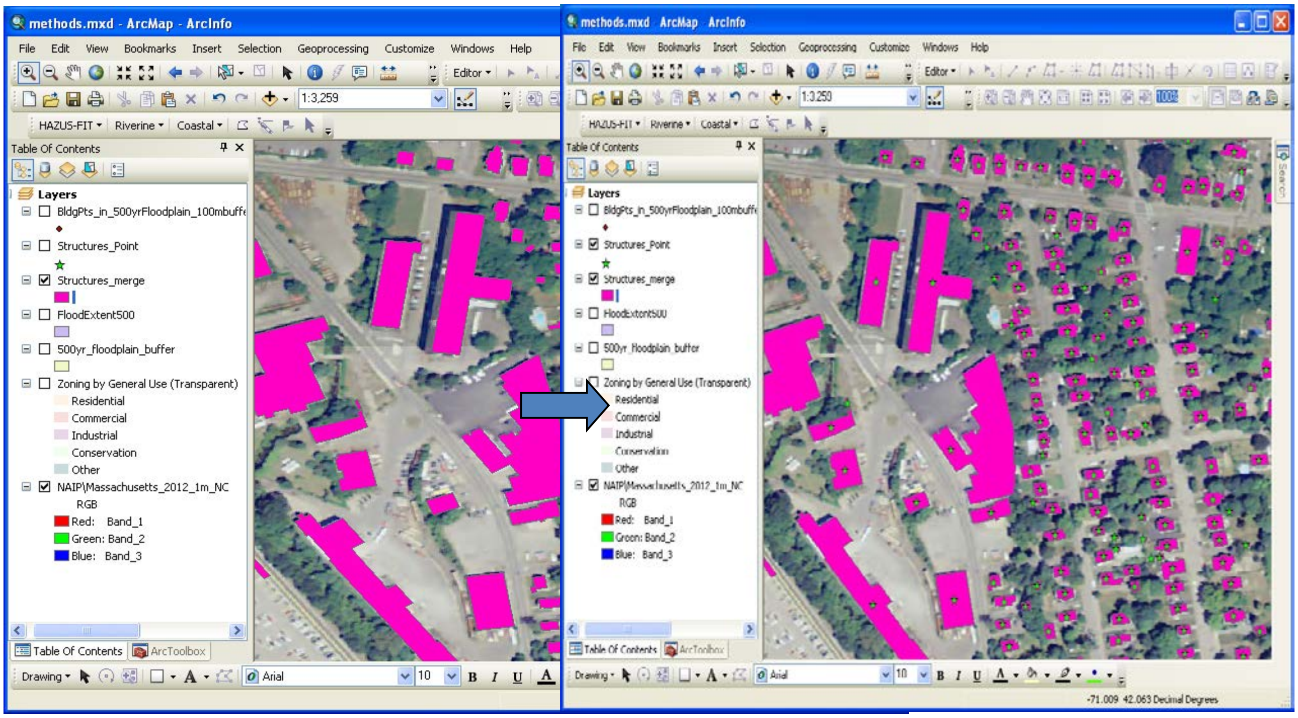
5. Repeat this procedure for all section lines.
6. Once all elevations are determined, the methodology to create the 100-ylear flood grid can be utilized to create flood depth grids for the 10, 50 and 500-year intervals.

4.5 Creating a Site Specific Building Inventory

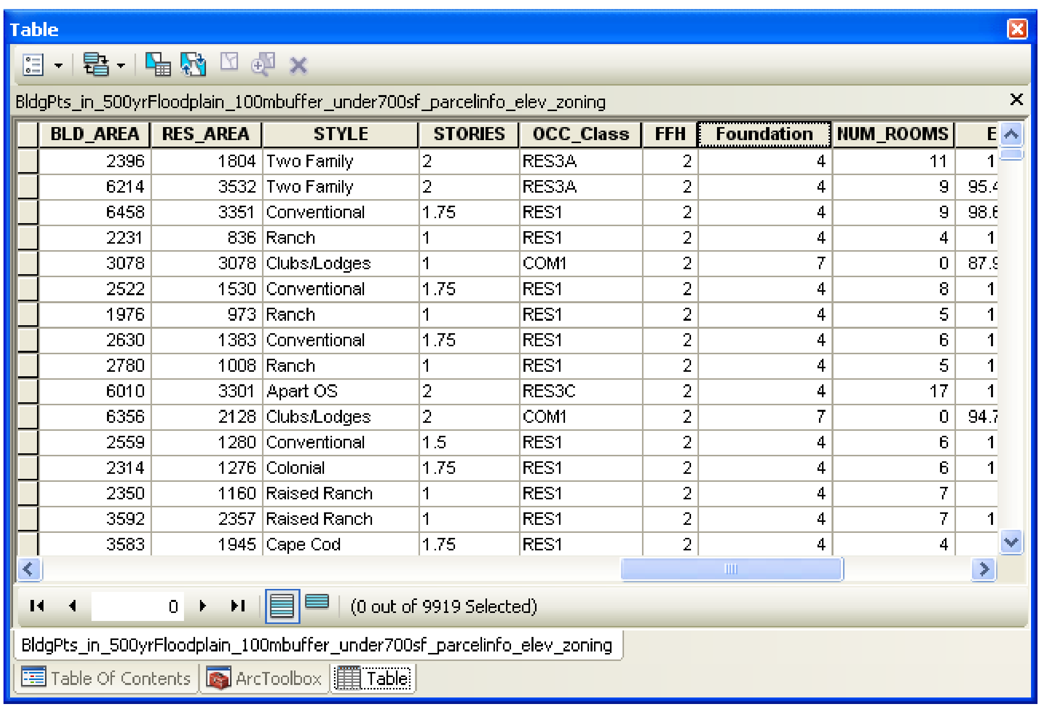
To determine flood damage, HAZUS assumes that all buildings are distributed evenly throughout a census tract. In order to get a more accurate assessment of the potential damage, it is helpful to build a user-defined building inventory. To create a detailed building inventory, the following information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

1. 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.[44] 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.

[44] Available from https://gdg.sc.egov.usda.gov/.



2. 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	
3592	2357	Raised Ranch	1	RES1	2	4	7	1
3583	1945	Cape Cod	1.75	RES1	2	4	4	

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

3. HAZUS has specific values for occupancy class and foundation type and these must correspond exactly in order to map correctly. The HAZUS Technical Manual[45] 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.

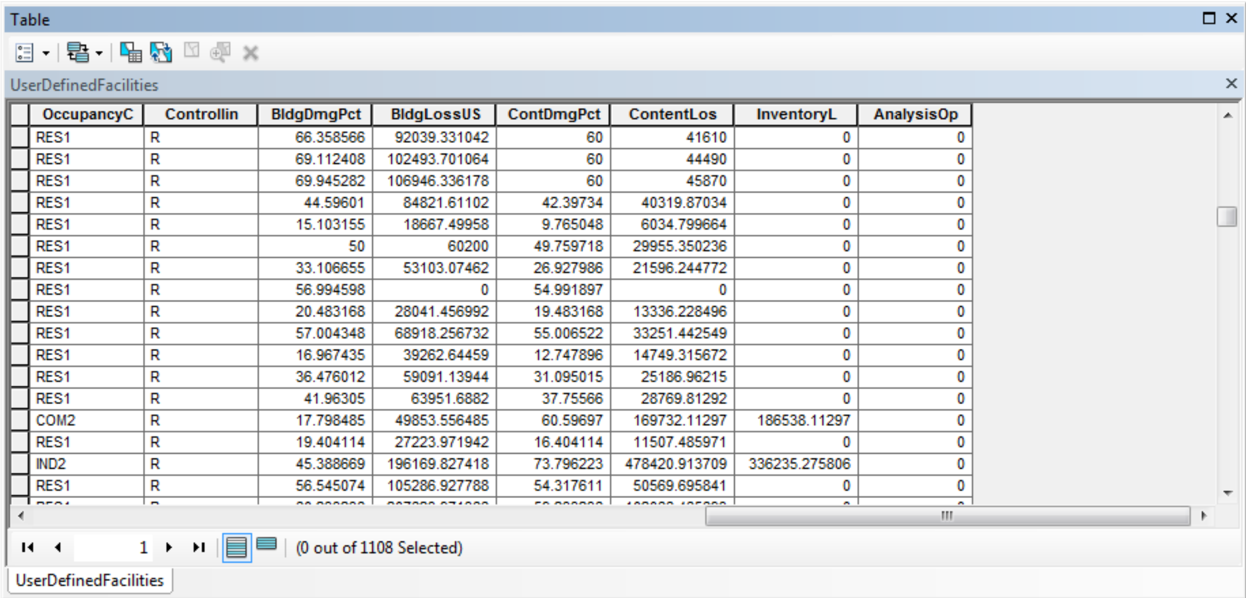
UDF_Mecklenburg_NC : Table

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.

[45] 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 in the WMOST v2. Flood module.

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

Flood cost curve in WMOST Flood Module

5. User Tips

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

- If the results show “1E+30” for Total Annual Cost, **the scenario run was infeasible.** This means 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.

- As detailed in the Theoretical Documentation, a “sustainability” constraint forces the initial and final groundwater and reservoir/surface water storage volumes to be equal. If only one year is modeled, then the watershed should be a “within-year” watershed, that is, the groundwater and reservoir volumes generally return to their initial levels each year. If multiple years are modeled, this sustainability constraint “softens” and the model may be applied to multi-year watersheds as well.

- A “simulation 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. Case study applications describe the process for performing a “simulation run” with WMOST.

- 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. Or 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[46].

- 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.

[46] http://www.epa.gov/osa/crem/training/module8.htm

6. References for HSPF Models Incorporated into WMOST Model Output Files

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.

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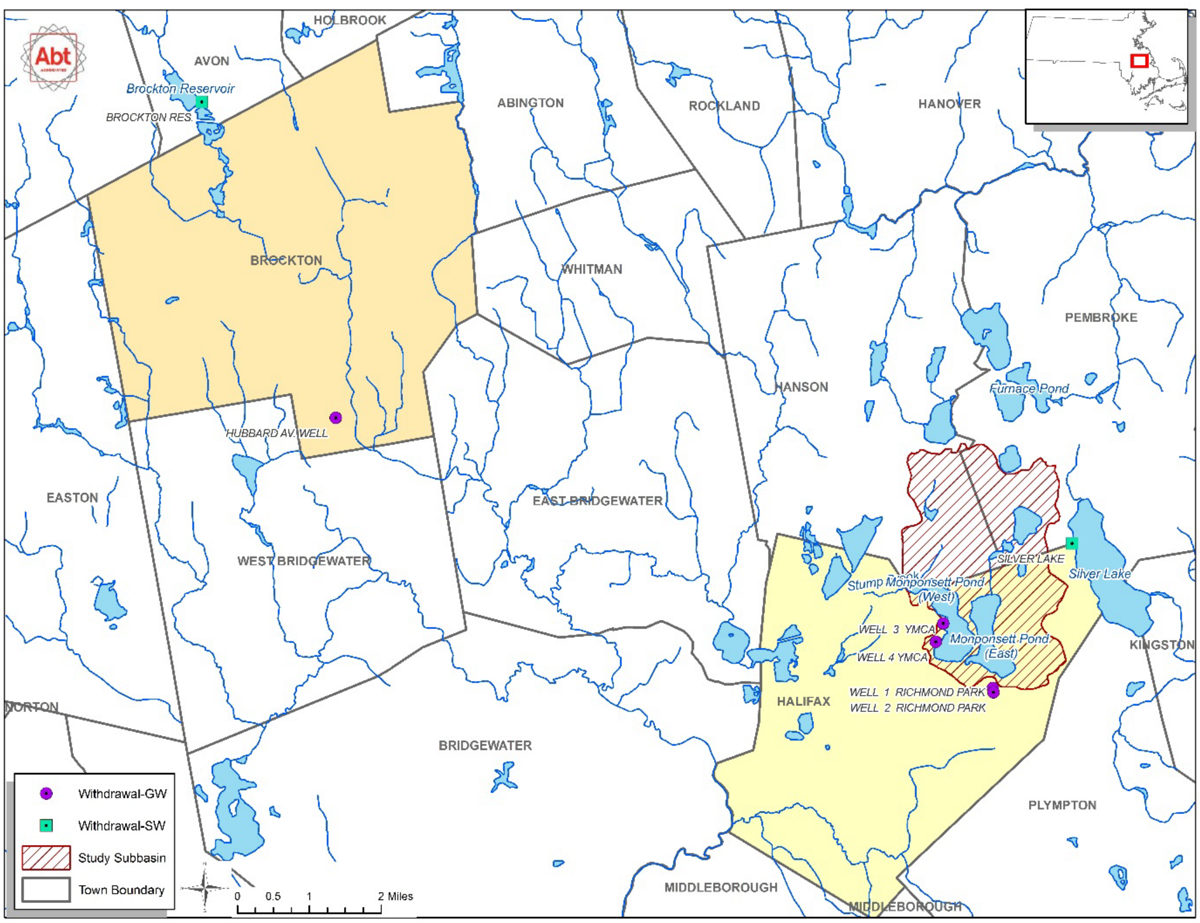
Appendix A. WMOST v2 Case Study Description

Background and Context

Legislative and Regulatory Framework

Following outreach to stakeholders in the Taunton River watershed by EPA Region 1, we selected the Monponsett Ponds (MP) watershed in Halifax, MA (**Exhibit 1**) as a case study for testing WMOST version 2. The MP system is part of the Taunton River watershed (Subbasin #24022: Middle Taunton River-Town River to Nemasket River). The Taunton River watershed is an area of concern for EPA Region 1 and the focus of a Healthy Watersheds Initiative project. The Taunton watershed contains a Wild and Scenic River but at the same time is subject to significant development pressure. Conditions in the MP watershed, and in the larger Taunton River watershed, illustrate the inherent connections between management of water quantity and water quality.

Exhibit 1: Monponsett Ponds



Monponsett Ponds is a large water system consisting of two basins, East and West. The two ponds are connected by a small culvert at their southern end supporting flow between the two basins. East Monponsett Pond serves as water supply to the City of Brockton through periodic diversions of water to Silver Lake (located in the adjacent Jones River watershed). West Monponsett Pond drains into Stump

Brook, a tributary of the Satucket River. There are estimates that Stump Brook only receives about one third of its potential annual discharge due to water diversions to Silver Lake (Princeton Hydro, 2013[47]). Monponsett Ponds' two basins have differing water quality, with higher pollutant loadings (notably phosphorus) in West Monponsett Pond resulting in the listing of the waterbody as impaired or threatened for one or more uses and requiring a TMDL.[48] By contrast, the East basin has higher water quality, as does Silver Lake, to which MP waters are diverted.

The Monponsett Pond Watershed Association in Halifax, MA, identified the following water resources management issues within the watershed and with interbasin transfers between Monponsett Pond and the Jones River watershed:

Water quantity

- Concerns over changes to natural flow regime of Stump Brook draining from Monponsett Ponds
  - Effects on anadromous fish passage once downstream dam impedances are removed;
  - Effects on regeneration of Atlantic cedar swamp downstream.
- Concerns over water volume fluctuations from water withdrawals by Brockton Water Department
  - Minimum volume required to support recreational uses;
  - Maximum volumes maintained for water storage can exacerbate flooding of properties surrounding Monponsett Ponds and possibly inputs from septic systems.

Water quality

- Blue-green algal blooms leading to public beach closures for West Monponsett Pond during most of the past few years and possibly linked to an October 2011 fish kill.
- If water withdrawals reverse the normal direction of flow between East and West Monponsett Ponds, this would transfer water from the basin with poor water quality (average TP = 0.134 mg P/L) to the basin with good water quality (average TP = 0.032 mg P/L).
- Regardless of flow reversals between the East and West basins, interbasin transfer from MP to Silver Lake in the Jones River watershed could degrade Silver Lake water quality (average TP = 0.02 mg P/L).

Droughts prompted a series of legislative actions that set in place a water management framework that authorizes transfers of water across basin in the region **(Exhibit 2**). These transfers affect the water quantity and quality issues in the Monponsett Ponds. The City of Brockton (Brockton Water System, BWS) obtains over 90 percent of its roughly 9 million gallon per day (MGD) water supply from Silver Lake. In order to meet demand, BWS diverts water from Monponsett Ponds (MP-W and MP-E) and Furnace Pond (FP) into Silver Lake (SL). Treated water is then piped 15 miles from SL to Brockton and following use, water is returned to the Taunton River (see **Exhibit 1** for the location of MP, FP, SL and

[47] Princeton Hydro. 2013. Sustainable Water Management Initiative Report: Monponsett Pond and Silver Lake Water Use Operations and Improvement SWMI Project No. BRP 2012-06. Prepared for Town of Halifax, MA and Massachusetts Department of Environmental Protection. Princeton Hydro, LLC. Ringoes, NJ. July 2013.

[48] The West Basin of Monponsett Pond is on Massachusetts' 2012 Integrated List of Waters requiring a TMLD due to nutrients enrichment (phosphorus), non-native aquatic plants, excess algal growth, and lack of water clarity (MassDEP, 2013).

Brockton).[1] These water transfers were originally authorized in 1899 by Chapter 356 "*An act to authorize the city of Brockton to take an additional water supply*" enacted by the Massachusetts Legislature. In 1964 the Massachusetts Legislature approved Act 371: "*An act establishing the Central Plymouth County Water District and authorizing the City of Brockton to extend its source of water supply*" in response to severe drought in the early 1960s. Act 371 established the Central Plymouth County Water District and set emergency provisions to further authorize flow from the Taunton River watershed by diversion from East Monponsett Pond into Silver Lake (in a separate watershed) and from the North River basin, by diversion of Furnace Pond into Silver Lake. (See **Exhibit 1** for water body locations.) Act 371 set timing and water elevation conditions when diversions into Silver Lake could occur; the water elevation conditions triggered Brockton to establish or modify water control structures at Monponsett and Furnace Ponds. Subsequently, Chapter 237 of the Acts of 1981 ("*An act further regulating the source of water supply for the City of Brockton*"), required establishment of water control structures to prevent diversion of water from East Monponsett Pond when the level of the pond is below an elevation of 52 feet and to prevent diversion of water from Furnace Pond below an elevation of 56 feet (National Geodetic Vertical Datum 1929). In 2002, Brockton entered into a 20 year contract with Aquaria setting the stage for minimum use of water created by a new desalination plant near the head-of-tide of the Taunton River.

Exhibit 2: A series of legislations set out the water management framework in the watershed by authorizing transfers of water across waterbodies and subbasins (Source: Princeton Hydro, 2013)

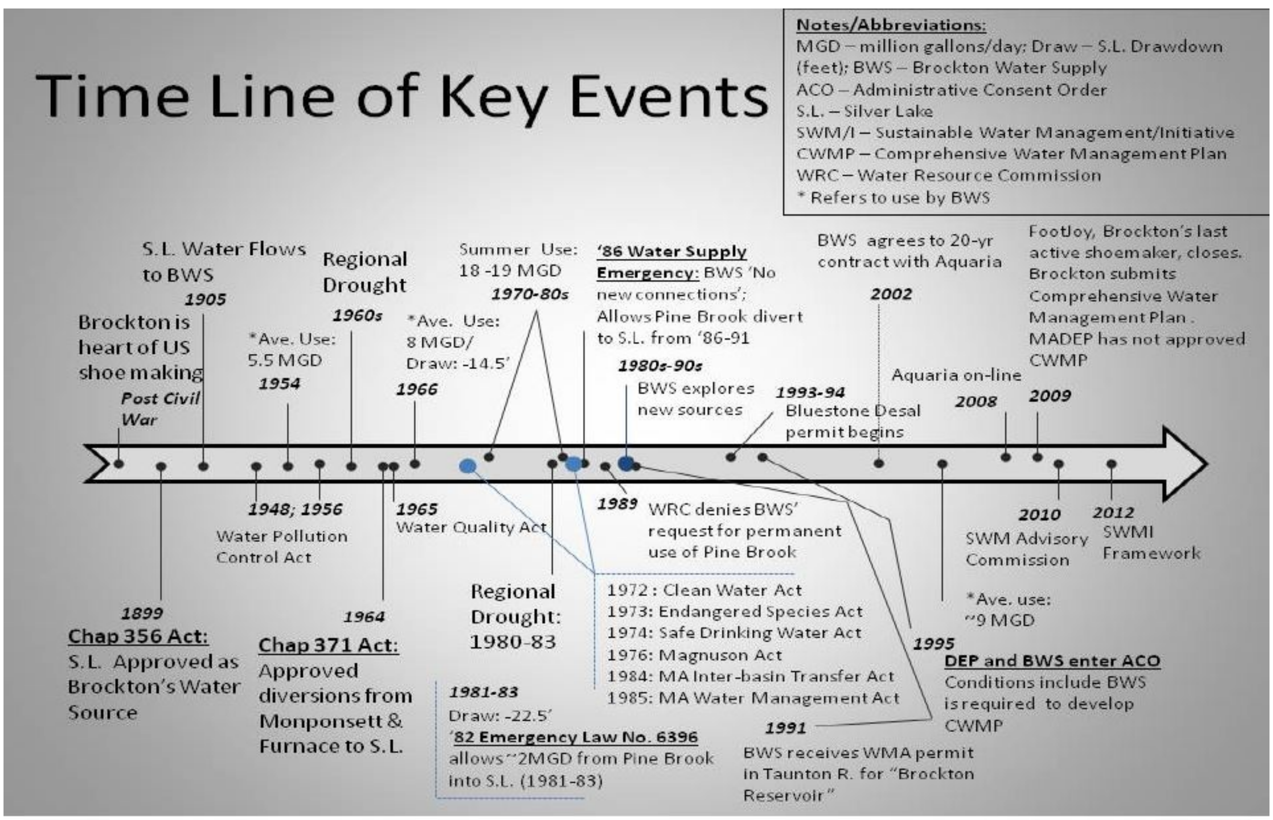


FIGURE 1. Time line (not to scale) of key events involving Brockton's water supply system as well as major federal and state legislative actions pertinent to natural resources management.

In 2010, Massachusetts established the Sustainable Water Management Initiative (SWMI), an associated Advisory Committee, and a technical subcommittee with an objective to develop and implement water policy that both supports ecological needs and fulfills human economic requirements. The overall principle adopted by SWMI is stated as:

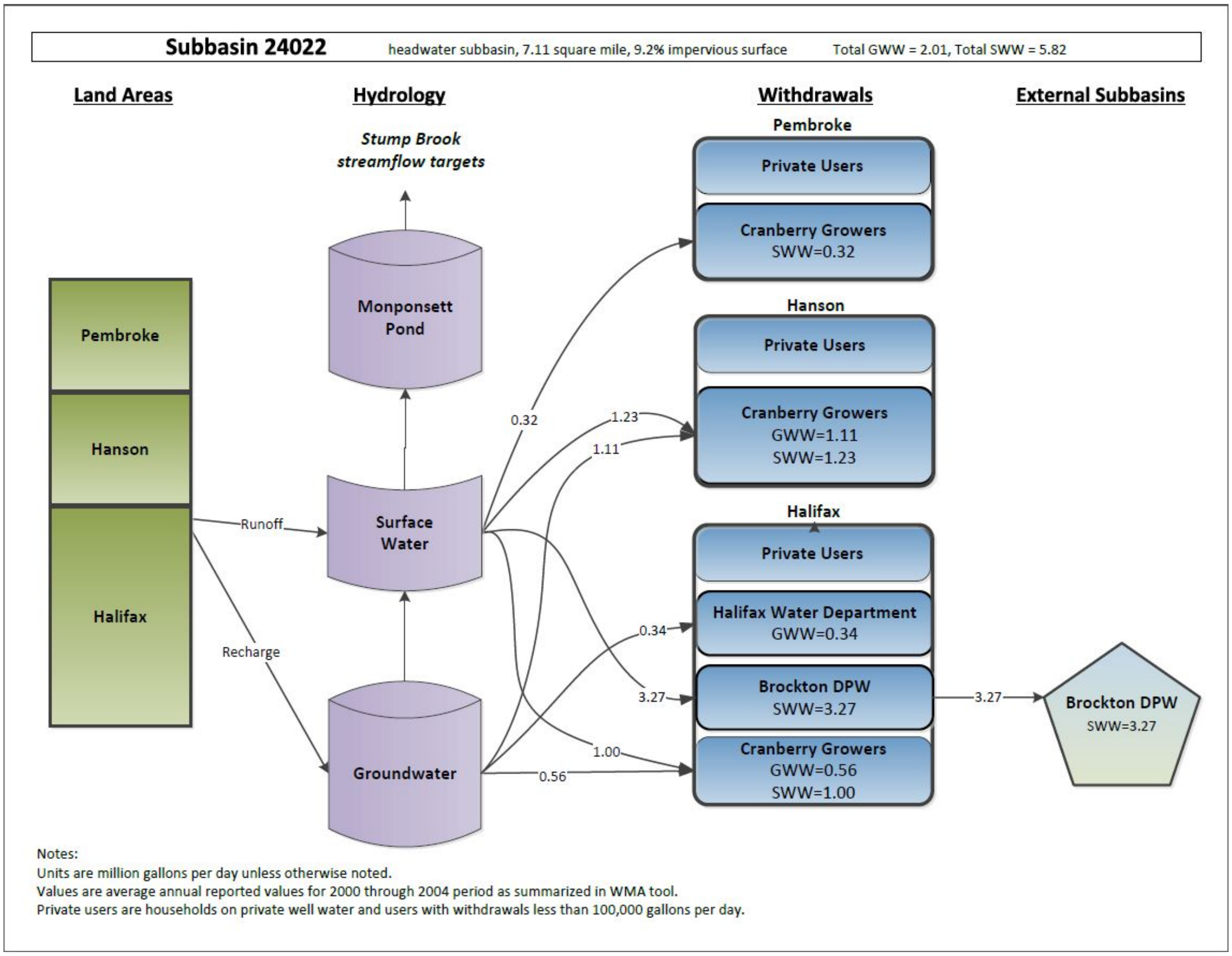
> *The Commonwealth's water resources are public resources that require sustainable management practices for the well-being and safety of our citizens, protection of the natural environment, and for economic growth.*

Beginning in 2014, the SWMI framework guides permitting decisions by the Massachusetts Department of Environmental Protection (MassDEP) via the Water Management Act, based on the principles of safe yield, seasonal streamflow criteria, and a baseline reference.

Monponsett Pond Watershed

The Monponsett Pond watershed is 1,732 hectares in size, split roughly equally between the East and West Ponds. The two ponds are similar in size (MP-East volume = 2.04 Mm3, average depth = 1.84 m; MP-West volume = 2.61 Mm3, average depth = 2.09 m). The annual water balance is dominated by groundwater inputs (Princeton Hydro 2013) and by diversion outflows (**Exhibit 3).**

Exhibit 3: Water balance in Monponsett Pond subbasin



The MP watershed is located in the 118,900 hectare Taunton River Basin (TRB). Within the TRB, 44 percent of the basin is underlain by sand and gravel deposits, supporting several well-developed aquifers. The remaining 56 percent of the basin is underlain by till and fine-grained stratified deposits, of which 36 percent is till, 7 percent is fine-grained deposits, and 13 percent is flood-plain alluvium. Land-use in the TRB in 1999 was predominantly undeveloped (67 percent), including forested, wetlands, open water, and open nonresidential categories. Agricultural land composed 5 percent of the basin, with another 2 percent devoted to cranberry bogs. Twenty two percent of the basin was classified as residential, 3 percent of which was high density, with the remaining 4 percent of the basin classified as commercial-industrial-transportation (Barbaro et al. 2012).

For the purposes of this modelling exercise, we focus on the MP drainage area bounded by the subbasin 24022 according to the Massachusetts Water Management Act (WMA) subbasin mapping (**Exhibit 1**). Subbasin 24022 is a headwater system with an area of 7.11 square miles, of which 9.2 percent is impervious. The drainage area is located approximately half in the town of Halifax, one-quarter in Pembroke and one-quarter in Hanson, MA. The town of Halifax has an annual demand of 0.45 to 0.55 MGD (2006-2012), more than 75 percent of which is residential, and some of which is sold to Pembroke Water. Halifax public water is supplied by 4 groundwater withdrawals in 2 subbasins, with some private wells in the basin as well. Halifax has a WMA baseline withdrawal allocation of 0.54 MGD.

Under the WMA, all groundwater withdrawal permittees must meet permit “standard conditions” 1-8 in the Regulations. These standard conditions include performance requirements for residential per capita water use, percent unaccounted-for-water (UAW), limits on non-essential outdoor water use, and minimum water conservation best management practices (BMPs) that follow Massachusetts’ Water Conservation Standards (EEA and WRC, 2012), such as leak detection and repair, among others. Halifax currently meets the WMA performance standards,[49] with a water usage rate of 53 Residential Gallons Per Capita per Day (RGPCD), UAW of 3.2 percent, and limitations on outdoor watering.

Purpose of the Modeling Study

We used WMOST to evaluate management approaches to meet water demand in Halifax, Brockton, and other towns that affect or depend on MP, while also ensuring streamflow targets out of MP that are environmentally protective of the critical habitat in Stump Brook.

Represented in the model are:

- Surface water reservoir representing the two MP basins;
- The land area draining to MP;
- Water diversions from MP to SL to meet Brockton water needs;
- Halifax groundwater withdrawals within the MP watershed;
- Septic system returns;
- Other withdrawals and returns occurring within the MP watersheds;
- Outlet of MP, which feeds into Stump Brook; and

[49] According to WMA, standard conditions include RGPCD of 65 or less, and UAW of 10 percent or less.

- Various water management approaches, including stormwater management practices, demand management, and aquifer storage and recovery.

The model was developed to explore various management questions such as: How much water can be diverted from MP to SL and during which period in order to maintain minimum outflows to Stump Brook? What improvements in outflow levels may be accomplished by changing water demand within the subbasin? Related water quality issues will not be addressed until development of version 3 of WMOST, which will include a water quality module.

In the next section, we describe the process used to set up the WMOST MP model.

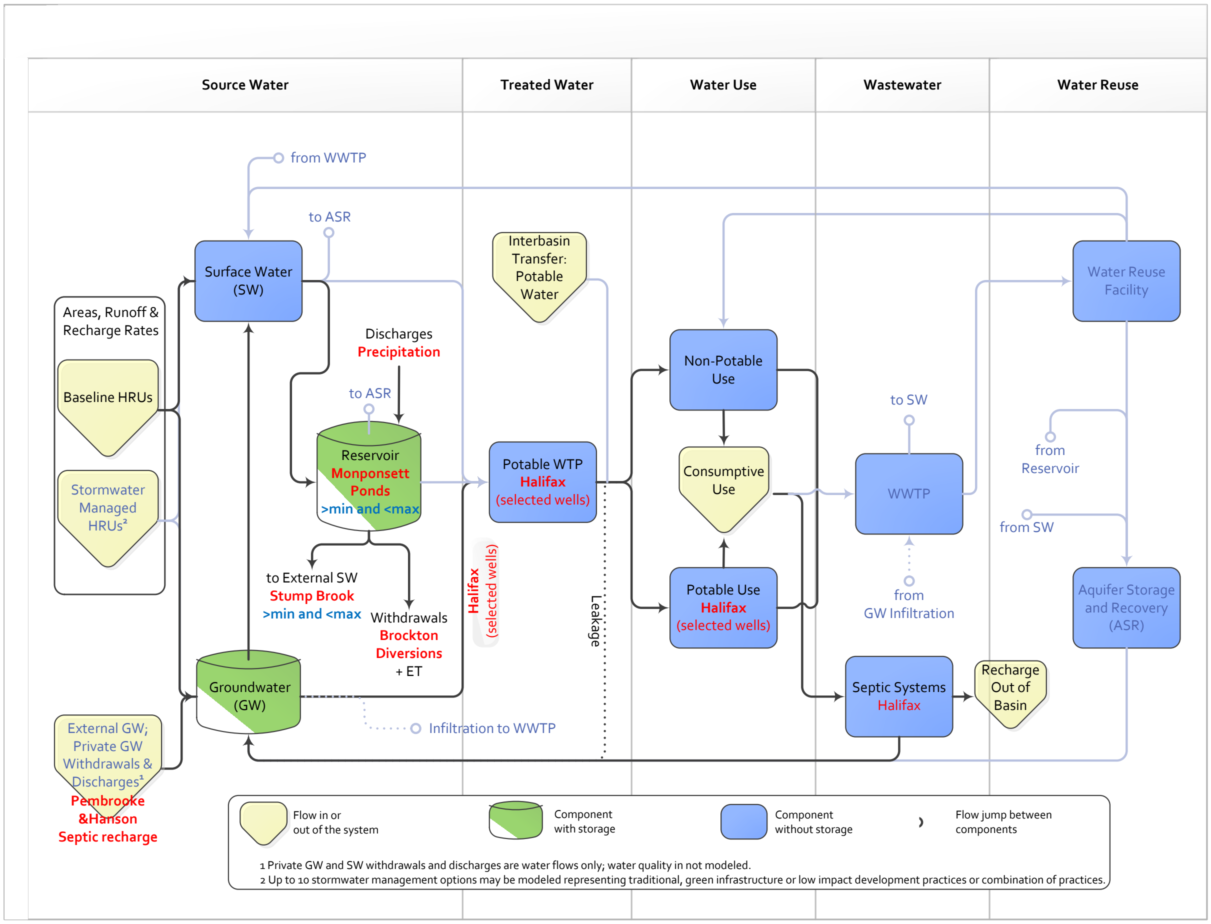
Model Setup

We defined desired performance measures for the model as follows.

- ***Significant water users are included especially those that may be targets for management alternatives***. Stakeholders have identified these users to be Brockton diversions, and stormwater and bog operations. In addition, the town of Halifax has two well fields located close to MP.
- ***Known, consequential processes are represented***. For example, stakeholders requested information and consideration of the interaction between the shallow aquifer system and MP.
- ***The model provides acceptable comparison of flow and lake elevation/volume with measured data***. As described below, we used lake elevation data for the MP outlet obtained from BWS for comparisons of modelled versus measured data. WMOST calculates and tracks volume rather than elevation; therefore we converted measured elevations into volumes using available bathymetry data (Princeton Hydro, 2013) and compared with WMOST to assess percent error, applying the total volume criteria of 10 percent.

Exhibit 4 shows selected relevant components of the MP system as represented in WMOST. We describe selected model components below.

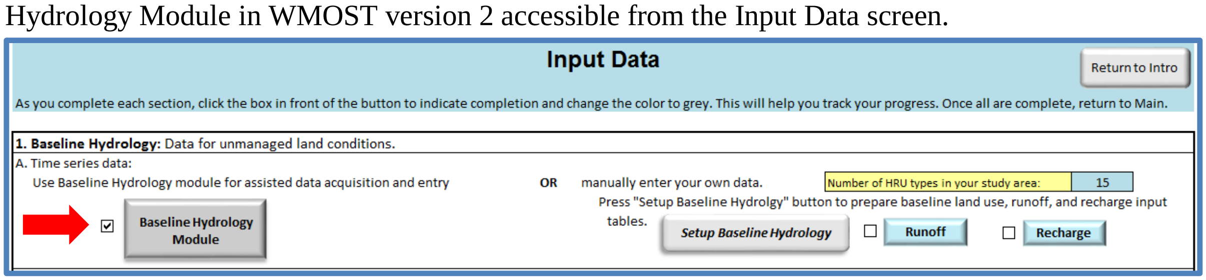
Exhibit 4: Selected model components and their representation of MP watershed features.



Land Use

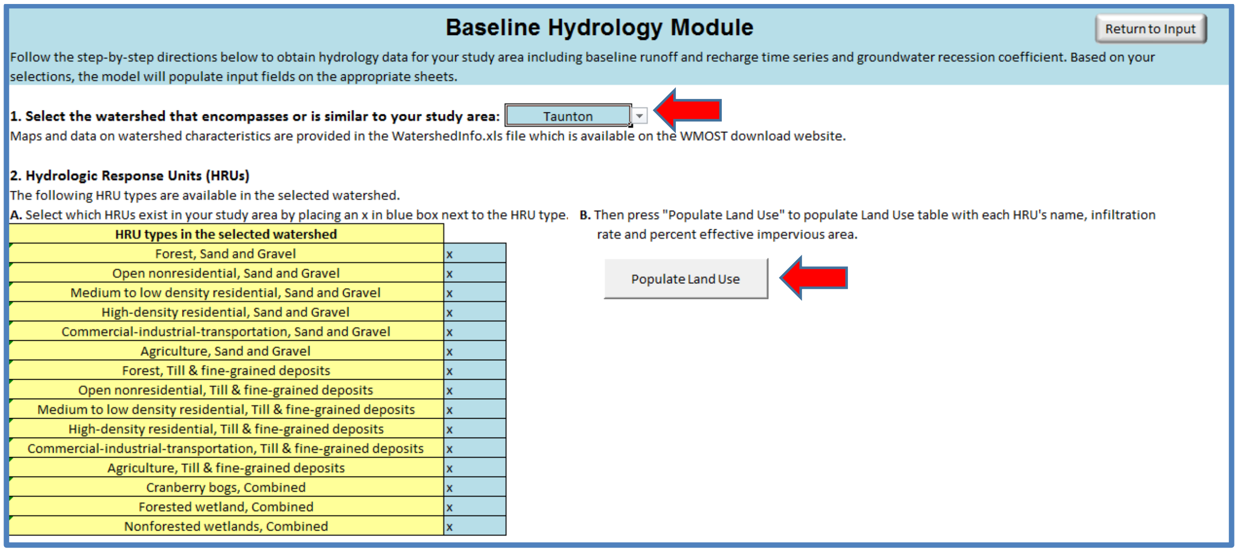
MP is one of the subbasins of the TRB. The USGS developed a detailed HSPF model of the TRB (Barbaro et al. 2013), which we used to obtain the data necessary to model the MP subbasin. These data include the area of hydrologic response units (HRUs)[50] within subbasins, HRU runoff and recharge rates, pumping rates and groundwater storage volumes (see Appendix B).

The Taunton watershed is covered by one of the "pre-processed" datasets available in the Baseline Hydrology Module in WMOST version 2 accessible from the Input Data screen.



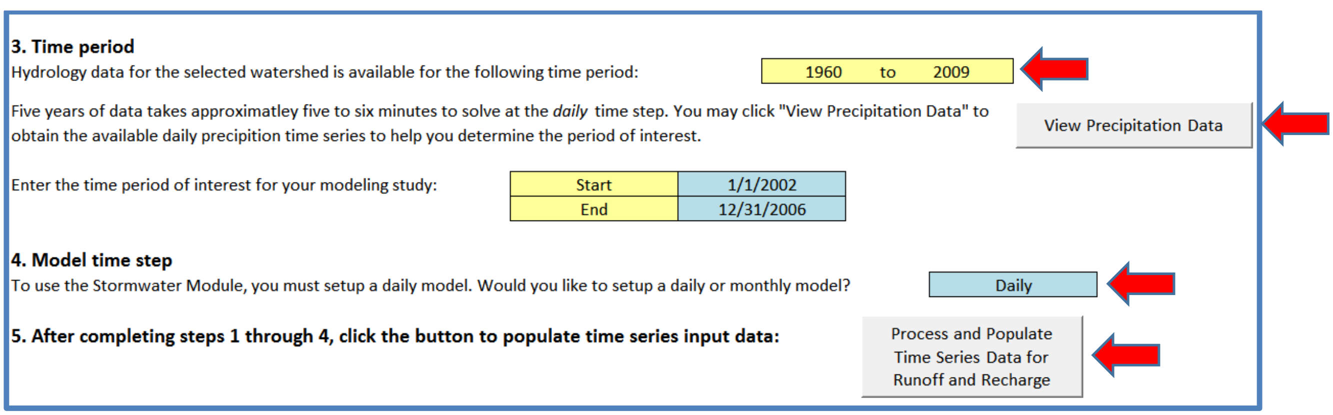
[50] HRUs are areas of similar hydrology due to similar characteristics such as land use, soil and/or slope.

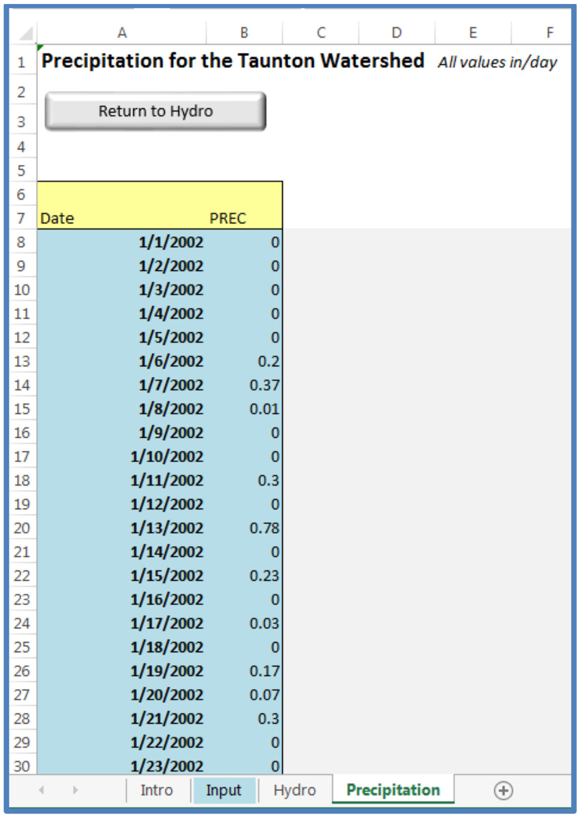
We populated the Hydrologic Response Units (HRUs) by selecting the Taunton Watershed from the Baseline Hydrology menu and then selecting those present within the MP subwatershed by marking the right-hand column with an X:



In this case, all 15 HRU types in the Taunton watershed are also present in the MP subwatershed so all were selected. We clicked on “Populate Land Use” to set up the HRU table.

WMOST next prompts the user to select the time series endpoints of interest from within the range of years for which hydrology data are available. We chose the period 2002-2006 to evaluate baseline conditions. This corresponds to the calibration period for the initial HSPF model. Users are encouraged to examine the 50-year historic record of precipitation by clicking on the “View Precipitation Data” button to compare optimum management strategies for a combination of wet and dry periods as well as average conditions.





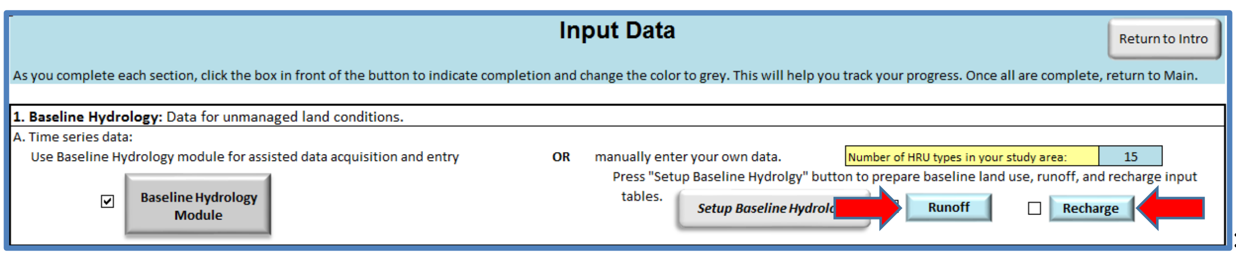
Precipitation for the Taunton Watershed *All values in/day*

Return to Hydro

Date	PREC
1/1/2002	0
1/2/2002	0
1/3/2002	0
1/4/2002	0
1/5/2002	0
1/6/2002	0.2
1/7/2002	0.37
1/8/2002	0.01
1/9/2002	0
1/10/2002	0
1/11/2002	0.3
1/12/2002	0
1/13/2002	0.78
1/14/2002	0
1/15/2002	0.23
1/16/2002	0
1/17/2002	0.03
1/18/2002	0
1/19/2002	0.17
1/20/2002	0.07
1/21/2002	0.3
1/22/2002	0
1/23/2002	0

Intro | Input | Hydro | Precipitation

In this case we chose the daily time step because we will be using the Stormwater Module. Then we clicked on the “Process and Populate Time Series Data for Runoff and Recharge” to populate the hydrology time series. These time series can be viewed by returning to the input data screen and clicking on the Runoff and Recharge buttons, respectively.



:

Runoff Rates

Return to Input

Time series of runoff rate from all HRUs for baseline condition and managed land use conditions.

Enter data in blue input fields for available time period. Time series must be consecutive, e.g., no skipped days. For monthly time step, the day of the mont

Units: inches/time step

min= 0

Date (mm/dd/yyyy)	Baseline HRU Set (HRU) HRU1	HRU2	HRU3	HRU4	HRU5	HRU6	HRU7	HRU8	HRU9	HRU10	HRU11	HRU12	HRU13	HRU14	HRU15
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1/1/2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1/2/2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1/3/2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1/4/2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1/5/2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1/6/2002	2.63E-05	0.008073	0.008326	0.028906	0.123933	4.14E-05	6.71E-06	0.008309	0.008345	0.028287	0.124716	0.000122	0.0015	0.00047	0.001515
1/7/2002	4.05E-05	0.016124	0.016635	0.05778	0.247798	6.28E-05	7.98E-05	0.016908	0.016826	0.056954	0.250734	0.000497	0.006142	0.002187	0.006277
1/8/2002	1.4E-07	0.000642	0.000663	0.002307	0.009904	2.1E-07	6.64E-06	0.000679	0.000677	0.002268	0.00994	1.75E-05	0.000097	7.92E-05	0.000099
1/9/2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1/10/2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1/11/2002	1.47E-05	0.012519	0.01292	0.044921	0.192813	2.2E-05	0.000455	0.012916	0.01307	0.043835	0.193129	0.000203	0.000522	0.000169	0.000538
1/12/2002	0	0	0	0	0	0	0	0	8.04E-08	0	0	2.16E-07	0	0	0
1/13/2002	7.75E-05	0.033823	0.034901	0.121252	0.520027	0.000113	0.000391	0.035805	0.035761	0.120471	0.527892	0.001258	0.022376	0.006318	0.021371
1/14/2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Recharge Rates

Return to Input

Time series of recharge rate from all HRUs for baseline condition and managed land use conditions.

Units: inches/time step

min= -0.1425

Date (mm/dd/yyyy)	Baseline HRU Set (HRU) HRU1	HRU2	HRU3	HRU4	HRU5	HRU6	HRU7	HRU8	HRU9	HRU10	HRU11	HRU12	HRU13	HRU14	HRU15
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1/1/2002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0040	0.0011	0.0028	0.0072	0.0034	0.0079	0.0050	0.0080
1/2/2002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0037	0.0011	0.0027	0.0065	0.0032	0.0072	0.0046	0.0073
1/3/2002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0034	0.0010	0.0025	0.0059	0.0030	0.0066	0.0044	0.0067
1/4/2002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0032	0.0010	0.0024	0.0054	0.0028	0.0061	0.0041	0.0062
1/5/2002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0030	0.0010	0.0022	0.0049	0.0027	0.0057	0.0038	0.0060
1/6/2002	0.0693	0.1015	0.0786	0.0875	0.0882	0.1018	0.0385	0.0628	0.0462	0.0492	0.0693	0.0593	0.0583	0.0454	0.0610
1/7/2002	0.1535	0.2141	0.1723	0.1896	0.2060	0.2147	0.1233	0.1855	0.1358	0.1553	0.2329	0.1751	0.1902	0.1352	0.1998
1/8/2002	0.0062	0.0083	0.0067	0.0079	0.0103	0.0084	0.0120	0.0231	0.0149	0.0204	0.0256	0.0223	0.0217	0.0154	0.0221
1/9/2002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0052	0.0130	0.0073	0.0112	0.0145	0.0124	0.0137	0.0095	0.0135
1/10/2002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0047	0.0111	0.0065	0.0095	0.0124	0.0107	0.0121	0.0083	0.0120
1/11/2002	0.1350	0.1818	0.1474	0.1643	0.2019	0.1814	0.1269	0.1626	0.1394	0.1438	0.1749	0.1591	0.1538	0.1129	0.1611
1/12/2002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0058	0.0125	0.0072	0.0109	0.0159	0.0122	0.0154	0.0103	0.0151
1/13/2002	3.9E-01	4.8E-01	4.1E-01	4.4E-01	4.9E-01	4.8E-01	3.5E-01	4.7E-01	3.7E-01	4.2E-01	5.8E-01	4.4E-01	5.5E-01	4.2E-01	5.6E-01
1/14/2002	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E-04	0.0E+00	2.0E-02	2.9E-02	2.4E-02	2.8E-02	2.4E-02	3.1E-02	2.2E-02	1.9E-02	2.2E-02

At this point, we returned to the Input screen and selected Land Use to populate land areas for each of the HRUs.

Input Data

Return to Intro

As you complete each section, click the box in front of the button to indicate completion and change the color to grey. This will help you track your progress. Once all are complete, return to Main.

1. Baseline Hydrology: 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. Number of HRU types in your study area: 15

☑ **Baseline Hydrology Module**

Press "Setup Baseline Hydrolgy" button to prepare baseline land use, runoff, and recharge input tables. ***Setup Baseline Hydrology*** ☐ **Runoff** ☐ **Recharge**

B. Land Use: Enter HRU areas and costs for land conservation ☑ **Land Use**

Land Use and Its Management

Return to Input | Return to Baseline Hydrology

For management options that are not applicable or desired for an HRU, enter -9 for costs.
For Minimum and Maximum Areas, enter -9 if there is no limit on the area for a type of HRU.
Allocation of area among Managed HRU sets are mutually exclusive (i.e., one acre may only receive one management type).
O&M = Operations and maintenance
Starred variables are **not required if the Hydrology Module is used* ***Starred variables are **not** required if the Stormwater*

Baseline HRU Characteristics

HRU ID	*HRU Name	Baseline Area [acre]	*Percent Effective Impervious	*Infiltration Rate [in/hr]
HRU1B	Forest, Sand and Gravel	834	0.0%	9.5
HRU2B	Open nonresidential, Sand and Gravel	74	4.3%	8.455
HRU3B	Medium to low density residential, Sand and Gravel	598	4.4%	8.075
HRU4B	High-density residential, Sand and Gravel	322	15.3%	5.95
HRU5B	Commercial-industrial-transportation, Sand and Gravel	61	65.7%	3.08
HRU6B	Agriculture, Sand and Gravel	10	0.0%	8.01
HRU7B	Forest, Till & fine-grained deposits	161	0.0%	0.938
HRU8B	Open nonresidential, Till & fine-grained deposits	2	4.3%	0.832
HRU9B	Medium to low density residential, Till & fine-grained deposits	29	4.4%	0.806
HRU10B	High-density residential, Till & fine-grained deposits	62	14.9%	0.605
HRU11B	Commercial-industrial-transportation, Till & fine-grained deposits	2	65.8%	0.336
HRU12B	Agriculture, Till & fine-grained deposits	13	0%	0.768
HRU13B	Cranberry bogs, Combined	340	0%	0.2
HRU14B	Forested wetland, Combined	64	0%	0.2
HRU15B	Nonforested wetlands, Combined	47	0%	0.2

Data for Land Conservation Option

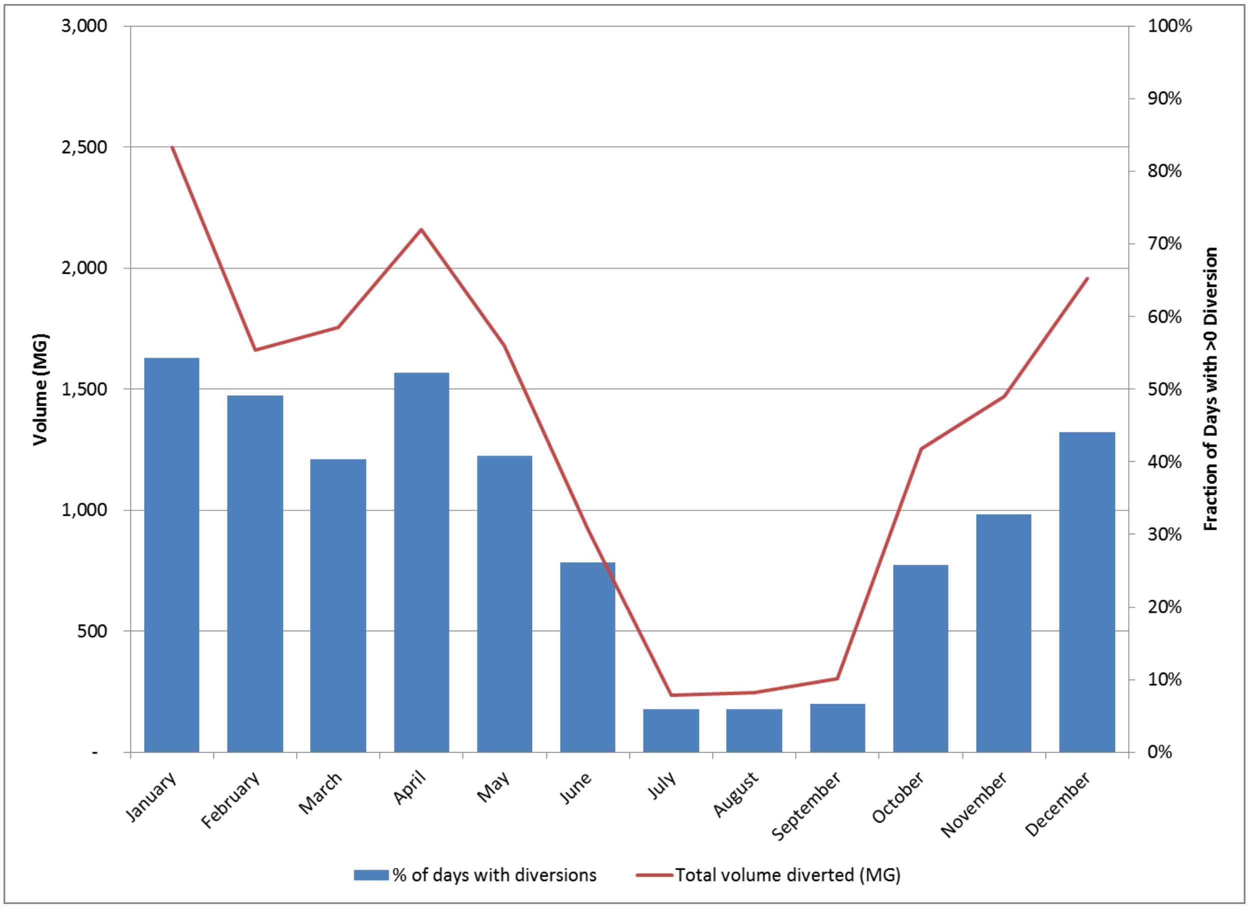
Minimum Area [acre]	Maximum Area [acre]	Initial Cost to Conserve [$/acre]	O&M Cost [$/acre/yr]
834	834	-9	-9
74	74	-9	-9
598	598	-9	-9
322	322	-9	-9
61	61	-9	-9
10	10	-9	-9
161	161	-9	-9
2	2	-9	-9
29	29	-9	-9
62	62	-9	-9
2	2	-9	-9
13	13	-9	-9
340	340	-9	-9
64	64	-9	-9
47	47	-9	-9

For the baseline simulation, we entered the baseline area associated with each HRU in the MP subwatershed. Percent effective impervious area and infiltration rates were automatically filled in based on the Taunton HSPF model parameters. For the initial set-up, the land areas associated with each HRU are fixed so minimum and maximum areas in the Land Conservation Option table are identical and set to existing values.

Brockton Diversions to Silver Lake and Precipitation on MP

We obtained the time series of water volumes diverted from MP to SL from BWS. The time series covers the period of October 1996 through December 2013 and provides the volume diverted from MP each day. **Exhibit 5** shows the pattern of average diversions by month for the period of 2001 through 2006.

Exhibit 5: Pattern of diversions from MP to SL during the 2001-2006 period, by month.



We combined this information with the evapotranspiration (ET) time series from HSPF as input in WMOST for Reservoir withdrawals in the Surface Water tab (**Exhibit 6**). Reservoir discharges, which represent inflow of water into the reservoir, were set to the amount of precipitation falling directly on MP.

For the baseline scenario, we specified the reservoir outflow to match observed data (see Section 1.3.1) whereas this parameter is a management decision in the management scenarios discussed in Section 1.3.

Exhibit 6: WMOST Surface Water input tab

Surface Water: Streamflow and Surface Storag Return to Input

Initial reservoir/surface storage volume			1,545	[MG]	*Stage Limit*	
Minimum target reservoir/storage volume			1,454	[MG]	52.00	
Existing maximum reservoir/storage volume			1,945	[MG]	54.50	
Initial construction cost			0	[$/MG]		-9
O&M costs			0	[$/MG]		No
sum over all time	0	0	0	17183	5957	-

Date (mm/dd/yyyy)	Private Sw Withdraw al [MG/time step]	Private Sw Discharge [MG/time step]	External Sw Inflow [cfs]	Res Withdraw al [MG/time step]	Res discharge[MG /timestep]	Res outflow [MG/time step]
1/1/2002	0.00	0.00	0.00	0.05	0.00	0.00
1/2/2002	0.00	0.00	0.00	0.09	0.00	0.00
1/3/2002	0.00	0.00	0.00	0.10	0.00	0.00
1/4/2002	0.00	0.00	0.00	0.08	0.00	0.00
1/5/2002	0.00	0.00	0.00	0.14	0.00	0.00
1/6/2002	0.00	0.00	0.00	0.18	4.89	0.00
1/7/2002	0.00	0.00	0.00	0.02	9.05	0.00
1/8/2002	0.00	0.00	0.00	0.06	0.24	0.00
1/9/2002	0.00	0.00	0.00	0.11	0.00	0.00
1/10/2002	0.00	0.00	0.00	0.26	0.00	0.00
1/11/2002	0.00	0.00	0.00	0.06	7.34	0.00
1/12/2002	0.00	0.00	0.00	0.14	0.00	0.00
1/13/2002	0.00	0.00	0.00	0.08	19.07	0.00
1/14/2002	0.00	0.00	0.00	29.15	0.00	0.00
1/15/2002	0.00	0.00	0.00	28.58	5.62	0.00
1/16/2002	0.00	0.00	0.00	30.02	0.00	0.00
1/17/2002	0.00	0.00	0.00	0.09	0.73	0.00
1/18/2002	0.00	0.00	0.00	0.11	0.00	0.00
1/19/2002	0.00	0.00	0.00	0.06	4.16	0.00
1/20/2002	0.00	0.00	0.00	0.12	1.71	0.00
1/21/2002	0.00	0.00	0.00	0.04	7.34	0.00
1/22/2002	0.00	0.00	0.00	22.99	0.00	0.00
1/23/2002	0.00	0.00	0.00	37.27	0.00	0.00
1/24/2002	0.00	0.00	0.00	24.70	0.98	0.00
1/25/2002	0.00	0.00	0.00	0.23	0.00	0.00
1/26/2002	0.00	0.00	0.00	0.36	0.00	0.00
1/27/2002	0.00	0.00	0.00	0.37	0.00	0.00
1/28/2002	0.00	0.00	0.00	0.40	0.00	0.00
1/29/2002	0.00	0.00	0.00	0.56	0.00	0.00
1/30/2002	0.00	0.00	0.00	0.07	2.20	0.00
1/31/2002	0.00	0.00	0.00	0.06	3.42	0.00
2/1/2002	0.00	0.00	0.00	0.05	5.14	0.00
2/2/2002	0.00	0.00	0.00	0.21	0.00	0.00
2/3/2002	0.00	0.00	0.00	0.08	0.00	0.00
2/4/2002	0.00	0.00	0.00	25.35	0.00	0.00
2/5/2002	0.00	0.00	0.00	28.53	0.00	0.00
2/6/2002	0.00	0.00	0.00	28.53	0.00	0.00
2/7/2002	0.00	0.00	0.00	3.68	0.49	0.00
2/8/2002	0.00	0.00	0.00	0.43	0.00	0.00

Surface Water | Septic | Interbasin | Measured Flow | Floc

Validation and Baseline Simulation

Ideally, WMOST user will have access to measured flow data or HSPF modelled flow data for the reach of interest. These data are entered using the "measured flow" button on the main data entry screen.

The first modeling step was to determine the accuracy of using data from the TRB HSPF model in WMOST to represent the water balance of the MP watershed. For this particular case study, there is no USGS gaging station at or near the watershed outlet. Only sporadic stage measurements are available for Stump Brook and discharge measurements are insufficient to develop a stage-discharge relationship. We initially tried to compare the HSPF model output for outflows from the MP reach with WMOST modelled flows but this approach failed for two reasons. Due to the large coverage of wetlands in the MP subbasin (>20%), USGS generated the HSPF model outputs for the MP subbasin using an artificial modelling construct termed a "virtual wetland" to allow for adjustment of wetlands ET during drought periods (Barbaro et al. 2012). In the HSPF model, all recharge and runoff are routed to a wetlands storage component and then released according to a specified stage-discharge curve. Maximum wetlands storage is calculated assuming a water depth of 1 meter in wetlands. When wetlands storage volume reaches a critical low level, the stage-discharge relationship shifts to reflect the potential decrease in surface area of wetlands and ET is reduced accordingly. WMOST is not designed to incorporate this intermediate storage compartment and does not replicate the HSPF flow time series for this particular reach. In addition, HSPF model developers did not account for flow regulation at the outlet of MP.

As an alternative approach to validate the WMOST water balance, we used the measured MP water levels and the available hypsographic curve for MP (Princeton Hydro 2013) to generate a volume time series for MP storage. We compare the estimated reservoir volume to this "observed" MP volume time series to verify that the model provides a reasonable approximation of volumes over time.

Baseline Model Setup

We used the hydrology runoff and recharge time series and pumping data from HSPF (Zariello et al. 2005). The time period of simulation was limited to the available surface water and groundwater pumping data in the HSPF model which covered the years from 2002 to 2006. We included cranberry bogs as an HRU and thus excluded withdrawals for cranberry bog irrigation (included in the HSPF model) to avoid double-counting ET. We used the following data for the baseline simulation:

- Precipitation time series from Daymet.[51] We noted differences between local precipitation and precipitation recorded at the Warwick RI station used by HSPF. Overall, precipitation in Halifax, MA was 20 percent greater than in Warwick RI during the period.
- Land areas, runoff rates, and recharge rates for 15 HRUs for 2002-2006. We adjusted the data to reflect differences in precipitation noted above. Notably, we adjusted precipitation, runoff, and evapotranspiration obtained from HSPF by a factor of 1.2.
- Surface water.
- This is a headwater basin so there are no external surface water inflows
- Reservoir/surface water storage: Two basins of MP are modelled as a single basin
- Private/other surface water withdrawal based on measured diversions to Brockton via Silver Lake. We did not include withdrawals for cranberry bog growers as cranberry bogs are also represented by HRUs and therefore included in the runoff and recharge time series.
- Daymet-based precipitation inputs to surface water area
- ET withdrawal from surface water area

Outflows from MP based on reservoir operating rules (see Section **Reservoir Outflows** below)

- Groundwater
- Minimum, maximum and initial storage as well as recession coefficient (groundwater recession coefficient of 0.067 was obtained directly from HSPF).
- No private/other groundwater withdrawals, discharges or external groundwater inflows:
- Surface water and groundwater pumping data from 2002 to 2006

[51] Downloaded from http://daymet.ornl.gov/singlepixel.html. The HSPF model relied mostly on weather station from T.F. Greene Airport near Warwick, RI and did not account for spatial variability in precipitation across the Taunton River basin

- Human demand
- Disaggregated HSPF pumping data based on MA Department of Environmental Protection (DEP) Annual Statistical Report (ASR) data into five user types. Monthly data from the ASRs were divided by the number of days in the month to construct a daily time series.
- Consumptive use values for each user based on literature values (Vickers 2012[52]):
- Wastewater
- Assumed all of Halifax and portions of Hanson and Pembroke in Subbasin 33 are on septic
- Assumed that half of the water is supplied to Halifax customers within the basin:
- Exclusion of all management options (-9 entered)
- Instream flow targets
- No constraint on minimum or maximum instream flows.

Reservoir Outflows

Outflows from the fishway in the MP Dam are currently monitored via flowmeter, but these data were not collected prior to 2013. We evaluated the stage-discharge relationship using measured MP levels and fishway flow data. However, the plotted relationship demonstrated multiple embedded curves due to shifts in dam operation (e.g., opening or closing the sluice gate upstream of the fishway, installation of stoplogs). Given the uncertainty in actual outflows, we ran a series of WMOST simulations using outflows estimated based on the following operating regimes:

1) Conservative mode (drought conditions):
    a. Full spillway discharge over dam flashboard (53.5 ft. elevation[53]) based on modified Princeton Hydro (2013) equation for narrow crest weir
    b. Release of 0.9 mgd through fishway only during Brockton diversions and during herring runs (GHD 2015[54]).
2) Minimum compliance plus stage management goal to maximize potential water withdrawals:
    a. Full spillway discharge over dam flashboard (53.5 ft. elevation) based on modified Princeton Hydro equation for narrow crest weir
    b. Release of average 0.9 mgd through fishway only during Brockton diversions and during herring runs (GHD 2015)
    c. Release of average 0.9 mgd through fishway when stage > 52.5 (to minimize potential flooding problems at stage of 53 ft.).
3) Maximum compliance for fishway goal of 0.9 mgd:
    a. Full spillway discharge over dam flashboard (53.5 ft. elevation) based on modified Princeton Hydro equation for narrow crest weir.
    b. Average release of 0.9 mgd through fishway year-round.

[52] Vickers, A. 2012. Handbook of Water Use and Conservation. WaterPlow Press. Amherst, MA.

[53] CDM. 1964. City of Brockton, Mass. Diversion Works Monponsett Pond (Outlet), License Plan No. 4987. Camp, Dresser, and McKee, Boston, MA.

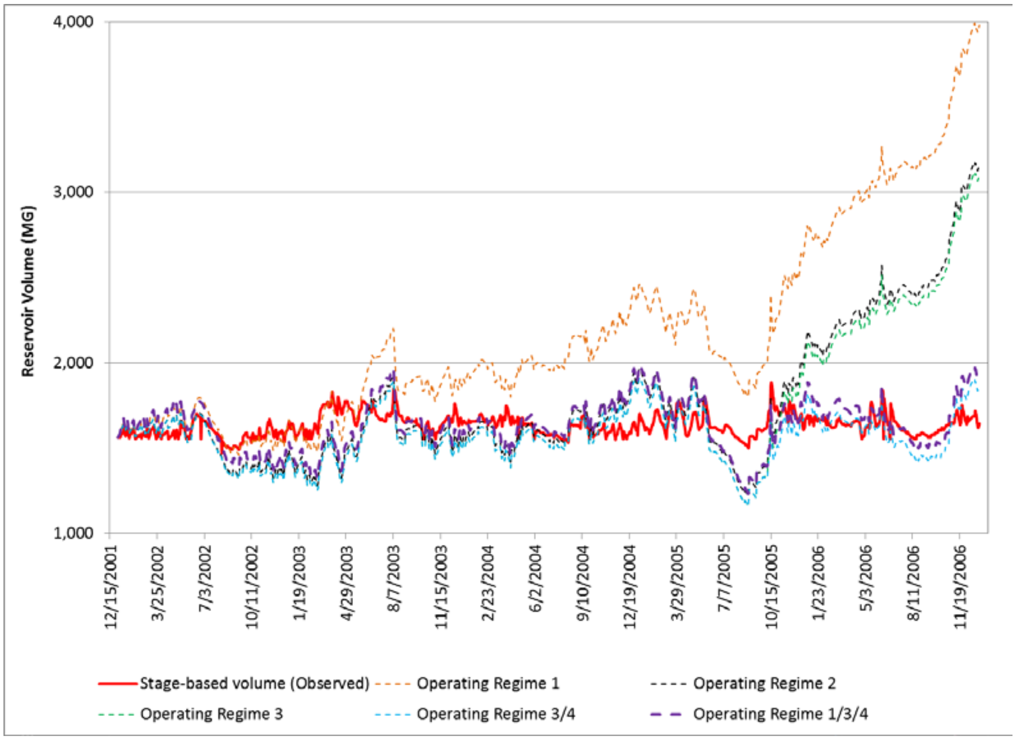
[54] GHD. 2015. Report for the Town of Halifax: Supervisory Control and Data Acquisition (SCADA) Feasibility and Design Memorandum at the Monponsett Pond System.

4) Stage management goal enabling maximum diversions, high water conditions:
    a. Full spillway discharge over dam flashboard (53.5 ft. elevation) based on modified Princeton Hydro equation for narrow crest weir
    b. Full fishway discharge (per Princeton Hydro 2013 equation) if stage > 52.5 ft.

Validation Results

Exhibit 7 compares the MP volumes modeled using the operating regimes described above including combination regimes which switch operating rules over time (3/4, 1/3/4). The simpler decision rules result in a marked break with the observed levels in October 2005 with the MP volume increasing to levels unmatched in the observed data. During the first week of October 2005, Tropical Storm Tammy hit New England, dumping up to 20 inches of rain throughout the region. This event likely triggered emergency management regimes to reduce flooding impacts and protect dam infrastructure. Accordingly, we also ran scenarios where we combined different operating regimes before and after October 2005.

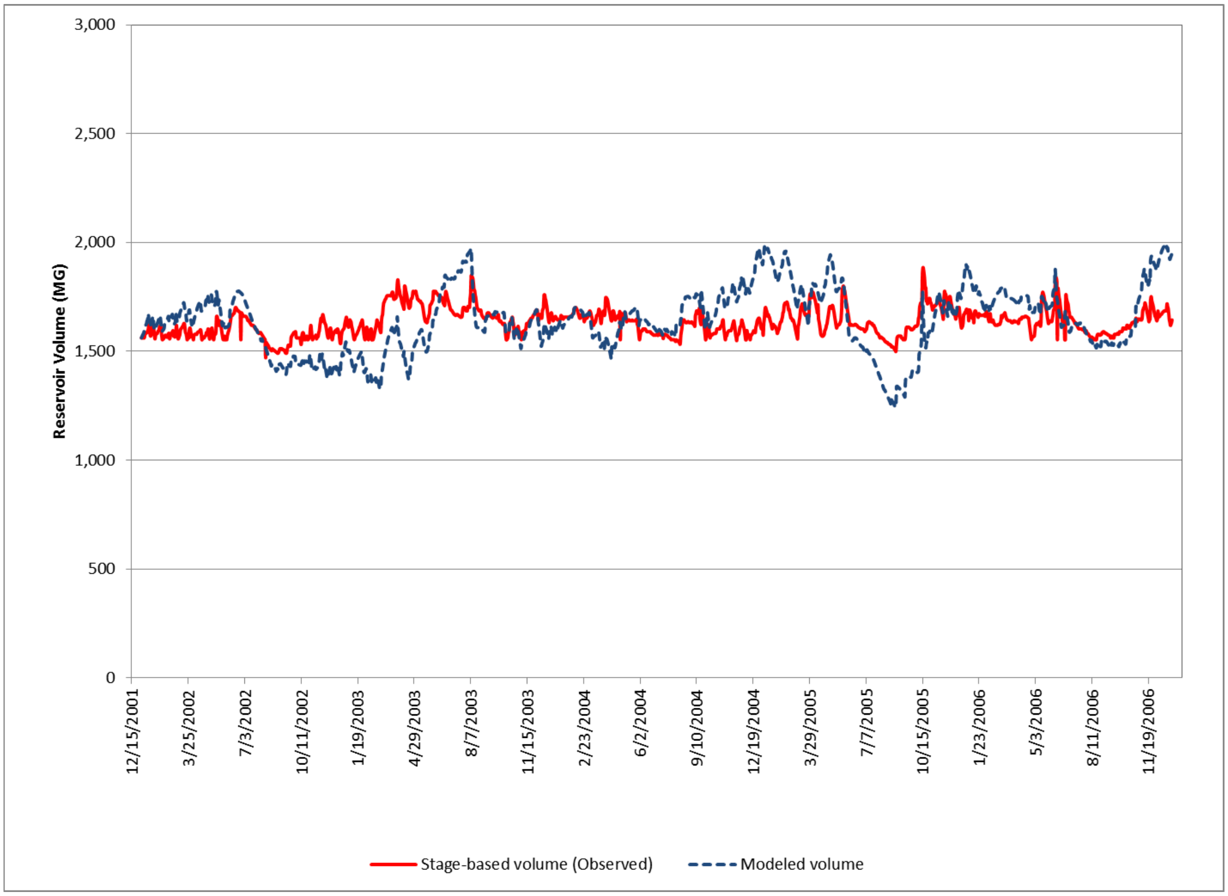
Exhibit 7: Comparison of modeled MP volume for different operating regimes to observed MP volume.



The best match between the modeled and calculated volume time series was obtained when we assumed that MP was managed under Operating Regime 3 up to October 2005 and under Operating Regime 4 after October 1, 2005.

Other adjustments to model parameters included further adjustment to the recharge by a factor of 1.4 (i.e., increased recharge by 40 percent relative to values obtained directly from HSPF), and setting the initial reservoir and groundwater volumes to match the observed MP volume at the start of the modeling period (1,545 MG and 100 MG, respectively). **Exhibit 8** shows the time series of MP volumes for the validated model, compared to observed values.

Exhibit 8: Observed and modeled MP volume during the period of 2001 through 2006. Modeled volume is based on assumed operation of the reservoir following Operating Regime 3 before October 2005 and Operating Regime 4 after October 1, 2005.



As shown in the graph of **Exhibit 8**, while patterns are similar, the modeled volume tends to be lower than derived from observed MP stage. The average difference is 4 percent over the analysis period, with the largest difference occurring toward the end of the simulation in December 2006 when the modeled pond volume is 29 percent larger than implied by the stage.

Error between observed and modeled volumes may be due to difference in the magnitude and timing of precipitation (which the coarse adjustment discussed above cannot address), as well as potential differences between the assumed operating rules and actual releases from MP. In addition, water withdrawals and returns to and from cranberry bogs for protection from freezing were not included in the water balance as they were expected to cancel one another out and only generic time series for these are available. Observed volumes are also uncertain as they were not measured directly but instead were derived from measured stage (available for only one basin of MP) and an elevation-volume relationship.[55]

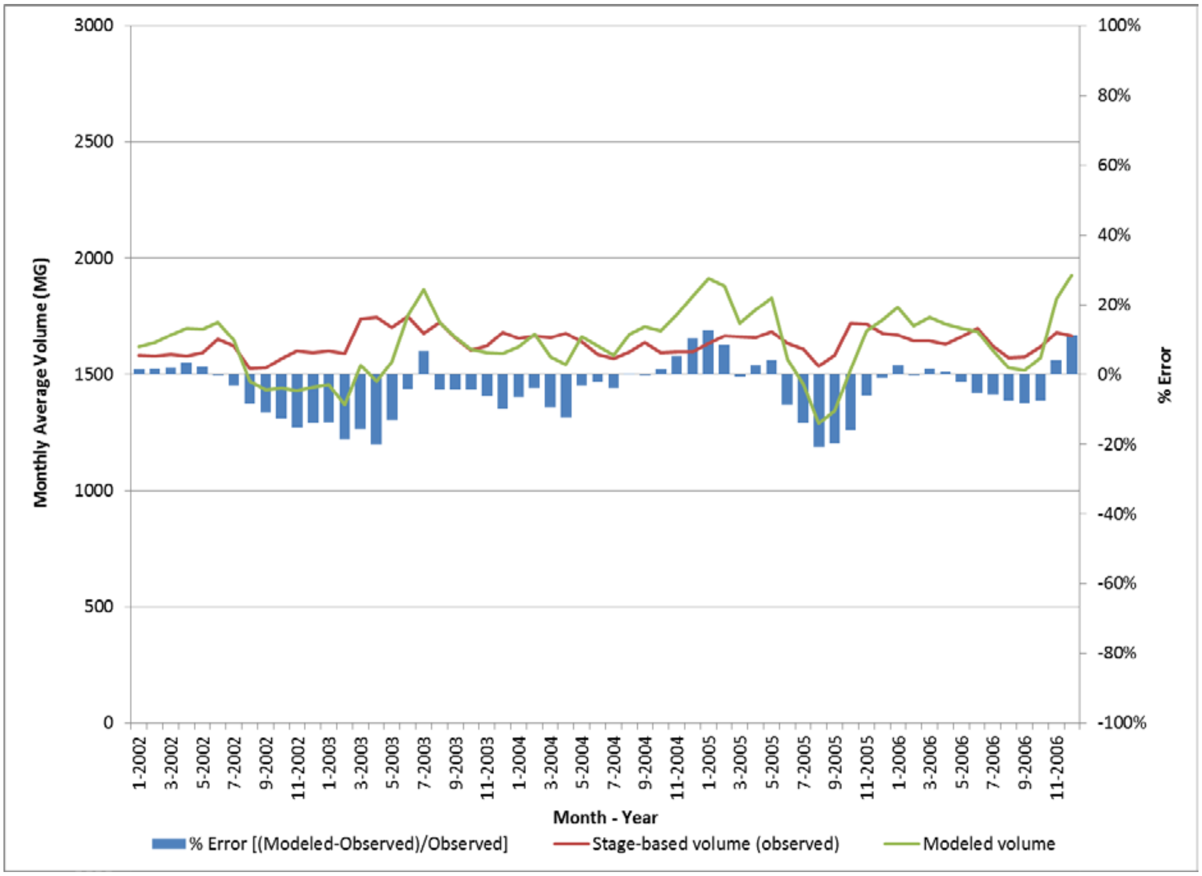
[55] The MP elevation-volume relationship is defined at 1-foot increments, to a maximum stage of 52 feet. However, the observed stage often exceeds this value, and ranged from 52.1 feet to 54.2 feet during the period of 2002 through 2006.

Exhibit 9 summarizes model fit statistics for daily, weekly, monthly and seasonal averages. **Exhibit 10** plots monthly average volumes and residuals.

Exhibit 9: Model fit statistics for different time periods.

Fit statistic	Daily	Weekly	Monthly	Annual	Seasonal
Average residual (%)	0%	0%	-4%	0%	0%
Maximum residual (%)	22%	19%	13%	3%	2%
R^2	0.170	0.171	0.162	0.070	0.998

Exhibit 10: Monthly average MP volume and residuals [(modeled-observed)/observed].



For the baseline WMOST run, we ran WMOST with the above settings and with the calibrated groundwater coefficient. Although there are options to exclude the use of new management practices, currently there is no capability to prevent the model from optimizing the use of existing infrastructure. For example, the model may select a different timing of PWS withdrawals from groundwater than the HSPF model simulated. To ensure the same behavior in WMOST as in the HSPF model, we input all human withdrawals and returns as private groundwater withdrawals and discharges under the groundwater input sheets as follows:

- Surface withdrawal: HSPF surface water withdrawals

- Groundwater withdrawal: HSPF groundwater withdrawals
- Groundwater discharge: Unaccounted for water calculated as percentage of total pumping and septic returns from Halifax adjusted for consumptive use

Management Optimization Scenarios

For the management scenarios, we specified the minimum and maximum outflows from MP, as well as minimum and maximum MP volumes (derived from specified water elevations). These specifications replace the outflow time series used in the validation simulation described in Section1.2.3. Thus, in the management scenarios, WMOST determines the outflows necessary to meet these flow and level objectives, subject to the available resources and constraints (e.g., runoff, recharge, water demand, diversions, etc.).

We ran several scenarios, changing inputs and constraints as described below, to identify the actions and associated costs for meeting management goals. The final scenario specifications were informed by results of initial runs.

Outflow Targets and MP Level Constraints

In the management scenarios, the outflow from MP is a decision variable, subject to minimum and maximum values. For most of the management scenarios we analyzed, we set the minimum value at the desired instream flows of 0.9 MGD (1.39 cfs) in Stump Brook, based on regulatory requirements. We set the maximum outflow to 60 percent of the maximum outflow estimated for the baseline scenario (84 MGD, or 130 cfs).

We also conducted model runs using higher minimum monthly flow targets corresponding to the 25th and 75th percentiles of the unaffected flow (**Exhibit 11**).

The minimum elevation of the pond was set to 52 ft. The maximum elevation of the pond was set at the crest height (53.5 ft.). This is also the height at which flooding damage may be expected to occur.[56] We converted the elevations into minimum and maximum volumes using the relationship used to derive the observed volume time series (see Section 1.2.3). For comparison purposes, we also did some model runs using a maximum volume corresponding to the old crest height of 53 ft. before Brockton raised it.[57]

[56] Note that in other cases in which users wish to minimize costs (including flooding damage), this will be accomplished via the flooding module. In this case study, potential flooding damage is limited to local areas surrounding MP rather than along downstream reaches. Data from the Flood Insurance Studies had too coarse a spatial resolution to include the outlet reach from MP. Instead, we estimated potential building damage in HAZUS after creating flood grids associated with different pond stages based on local topography.

[57] Per suggestions in the Princeton Hydro (2013) report, the dam height could be lowered to that level and automated dam controls could be installed; these options are being evaluated under a current SWMI grant.

Exhibit 11: Unimpacted streamflows (cfs) for Stump Brook at dam from SYE tool[58] for 1961-2004.

	Percentile				
Month	**10th**	**25th**	**50th**	**75th**	**90th**
January	4.33	7.49	11.46	17.43	23.10
February	7.04	9.59	12.03	19.18	25.41
March	10.97	13.74	19.46	27.31	33.86
April	8.02	10.39	16.60	25.07	32.14
May	4.74	6.14	9.32	13.93	17.02
June	1.98	2.99	4.22	7.54	13.18
July	0.79	1.12	2.25	3.33	6.29
August	0.62	1.15	2.21	3.33	6.23
September	0.51	0.99	2.12	2.91	5.49
October	1.13	2.43	3.07	7.30	12.80
November	2.49	4.63	7.91	13.74	19.43
December	4.53	6.32	11.17	21.04	25.75

Water Demand and Diversions

For the management scenarios, we scaled the water demand for Halifax to match the most recent levels for 2009-2013, which were 6.7 percent lower than those recorded in 2002-2006. We further adjusted the demand to reflect compliance with the WMA standard permit conditions of 10 percent UAW. As noted in Section 1.2.3, Halifax already meets the other standard permit conditions of 65 RGPCD and non-essential outdoor watering.

We also adjusted the magnitude of Brockton's diversions to reflect the slightly lower demand (by 1.8 percent) during the period of 2009-2013, as compared to demand during 2002-2006. For some scenarios, we further adjusted diversions to reflect use of water from the Aquaria desalination plant (3 MGD during November-July). For the purpose of this adjustment, we assumed that Aquaria would offset diversions from MP on a gallon-for-gallon basis, i.e., using water from Aquaria reduces the amount of water needing to be diverted from MP by 23.6 percent relative to total diversions in 2002-2006.

Management Actions

We enabled different types of management actions within the model to allow selection of the lowest-cost approach to meet the specified constraints. Specifically, these actions include retrofitting stormwater BMPs and constructing and operating an aquifer storage and recovery (ASR) facility.

[58] Archfield, S.A., Vogel, R.M., Steeves, P.A., Brandt, S.L., Weiskel, P.K., and Garabedian, S.P., 2010. The Massachusetts Sustainable-Yield Estimator: A decision-support tool to assess water availability at ungauged stream locations in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2009–5227, 41 p. plus CD-ROM.

Scenarios

Exhibit 12 summarizes the menu of model specifications combined for the various scenarios analyzed in this case study.

Exhibit 12: Menu of model specifications for validation management scenarios

Model Component	Validation Scenario	Management Scenarios (Select One)		
Halifax water demand	Historical 2001-2006	Scaled to reflect more recent demand (2009-2013) and meet 10% UAW		
Brockton water diversions	Historical	Scaled to reflect more recent demand (2009-2013)	Scaled to reflect more recent demand (2009-2013) + Aquaria at 3 MGD in November-July	Scaled to reflect more recent demand (2009-2013) + Aquaria at 3 MGD in Nov-July + additional 10-20% demand reduction
Reservoir volume (based on stage)	No constraint	52ft - 54.5ft	52ft - 53.5ft	52ft - 53ft
Stump brook flow	No constraint	Uniform target of 1.39 cfs	Monthly target based on 25th percentile of SYE	Monthly target based on 75th percentile of SYE
Reservoir withdrawals	Specified based on historical record	Scaled diversions based on adjusted demand and historical distribution	Scaled diversions based on adjusted demand and uniform distribution	
Reservoir outflows	Specified based on historical record	Estimated in model		
Management options	None	Stormwater BMPs (bioretention basins and infiltration trenches sized for 0.6”, 1”, or 2” events)	Stormwater BMPs (bioretention basins and infiltration trenches sized for 0.6”, 1”, or 2” events) and ASR	Stormwater BMPs (bioretention basins and infiltration trenches sized for 0.6”, 1”, or 2” events) and IBT

We discuss selected scenarios below.

Results Comparing Historical Versus Uniform Pattern of Diversions

Two scenarios were run to evaluate the effect of changing the pattern of Brockton diversions from the historic record to a uniform distribution over the entire year. The two following scenarios would normally be infeasible and runs of WMOST would produce null results due to insufficient water being available to meet the system constraints. To ensure that results were obtained for review, we allowed for a hypothetical, very expensive source of supplemental water as a possible management option on the infrastructure input tab (see “make-up water” specifications on **Exhibit 13**). The specified cost for this variable determines the “penalty” the model will incur for having to use the decision variable to meet the constraint; we set this cost to a significantly greater value than that of any other water source available within the watershed so that the management practice is used as final resort when there is no other way to reach water balance in the system.

Exhibit 13: WMOST infrastructure input tab

Nonpotable Water Distribution System	Value	Units	Exclude New/Additional
Consumer's pricefor nonpotable water: Fixed fee	0.00	$/month	-9
Consumer's pricefor nonpotable water: Variable, volume-based fee	3.02	$/HCF	
Capital cost for additional capacity	29,119,740	$/MGD	
O&M costs	1,716	$/MG	
Existing maximum capacity	0.00	MGD	
Lifetime remaining on existing infrastructure	0	yrs	
Lifetime of new construction	35	yrs	

Aquifer Storage and Recovery (ASR)	Value	Units	Exclude New/Additional
Capital cost for additional/new capacity	1,882,957	$/MGD	-9
O&M costs	3,769	$/MG	
Existing maximum capacity	0	MGD	
Lifetime remaining on existing infrastructure	0	yrs	
Lifetime of new construction	35	yrs	

Make-Up Water			Exclude New/Additional
Cost for make-up water	100,000	$/MG	-9

Nonpotable Demand | Demand Mgmt | **Infrastructure** | Potable Demand | Groundwater | Surface Water | Septic | Interbasin | Meas

The two runs each specified minimum and maximum stages of 52.0 and 54.0 feet, respectively, and the regulatory target flow rate of 1.39 cfs. Halifax water demand was adjusted downwards based on recent use rates (2009-2013). In one scenario, the historical pattern of Brockton withdrawals was used, while in the second scenario, Brockton diversions were spread evenly over all days of the year. Results showed that the number of days showing a deficit (i.e., inadequate volume for water withdrawals) increased from 7 to 61 and the water deficit increased from 1.4 percent to 12.3 percent of the Brockton diversion volume. **Exhibit 14** shows the time series of reservoir volumes, withdrawals, outflows and make-up water flows for the scenario assuming uniform daily withdrawals. The red line shows the 61 days with water deficits.

Exhibit 14: Time series of Reservoir Volumes, Withdrawals, Outflows and Water Deficits for the Uniform Withdrawal Scenario (Daily Time Interval)

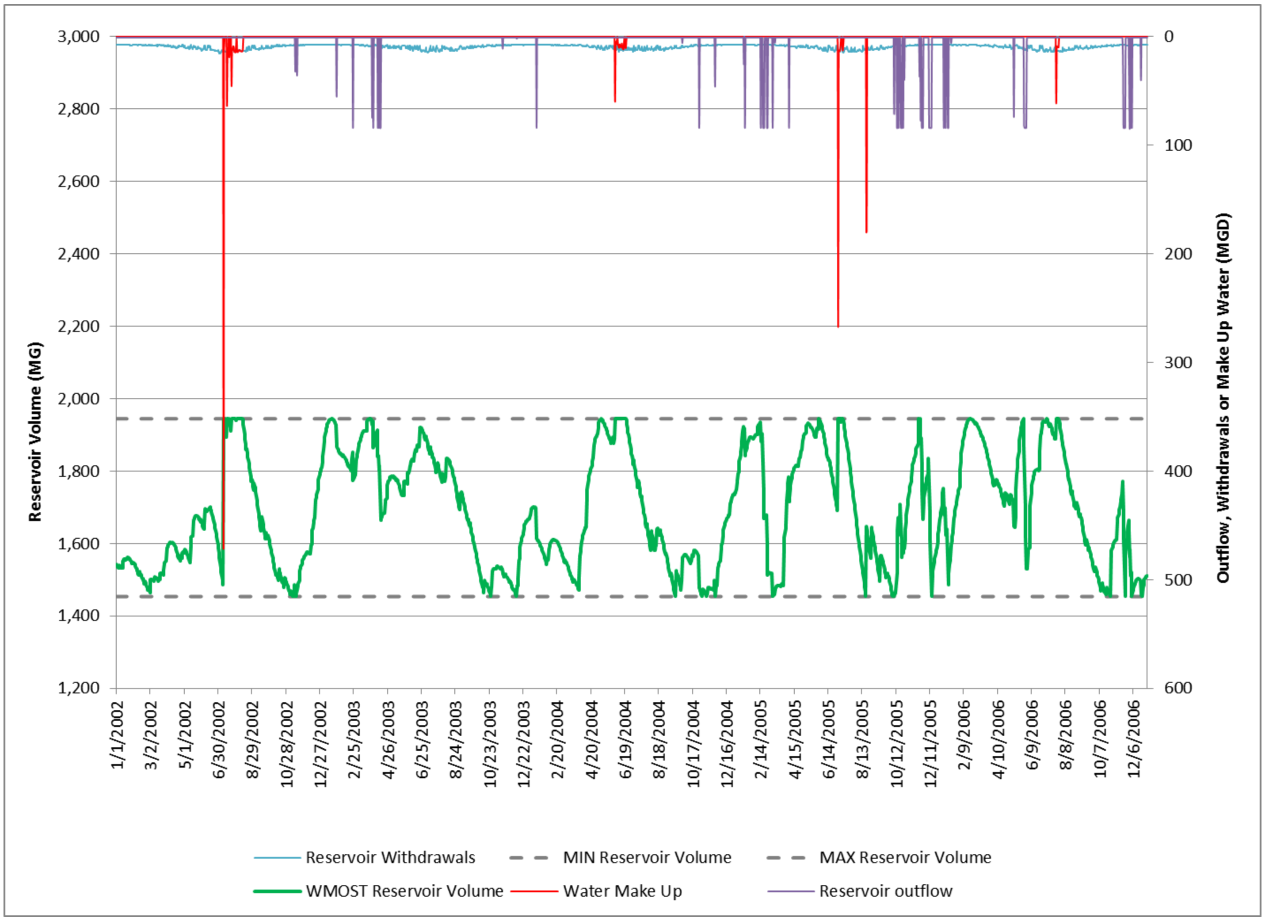


Exhibit 15: Specifications for Scenarios Varying the Timing of Brockton Diversions

Halifax Water Demand	Basis	Existing 2009-2013	Existing 2009-2013
	Annual Total (MGY)	120.34	120.34
	Max (MGD)	0.49	0.49
Brockton Water Diversions	Basis	Historical	Historical
	Magnitude (MG, over 5 years)	13,871.3	13,871.3
	Pattern	Historical	**Uniform all days**
Reservoir volume	Min stage (ft)	52.0	52.0
	Max stage (ft)	54.5	54.5
	Min allowed (MG)	1,453.9	1,453.9
	Max allowed (MG)	1,944.6	1,944.6
	Actual Min (MG)	1,453.9	1,453.9
	Actual Max (MG)	1,944.6	1,944.6
Stump Brook flow	Basis	DCR	DCR
	Min (cfs)	1.39	1.39
	Max (cfs)	130.0	130.0
	Pattern	Uniform target	Uniform target
Reservoir Withdrawals (includes ET)	Basis	Historical	Modified historical
	Max (MGD)	37.3	15.6
	Total (MG)	17,183.4	17,183.4
Reservoir Outflows	Basis	Decision	Decision
	Min (MGD)	0.9	0.9
	Max (MGD)	84.0	84.0
	Average (MGD)		
	Total (MG)	4,398.5	6,319.3
Reservoir Water Deficit	No Days with Deficit	7	61
	Max (MGD)	108.9	471.6
	Total Deficit (MG)	191.6	1,711.6
	% Water Deficit, Relative to Diversion	1.4%	12.3%
Management Options	Available	None	None
	Selected	N/A	N/A
Costs	Total costs (Million $)	$19.6	$171.6
	Water supply costs ($)	$466,514	$466,514
	Penalty for make-up water (Million $)	$19.16	$171.16

Specified as Input
Calculated by Model
Results of Concern

Results Comparing Effect of Stage Constraint with Diversion Reduction

Two scenarios were run to compare the effect of stage constraints (Exhibit 16) with stormwater BMP and interbasin transfers (IBT, transfers from Halifax wells outside of the MP subbasin) management options available after Brockton water diversions were reduced by a 3 MGD supply from the Aquaria desalination plant. If the stage was restricted to between 52 and 53.5 feet, there was still a slight water deficit over 2 days (0.4% of diversions), which disappeared when the stage was allowed to vary between 52 and 54.0

feet (Exhibits 17, 18). In the first case, both IBT and stormwater BMPs were implemented (on 53 acres), while in the second, only IBT was implemented (Exhibit 19).

Exhibit 16: Specifying Stage Constraints on the Surface Water Input Tab (Stage Volume Constraints are Calculated from Entered Stage Heights).

Surface Water: Streamflow and Surface Storage — Return to Input

Initial reservoir/surface storage volume	1,545	[MG]	*Stage Limit (ft)*	
Minimum target reservoir/storage volume	1,454	[MG]	52.00	
Existing maximum reservoir/storage volume	1,849	[MG]	54.00	
Initial construction cost	0	[$/MG]		-9
O&M costs	0	[$/MG]		No

Date (mm/dd/yyyy)	Private Sw Withdrawal [MG/time step]	Private Sw Discharge [MG/time step]	External Sw Inflow [cfs]	Res Withdrawal [MG/time step]	Res discharge[MG/timestep]	Res outflow [MG/time step]
sum over all time	0	0	0	13729	5957	-
1/1/2002	0.00	0.00	0.00	0.05	0.00	0.00
1/2/2002	0.00	0.00	0.00	0.09	0.00	0.00
1/3/2002	0.00	0.00	0.00	0.10	0.00	0.00
1/4/2002	0.00	0.00	0.00	0.08	0.00	0.00
1/5/2002	0.00	0.00	0.00	0.14	0.00	0.00
1/6/2002	0.00	0.00	0.00	0.18	4.89	0.00
1/7/2002	0.00	0.00	0.00	0.02	9.05	0.00
1/8/2002	0.00	0.00	0.00	0.06	0.24	0.00
1/9/2002	0.00	0.00	0.00	0.11	0.00	0.00
1/10/2002	0.00	0.00	0.00	0.26	0.00	0.00
1/11/2002	0.00	0.00	0.00	0.06	7.34	0.00
1/12/2002	0.00	0.00	0.00	0.14	0.00	0.00
1/13/2002	0.00	0.00	0.00	0.08	19.07	0.00

Potable Demand | Groundwater | **Surface Water** | Septic | Interbasin | Measured Flow | Flood

Exhibit 17: Time series of Reservoir Volumes, Withdrawals, Outflows and Water Deficits for the Scenario with Stage of 54 feet

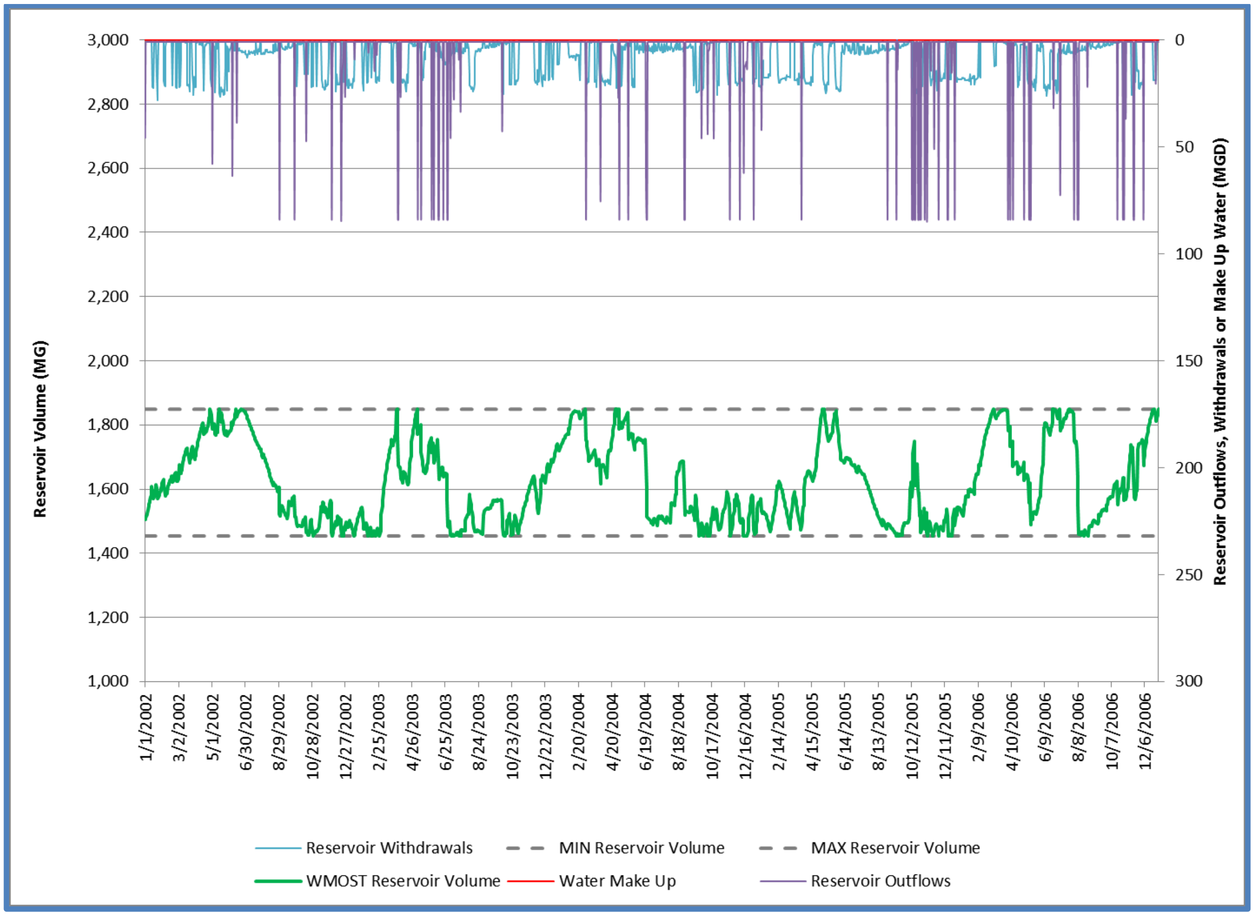


Exhibit 18: Time series of Reservoir Volumes, Withdrawals, Outflows and Water Deficits for the Scenario with Stage of 53.5 feet

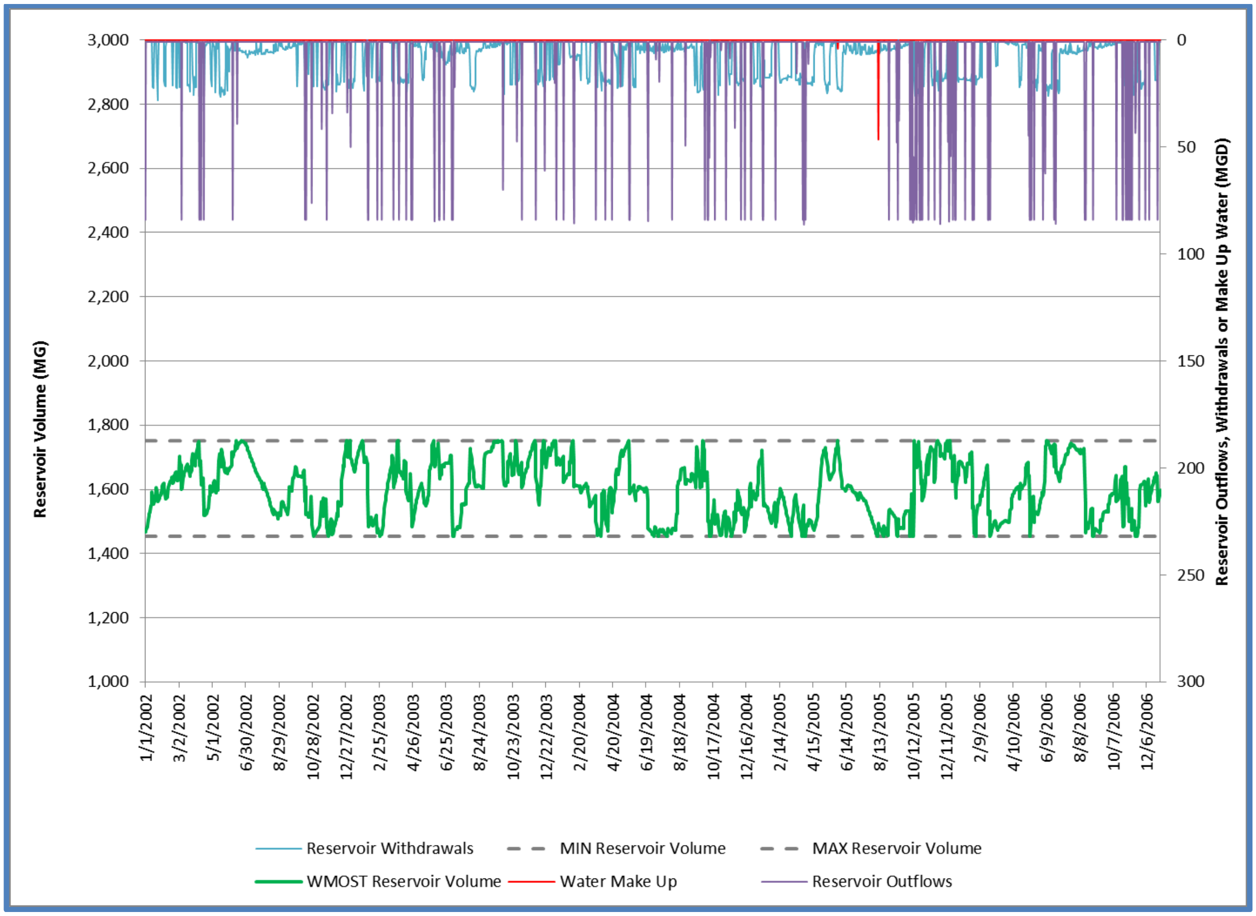


Exhibit 19: Specifications for Scenarios with Varying Stage Constraints

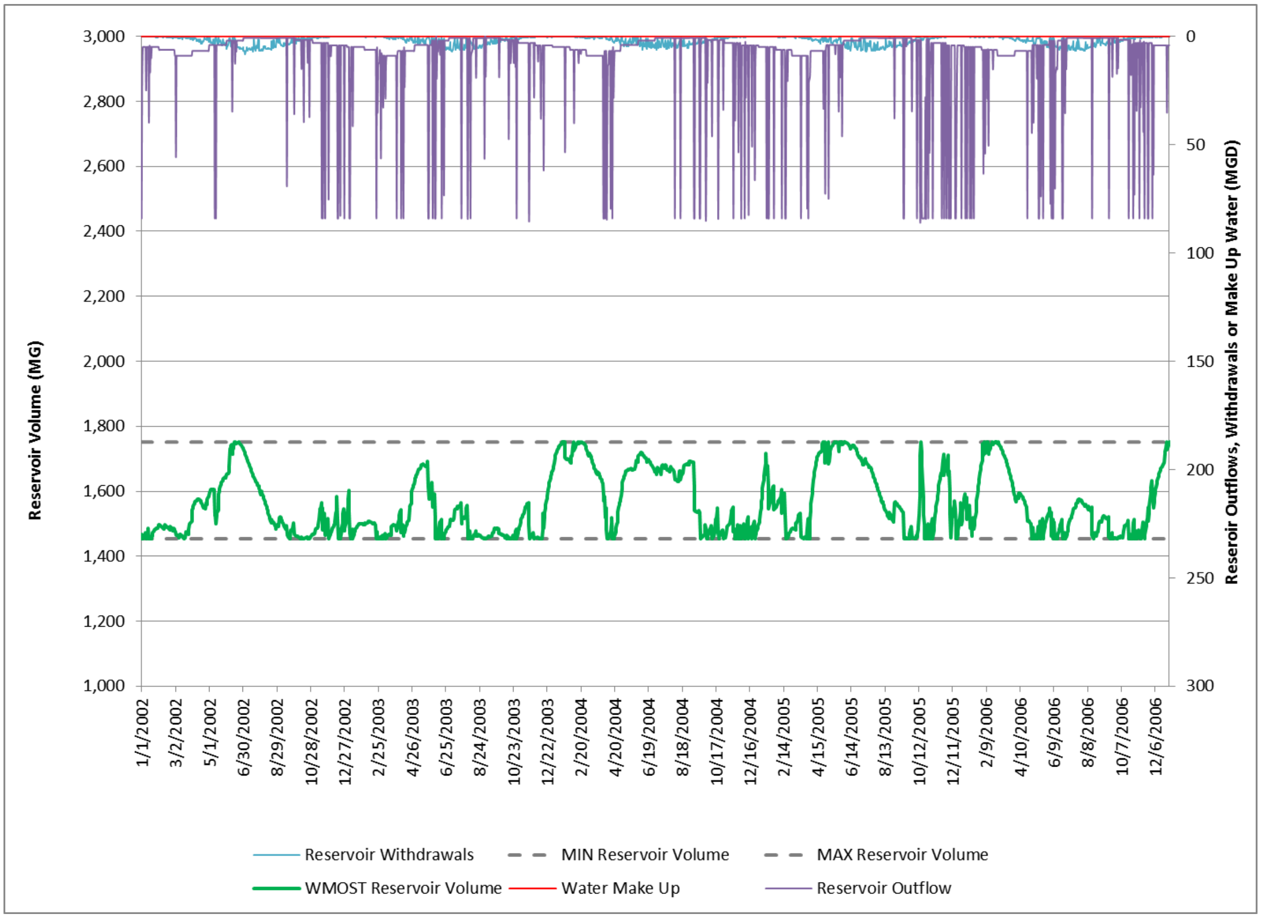
Halifax Water Demand	Basis	Existing 2009-2013	Existing 2009-2013
	Annual Total (MGY)	120.34	120.34
	Max (MGD)	0.49	0.49
Brockton Water Diversions	Basis	Adjusted based on 2009-2013 diversions + Aquaria	Adjusted based on 2009-2013 diversions + Aquaria
	Magnitude (MG, over 5 years)	10,417.4	10,417.4
	Pattern	Historical	Historical
Reservoir volume	Min stage (ft)	52.0	52.0
	Max stage (ft)	**54.0**	**53.5**
	Min allowed (MG)	1,453.9	1,453.9
	Max allowed (MG)	1,848.9	1,751.3
	Actual Min (MG)	1,453.9	1,453.9
	Actual Max (MG)	1,848.9	1,751.3
Stump Brook flow	Basis	DCR	DCR
	Min (cfs)	1.39	1.39
	Max (cfs)	130.0	130.0
	Pattern	Uniform target	Uniform target
Reservoir Withdrawals (includes ET)	Basis	Historical, Adjusted	Historical, Adjusted
	Max (MGD)	28.0	28.0
	Total (MG)	13,729.4	13,729.4
Reservoir Outflows	Basis	Decision	Decision
	Min (MGD)	0.9	0.9
	Max (MGD)	84.0	84.0
	Average (MGD)		
	Total (MG)	8,059.2	11,609.5
Reservoir Water Deficit	No Days with Deficit	-	2
	Max (MGD)	-	46.6
	Total Deficit (MG)	-	50.6
	% Water Deficit, Relative to Diversion	0.0%	0.4%
Management Options	Available	**Stormwater BMPs+IBT**	**Stormwater BMPs+IBT**
	Selected	IBT	Stormwater BMP (53 acres) and IBT
Costs	Total costs (Million $)	$0.5	$5.6
	Water supply costs ($)	$466,514	$529,645
	Penalty for make-up water (Million $)	$0.00	$5.07

Specified as Input
Calculated by Model
Results of Concern

Results Comparing Effect of Stage Constraint with 25%ile SYE Target and Elimination of Diversions

Two management scenarios were evaluated to see if it would be possible to meet a higher base flow target (25% of unimpacted flows for Stump Brook based on the USGS Sustainable Yield Estimator[59] for Massachusetts; http://pubs.usgs.gov/sir/2009/5227/). To accommodate the need for increased flows in these two scenarios, we assumed Brockton diversions would be eliminated entirely. The management scenario with a range of pond stages from 52 to 53.5 feet (or higher) was feasible, while the management scenario with a more restricted range of 52 to 53.0 feet predicted three days with volume deficits totaling 3.3% of current Brockton diversions even after implementation of stormwater BMPs on 14 acres. (Exhibits 20, 21)

Exhibit 20: Time series of Reservoir Volumes, Withdrawals, Outflows and Water Deficits for the Scenario without Brockton Diversions, Maximum Stage of 53 feet, and 25th Percentile Flow Target.



[59] Archfield, S.A., Vogel, R.M., Steeves, P.A., Brandt, S.L., Weiskel, P.K., and Garabedian, S.P., 2010, The Massachusetts Sustainable-Yield Estimator: A decision-support tool to assess water availability at ungaged stream locations in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2009–5227, 41 p. plus CD-ROM.

Exhibit 21: Specifications for Scenarios with 25th Percentile Flow Targets

Halifax Water Demand	Basis	Existing 2009-2013	Existing 2009-2013
	Annual Total (MGY)	120.34	120.34
	Max (MGD)	0.49	0.49
Brockton Water Diversions	Basis	None	None
	Magnitude (MG, over 5 years)	-	-
	Pattern	N/A	N/A
Reservoir volume	Min stage (ft)	52.0	52.0
	Max stage (ft)	**53.5**	**53.0**
	Min allowed (MG)	1,453.9	1,453.9
	Max allowed (MG)	1,751.3	1,652.5
	Actual Min (MG)	1,453.9	1,453.9
	Actual Max (MG)	1,751.3	1,652.5
Stump Brook flow	Basis	DCR 25th Percentile	DCR 25th Percentile
	Min (cfs)	7.49	7.49
	Max (cfs)	130.0	130.0
	Pattern	Monthly Min	Monthly Min
Reservoir Withdrawals (includes ET)	Basis	**No Diversions**	**No Diversions**
	Max (MGD)	37.3	37.3
	Total (MG)	17,183.4	17,183.4
Reservoir Outflows	Basis	Decision	Decision
	Min (MGD)	0.6	0.6
	Max (MGD)	84.0	84.0
	Average (MGD)		
	Total (MG)	18,253.0	19,326.3
Reservoir Water Deficit	No Days with Deficit	-	3
	Max (MGD)	-	65.4
	Total Deficit (MG)	-	109.0
	% Water Deficit, Relative to Diversion	0.0%	3.3%
Management Options	Available	Stormwater BMPs	Stormwater BMPs
	Selected	SW BMPs: 0 acres	SW BMPs: 14 acres
Costs	Total costs (Million $)	$0.5	$11.4
	Water supply costs ($)	$466,514	$483,284
	Penalty for make-up water (Million $)	$0.00	$10.92

Specified as Input
Calculated by Model
Results of Concern

Findings

Review of the results across these various scenarios provides the following planning insight:

- The system is highly constrained, with a very tight operating range.
  - Setting constraints on the reservoir volume between 52ft and 54.5 ft provides the broadest range of options to meet both environmental and water needs. For example, when we allow the reservoir stage to vary by up to 2.5 ft over the simulation period, the model is able to meet both the existing water demand and a 1.39 cfs minimum outflow to Stump Brook by retrofitting stormwater BMPs on approximately 100 acres, for an annual cost of approximately $35,000. This range of operation, however, may cause periodic flooding and is unlikely to be acceptable.
  - Tightening the operating range to be between 52 and 53 feet makes it impossible to meet the water demand even when using the least stringent flow targets for Stump Brook (1.39 cfs) and the greatest reduction in diversions; the reservoir is unable to accumulate enough water to make it through the relatively drier months.
  - Increasing the upper bound of the operating range to 53.5 feet yields outcomes that are between these two scenarios. The system does show water deficits during the modeling period (i.e., must add water to the system to provide sufficient storage to meet the environmental and/or water needs), but such deficits are less frequent.
- Distributing Brockton diversions uniformly over the year actually increases the frequency of water deficits in the system due to a mismatch in the timing of inflows and outflows from the reservoir.
- Stormwater BMPs were selected in several of the simulations in which water deficits are relatively small and/or infrequent, suggesting that the BMPs are a cost effective approach for mitigating the impacts.
- Relatively large reductions (~25 percent) in the magnitude of diversions, which we calculated based on the assumed use of 3 MGD from Aquaria in November-July mitigates the projected water deficit, but does not eliminate it completely for scenarios where the reservoir is only allowed to operate within a 1.0-1.5ft range.
- When ASR is available, it is invariably selected as the cost-effective action to meet the constraints. ASR is very effective at eliminating the water deficit in the simulations and providing sufficient water during relatively drier periods. However, estimated ASR costs are substantial, i.e., several million dollars. Further, additional investigation would be needed to assess the feasibility of ASR in the watershed.

Supplemental Information on Flooding Costs around Monponsett Ponds

Most users of WMOST v2 will be able to use the flooding module within the tool to include flooding costs in the cost-benefit analysis and optimization. However, in this case, we are estimating flooding costs associated not with streamflow of different recurrence intervals, but with elevation of the Monponsett Ponds. Therefore, we conducted a separate analysis to estimate flooding costs using the HAZUS software. HAZUS is a regional multi-hazard loss estimation model that was developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). The primary purpose of HAZUS is to provide a methodology and software application to develop multi-hazard losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from multi-hazards and to prepare for emergency response and recovery.

To assess potential flood-related damages within the Monponsett Pond watershed (shown in dark blue in **Exhibit 22**), we selected the four census tracts that contain Monponsett Pond as our study region.

Exhibit 22: Census tracts intersecting with Monponsett Ponds.

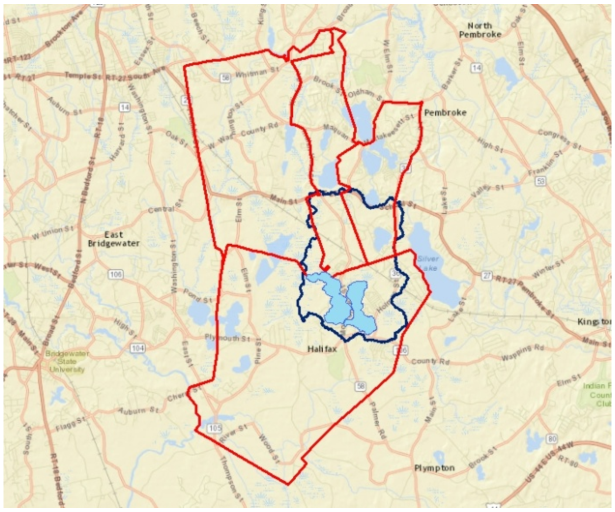
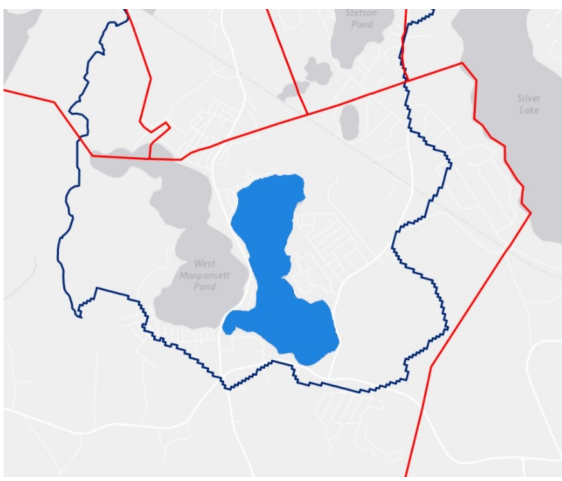


Exhibit 23: Monponsett Ponds with watershed boundary

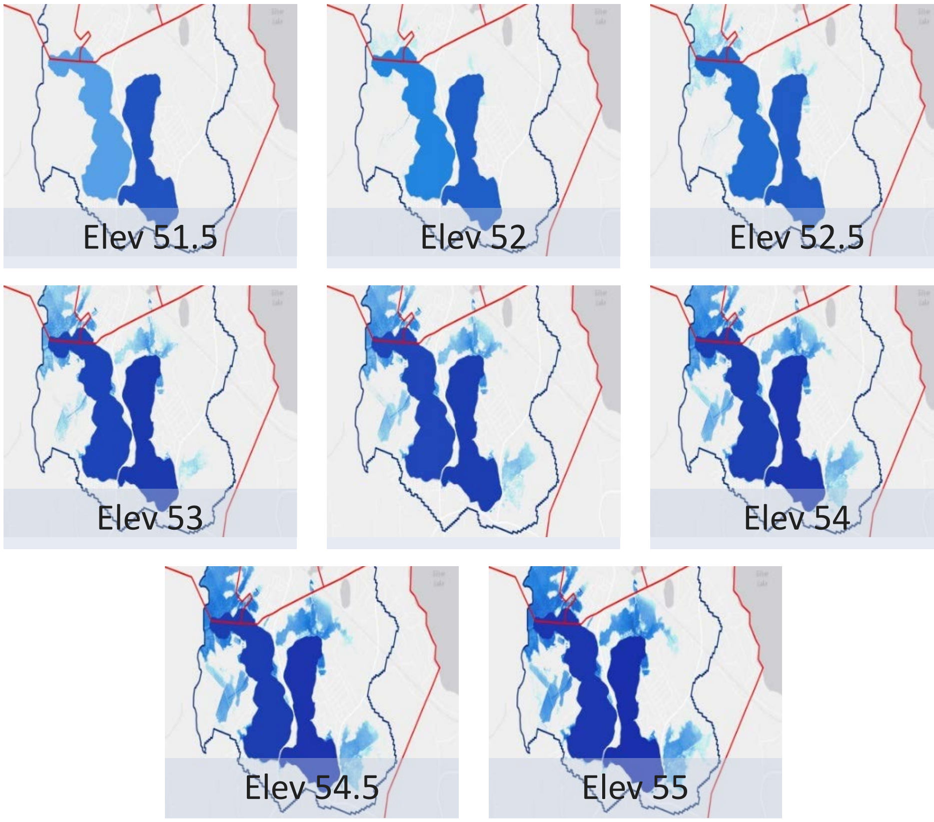


From the Massachusetts GIS website (http://www.mass.gov/ office-of-geographic-information-massgis/datalayers/lidar.html) we obtained LiDAR elevation data for the digital elevation model input into HAZUS.

Elevation 51 was used as a base line elevation for flood depth calculations. The LiDAR elevation at the surface of the eastern portion of Monponsett Pond was 50.918 and the elevation of the western portion was 51.050 (**Exhibit 23**).

To determine the flood depth grids, we used the LiDAR elevation data and increased the elevation of flooding by half foot increments, beginning at Elevation 51.5 and increasing to Elevation 55 (**Exhibit 24**).

Exhibit 24: Increase in flood elevation from 51.5 feet to 54.0 feet.



Using the building footprint layer, we located all the structures within the study area and eliminated buildings less than 300 ft^2 assuming these smaller buildings were garages, sheds and other miscellaneous structures. Attributes associated with this layer were number of stories, site address, and approximate building value. It was assumed for analysis purposes that all residential buildings had a basement type of foundation and the first floor was located 4 feet above the ground elevation.

We then used HAZUS to determine the number of user-defined facilities that were impacted by flooding at various elevations. As shown, there were no buildings damaged at the 51.5, 52 and 52.5 elevations. We determined amount of building damage by the HAZUS methodology. The anticipated building damage for the user defined structures is shown in **Exhibit 25**.

Exhibit 25: Extent of building damage for flood elevations of 53.0 feet to 55.0 feet.

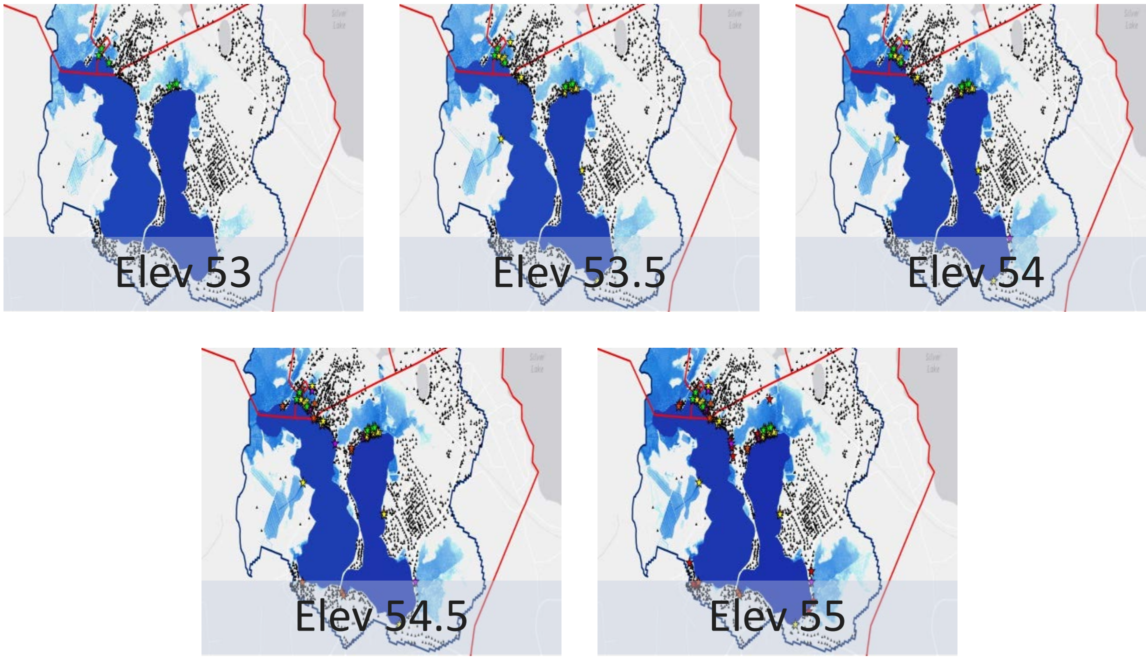
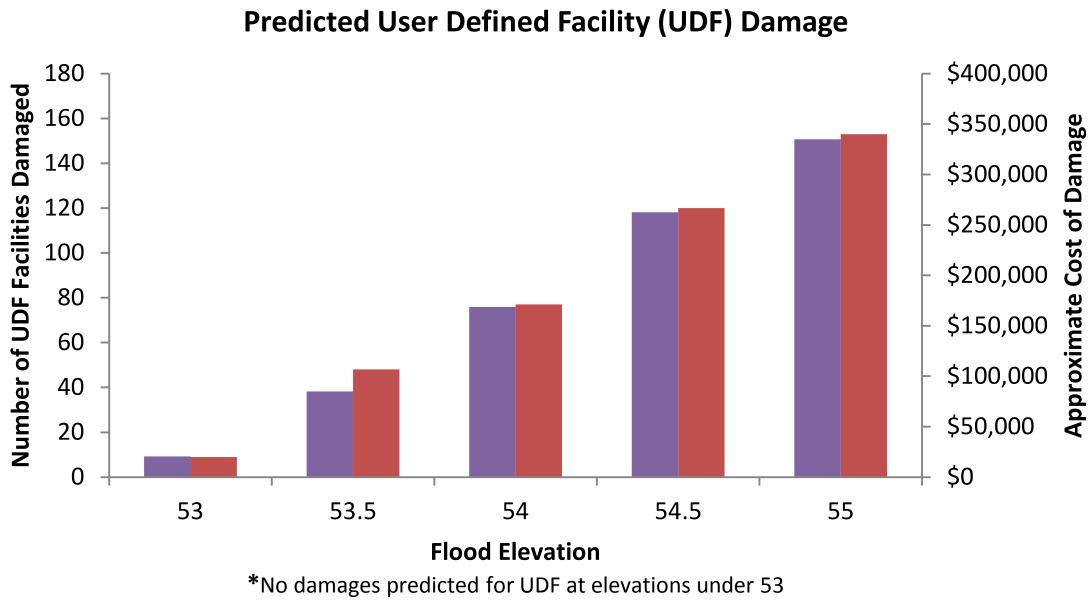


Exhibit 26 shows the estimated building damage for the user defined structures for increasing flood elevations.

Exhibit 26: Estimated value of building damage for flood elevations of 53.0 feet to 55.0 feet.



Next Steps and Refinements

The preliminary results presented above demonstrate the need for a regional solution to water supply and use issues in the larger Taunton River watershed, with inherent trade-offs between different water uses and between the needs of different communities. To help inform discussions of a regional solution, we will be completing a regional analysis of the trade-offs between flooding costs and the cost of implementation of green infrastructure stormwater BMPs in the upper Taunton River watershed.

As shown above, implementation of GI stormwater BMPs contributes to some of the lowest cost solutions for water supply in the Monponsett Ponds subbasins, and it is possible that they could contribute to a solution for other communities in the Taunton watershed as well, thus minimizing the need for diversions from MP. In addition, we will be adding a water quality module to WMOST and applying the new module to evaluate cost-effective solutions to the combined water quantity and water quality problems in MP.

Appendix B. Halifax Case Study Input Data

Input Data	Units	Scenario	Value	Sources/Approach
LAND USE (LU)				
Number of land uses/HRUs	Numerical value	*Validation/ Optimization*	15	Based on delineation in USGS Taunton HSPF watershed simulation model
Stormwater Management Sets	Numerical value	*Validation*	-	NA
		Optimization	6	Infiltration trench and bioretention basin, sizing: 0.6, 1.0, 2.0 inches
Existing land use for each HRU	Acres	*Validation/ Optimization*	See model interface	Intersection of MassGIS 1999 LU/SurfGeo layers crosswalked to HSPF HRU categories
Minimum area for each HRU	Acres	*Optimization*	Existing HRU Area	Combination of data sets: MassGIS 2005 Land Use, protected areas, stormwater managed areas
Maximum area for each HRU	Acres	*Optimization*	Existing HRU Area	Same as minimum area data sources
Capital cost to conserve land use/HRU	$/acre	*Optimization*	4704	Previous purchases of land for preservation by the state of Massachusetts (The Trust for Public Land, 2013)
O&M cost to conserve land use/HRU	$/acre/year	*Validation*	-	NA
		Optimization	47	Default value: 1% of capital costs
Stormwater Management				
Capital installation cost	$	*Validation*	-	NA
		Optimization	Varies by BMP and size	Previous case studies and report including Charles River Watershed Association and EPA Region 1 (TetraTech, 2014)
O&M cost	$	*Validation*	-	NA
		Optimization	Varies by BMP and size	Based on case studies by CRWA/EPA Region 1 (5% of capital costs)
RUNOFF AND RECHARGE (Ru and Re)				
Recharge rates for each original or “baseline” land use	in/day	*Validation/ Optimization*	See model interface	USGS Taunton HSPF Model Outputs
Runoff rates for each original or “baseline” land use	in/day	*Validation/ Optimization*	See model interface	USGS Taunton HSPF Model Outputs
Recharge rates for each “managed” land use	in/day	*Validation*	-	NA
		Optimization	See model interface	WMOST stormwater module
Runoff rates for each “managed” land use	in/day	*Validation*	-	NA
		Optimization	See model interface	WMOST stormwater module

Input Data	Units	Scenario	Value	Sources/Approach
WATER DEMAND (Demand) - Halifax Public Water Supply				
Number of water user types	Numerical value	*Validation/ Optimization*	5	Residential, commercial, industrial, municipal, UAW (based on Halifax ASR)
Demand for each user for each day	MG/time step	*Validation*	See model interface	Validation: Daily water pumping time series from public water supplier Percent use by each user (e.g., 55% commercial) from Annual Statistical Report
		Optimization	See model interface	Daily water pumping time series altered to include summer outdoor watering restrictions and a basic demand management program
Unaccounted-for-water (i.e., leakage from potable water distribution system)	MG/time step	*Validation*	12	Average UAW from 2002-2006 from Halifax ASR
		Optimization	10	Validation value or the WMA standard condition requirement of 10% maximum UAW (i.e., assume utility will reduce to 10% before permit renewal)
Percent consumptive use for each water user for each month	%	*Validation/ Optimization*	Default values	Based on data in Amy Vickers (2002) Handbook of Water Use and Conservation
Nonpotable Water		NOT USED IN Validation		
Maximum percent demand that can be met by nonpotable water for each user	%	*Optimization*	Default values	Based on data in Amy Vickers (2002) Handbook of Water Use and Conservation
Percent consumptive use for nonpotable water for each user for each month	%	*Optimization*	Default values	Based on data in Amy Vickers (2002) Handbook of Water Use and Conservation
Demand Management		NOT USED IN Validation		
Price elasticity for each user	Fraction	*Optimization*	Default values	Based on Littleton case study (Abt Associates et al. 2014)
Capital cost to implement price increase	$	*Optimization*	10,000	
O&M cost to administer price increase (e.g., resurvey for appropriate price etc.)	$/year	*Optimization*	1,000	
Maximum price change over Optimization horizon	%	*Optimization*	49	Based on 2% increase over 20 years
Initial cost of providing rebates	$	*Optimization*		
O&M cost of providing rebates	$/year	*Optimization*		

Input Data	Units	Scenario	Value	Sources/Approach
Maximum demand reduction	MGD	*Optimization*		
SEPTIC (Sep)				
Percent septic use for public water user draining inside the study area	%	*Validation/ Optimization*	100	No public sewer systems exist in Halifax, Hanson, or Pembroke
Percent septic use for public water user draining outside the study area	%	*Validation/ Optimization*	0	
SURFACE WATER (SW)				
Reservoir Storage - Monponsett Pond				
Initial reservoir volume	MG	*Validation/ Optimization*	Based on model	For validation: Calculated based on reservoir stage time series For optimization: Calculated by the model
Minimum reservoir volume	MG	*Validation/ Optimization*	Based on model	For validation, set to 0 MG (no constraint) For optimization, based on minimum stage of 52 ft
Current maximum reservoir volume	MG	*Validation/ Optimization*	Based on model	For validation, set to 5800 MG (high enough not to be a constraint) For optimization, based on minimum stage of 53 ft, 53.5 ft or 54.5 ft
Capital construction cost	$/MG	*Optimization*	-	NA
O&M costs	$/MG	*Optimization*	-	NA
Streamflow				
Inflow from external surface water	MG/time step	*Validation/ Optimization*	-	NA - Headwater subbasin
Minimum in-stream flow standards	cfs	*Validation*	-	NA
		Optimization	Based on model	MA DER
Maximum in-stream flow standards	cfs	*Validation*	-	NA
		Optimization	Based on model	130 cfs
Minimum surface water discharging outside of study area	cfs	*Validation/ Optimization*	-	Standard was not used in model
Private withdrawals of surface water	MG/time step	*Validation/ Optimization*	See model interface	USGS Taunton HSPF Model Outputs
Private discharge of surface water	MG/time step	*Validation/ Optimization*	See model interface	USGS Taunton HSPF Model Outputs

Input Data	Units	Scenario	Value	Sources/Approach
GROUNDWATER (GW)				
Groundwater recession coefficient	1/time step	*Validation/ Optimization*	0.0673	Calculated using USGS Taunton HSPF model: [1 - (area-weighted average of AGWRC across HRUs)] based on distribution of HRUs in each subbasin. The groundwater recession coefficient was used to calibrate the model, and the calibrated value is shown.
Initial groundwater volume	MG	*Validation/ Optimization*	3,275	Based on USGS Taunton HSPF model groundwater storage
Minimum volume	MG	*Validation/ Optimization*	3,128	
Maximum volume	MG	*Validation/ Optimization*	7,062	
Flow from external groundwater	cfs	*Validation/ Optimization*	-	NA - Headwater subbasin
Private withdrawals of groundwater (all but public water system)	MG/time step	*Validation/ Optimization*	See model interface	USGS Taunton HSPF Model Outputs minus Halifax public water system withdrawals
Private discharge of groundwater	MG/time step	*Validation/ Optimization*	See model interface	USGS Taunton HSPF Model Outputs
INTERBASIN TRANSFER (IBT) (based on water from other wells in Halifax)				
Purchase price for IBT potable water	$/MG	*Validation/ Optimization*		
Purchase price for IBT wastewater	$/MG	*Validation/ Optimization*		NA
Initial cost for new/additional IBT potable water	$/MG	*Validation*	-	NA
		Optimization		
Initial cost for new/additional IBT wastewater	$/MG	*Validation*	-	NA
		Optimization		
Maximum additional capacity for water and wastewater	MGD	*Validation*	-	NA
		Optimization		
Daily, monthly and/or annual limits for water and/or wastewater	MGD	*Validation/ Optimization*		
INFRASTRUCTURE				
Optimization horizon	years	*Validation/ Optimization*	20	Based on town/utility practices
Interest rate	%	*Validation/ Optimization*	3	Based on previous bonds by town/utility

Input Data	Units	Scenario	Value	Sources/Approach
Water Treatment Plant (WTP)				
Customer's price for potable water	$/HCF	*Validation*	3.78	Based on 2015 Halifax water rates and volume-weighted average of water rates across user types from 2002-2006
		Optimization	3.72	Based on 2015 Halifax water rates and volume-weighted average of water rates across user types from 2009-2013
Customer fixed monthly account fee	$/month	*Validation*	8.33	Based on 2015 Halifax water rates. All users pay the same fixed fee, independent of volume used
		Optimization		
GW pumping–Capital construction cost	$/MGD	*Validation*	-	NA
		Optimization	5,787,037	Based on previous Littleton study estimate for developing a new well source
GW pumping–O&M costs	$/MG	*Validation/ Optimization*		Based on Halifax 2015 Water Budget
GW pumping–Current max capacity	MGD	*Validation/ Optimization*	2.742	Based on maximum approved daily pumping at wells (2013 ASR)
GW pumping lifetime–remaining on existing construction	years	*Validation/ Optimization*	25	Values set higher than Optimization horizon to exclude replacement costs from analysis
GW Pumping lifetime–new construction	years	*Validation/ Optimization*	35	
SW pumping–Capital construction cost	$/MGD	*Validation*	-	NA
		Optimization	453,885	Based on previous Danvers-Middleton MA case study (EPA 2013[60])
SW pumping–O&M costs	$/MG	*Validation/ Optimization*	31,772	Default value: 7% of capital costs
SW pumping–Current max capacity	MGD	*Validation/ Optimization*	0	No surface water sources
SW pumping lifetime–remaining on existing construction	years	*Validation/ Optimization*	0	
SW Pumping lifetime–new construction	years	*Optimization*	35	
WTP–Capital construction cost	$/MGD	*Validation*	-	NA
		Optimization	6,229,186	Based on previous Littleton study estimate for new water treatment capacity (Abt Associates et al 2014[61])
WTP–O&M costs	$/MG	*Validation*	-	Included in groundwater O&M costs

[60] U.S. EPA. Watershed Management Optimization Support Tool (WMOST) v1: User Manual and Case Study Examples. U.S. EPA, Office of Research and Development, Washington, DC, EPA/600/R-13/174, 2013.

[61] Town of Littleton, MA, Abt Associates Inc., Horsley Witten Group and Charles River Watershed Association. 2014. Maximizing Sustainable Water Management by Minimizing the Cost of Meeting Human and Ecological Water Needs: Sustainable Water Management Initiative Project Report BRP 2013-06. June 2014. Prepared for Commonwealth of Massachusetts, Executive Office of Energy and Environmental Affairs and Department of Environmental Protection.

Input Data	Units	Scenario	Value	Sources/Approach
		Optimization	-	
WTP lifetime–remaining on existing construction	years	*Validation*	25	Values set higher than Optimization horizon to exclude replacement costs from analysis
		Optimization	25	
WTP lifetime–new construction	years	*Optimization*	35	
WTP–Current max capacity	MGD	*Validation/ Optimization*	1.742	Based on water treatment plant capacity and maximum allowed pumping (2013 ASR)
Capital cost of survey & repair	$	*Optimization*	267,231	Cost for survey and repair of all Halifax water mains
O&M costs for continued leak repair	$/year	*Optimization*	0	Assume one-time survey
Maximum percent of leaks that can be fixed	%	*Optimization*	99	Default values
Wastewater Treatment Plant (WWTP)				
Customer's price for wastewater	$/HCF	*Validation/ Optimization*	0	Halifax is all septic
Capital construction cost	$/MGD	*Optimization*		
Charged based on water or wastewater?	Binary (water or wastewater)	*Optimization*	water	
O&M costs	$/MG	*Optimization*		
Lifetime remaining on existing construction	years	*Optimization*	0	
Lifetime of new construction	years	*Optimization*	35	
Current maximum capacity	MGD	*Optimization*	0	
Initial groundwater infiltration into WW collection system	%	*Validation/ Optimization*	0	No existing wastewater system
Initial cost of repairs	$	*Optimization*	0	No existing wastewater system
O&M costs of repairs	$/year	*Optimization*		
Maximum percent of leakage that can be fixed	%	*Optimization*	0	No existing wastewater system
Water Reuse Facility (WRF)				
Capital construction cost	$/MGD	*Optimization*	18,644,791	Values from Littleton study (Abt Associates et al, 2014)
O&M costs	$/MG	*Optimization*	1,305,135	
Lifetime remaining on existing construction	years	*Optimization*	0	No existing capacity

Input Data	Units	Scenario	Value	Sources/Approach
Lifetime of new construction	years	*Optimization*	35	Values set higher than Optimization horizon to exclude replacement costs from analysis
Current maximum capacity	MGD	*Optimization*	0	No existing capacity
Nonpotable Water Distribution System (NPDist)				
Consumer cost for nonpotable water	$/HCF	*Optimization*	3	Values from Danvers-Middleton case study (EPA 2013)
Capital construction cost for nonpotable distribution system	$/MGD	*Optimization*	12,529,440	
O&M cost for nonpotable distribution system	$/MG	*Optimization*	1,716	
Aquifer Storage and Recovery (ASR)				
Capital construction cost	$/MGD	*Optimization*	1,965,727	Values from Danvers-Middleton case study (EPA 2013)
O&M costs	$/MG	*Optimization*	538	
Lifetime remaining on existing construction	years	*Optimization*	0	No existing capacity
Lifetime of new construction	years	*Optimization*	35	Values set higher than Optimization horizon to exclude replacement costs from analysis
Current maximum capacity	MGD	*Optimization*	0	No existing capacity
MEASURED FLOW				
Measured flow	cfs	*Validation/ Optimization*		None (comparison is done for calculated pond volume)