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WMOST Case Study for UConn's Storrs Campus to Optimize Water Purchases from Connecticut Water Company

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WMOST Case Study for UConn's Storrs Campus to Optimize Water Purchases from Connecticut Water Company

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Abstract

The University of Connecticut currently provides all of the potable water to its Storrs campus and nearby Mansfield from groundwater pumps in the Willimantic and Fenton River Wellfields which are capable of producing 1.48 MGD and 0.8442 MGD respectively. In 2005, sections of the Fenton River ran dry as a result of low flows and overuse. Since that time, the University has undertaken successful efforts to understand and manage its water resources more conservatively. The wellfields' supply is currently inadequate for meeting the 15% margin of safety desired during peak monthly demands. In addition, UConn is planning significant expansions expected to bring 6,500 more students to campus, with the facilities to accommodate them. UConn is projected to need an additional supply of 1.385 MGD for average days, which will be supplied by Connecticut Water Company (CWC) through interconnection with their Western System.

The Environmental Protection Agency recently released the Watershed Management Optimization Support Tool (WMOST) which allows researchers and planners to define a study area with hydrology parameters, water infrastructure information, water utility data, and site specific capital and O&M costs. WMOST produces a set of select watershed management alternatives optimized for least cost while meeting system constraints.

The objective of this Thesis was to develop a case study in WMOST to determine how much water the University will need to purchase from CWC in the 50 year planning period within an optimized set of management alternatives. The WMOST model recommends 0.55 MGD of CWC purchases along with the repair of water supply and wastewater infrastructure, expansion of the wastewater plant, infrastructure replacements as needed, and imparting water costs to end users to conserve water.

Chapter 1-Introduction

Background

The University of Connecticut currently provides all of the potable water to its Storrs campus and nearby town of Mansfield users from groundwater pumps in the Willimantic and Fenton River Wellfields (See Figure 1-1). As the University seeks to expand and develop, it must maintain a 15% supply margin of safety (MOS) above the system demands. Under dry conditions during peak campus demands in the late summer of 2005, sections of the Fenton River ran dry. Since this occurrence, the University has commissioned several water and river studies to better manage its water supply and potable demand, in order to maintain the appropriate MOS. Although these efforts have been very effective to date, the University has determined that additional water supplies will be needed in the 50 year planning period from 2010-2060. Plans to construct the North Campus Technology Park and meet the goals of the NextGenCT STEM development program, as well as growth in the adjacent Town of Mansfield, are expected to push potable water demands over the existing maximum supply (UConn Water Supply Plan, 2011). In accordance with the Connecticut Environmental Protection Act (CEPA), the University investigated five alternatives for meeting these demands including the no-build scenario, replacing Fenton Well A for better yield, new wellfields adjacent to the Willimantic River or Mansfield Hollow Lake, and interconnecting with Connecticut Water Company (CWC), The Metropolitan District Commission (MDC), or Windham Water Works (WWW). The result of this Environmental Impact Assessment (EIE) was the decision UConn would purchase potable water supplied through an interconnection constructed by CWC from their supply main in Tolland. This alternative was preferred for several reasons including its consistency with state water supply plans, ability to compensate for increased demand from its own water sources, lower construction cost relative to other interconnection options, lower end user water costs relative to other interconnection options, allowance for purchases as demands occur, capability to phase in of necessary supply improvements, and relatively shorter duration for implementation (UConn Final Record of Decision, 2013).

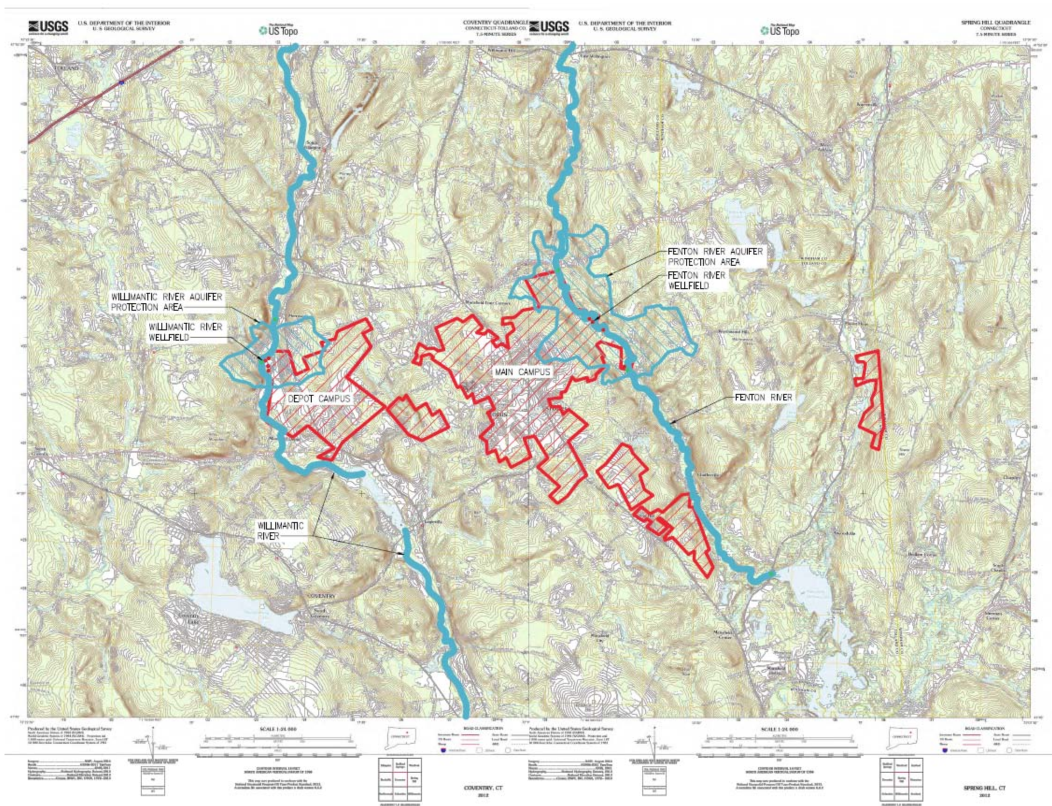


Figure 1-1: Case study area, USGS 2012 7.5 minute topographic maps overlain with Storrs Campus areas and pertinent hydrologic features (U.S. Geological Survey, 2012 and UConn Water Supply Plan, 2011)

Objective

The objective of this thesis is to provide a real world case study of the newly released EPA WMOST and determine how much water the University will need to purchase from CWC during the 50 year planning period 2010-2060 while implementing the most cost effective management alternatives. First, WMOST will be populated with the necessary parameters as defined and justified in Chapter 2. Then, these parameters will then be modified in the context of the case study to provide a better idea of how management alternative selection shifts with the variation in key variables. Next, the results will be evaluated to provide a realistic projection for management alternative selection to minimize the cost of CWC purchases over the planning period. Finally, an evaluation of the effectiveness of WMOST for completing this case study will be provided with possible model improvements and alternative approaches to completing this effort.

Watershed Management Optimization Support Tool

The Environmental Protection Agency (EPA) released the first version of its Watershed Management Optimization Support Tool (WMOST) in December 2013. The model was developed from the Integrated Watershed Management Optimization Model created by Viktoria Zoltay as part of her Master's Thesis at Tufts University. The model was then developed, under EPA contract, by Abt Associates in Cambridge, MA. WMOST seeks to optimize watershed management decisions through infrastructure, water demand, and watershed inputs to create a least cost scenario of management alternatives to meet constraints set by the study area. The objective of WMOST is defined on the host website as follows:

> The objective of the Watershed Management Optimization Support Tool (WMOST) is to serve 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 watershed or jurisdiction for cost-effectiveness as well as environmental and economic sustainability (Zoltay et al. 2010)

For this study, the use of select management options will be modeled and optimized within the context of the UConn system in an attempt to reach maximum ‘economic sustainability’ while meeting the predetermined conditions necessary for ‘environmental sustainability.’ See Figure 1-2 for WMOST schematic layout of water distribution. The caption is a description detailing how certain water flows are included (or excluded) in the case study. For instance, surface water pumping is not used in the UConn system; therefore it is not included and color coded orange. Interbasin transfer of water is being evaluated for an increase (blue), from zero, while groundwater pumping is being decreased (red) from its current capacity in most scenarios being evaluated. Certain system components, such as the water storage facilities, will incur replacement and operation and maintenance (O&M) costs during the planning period so they are included, but not explicitly evaluated for increased or decreased capacity (USEPA User Guide, 2013).

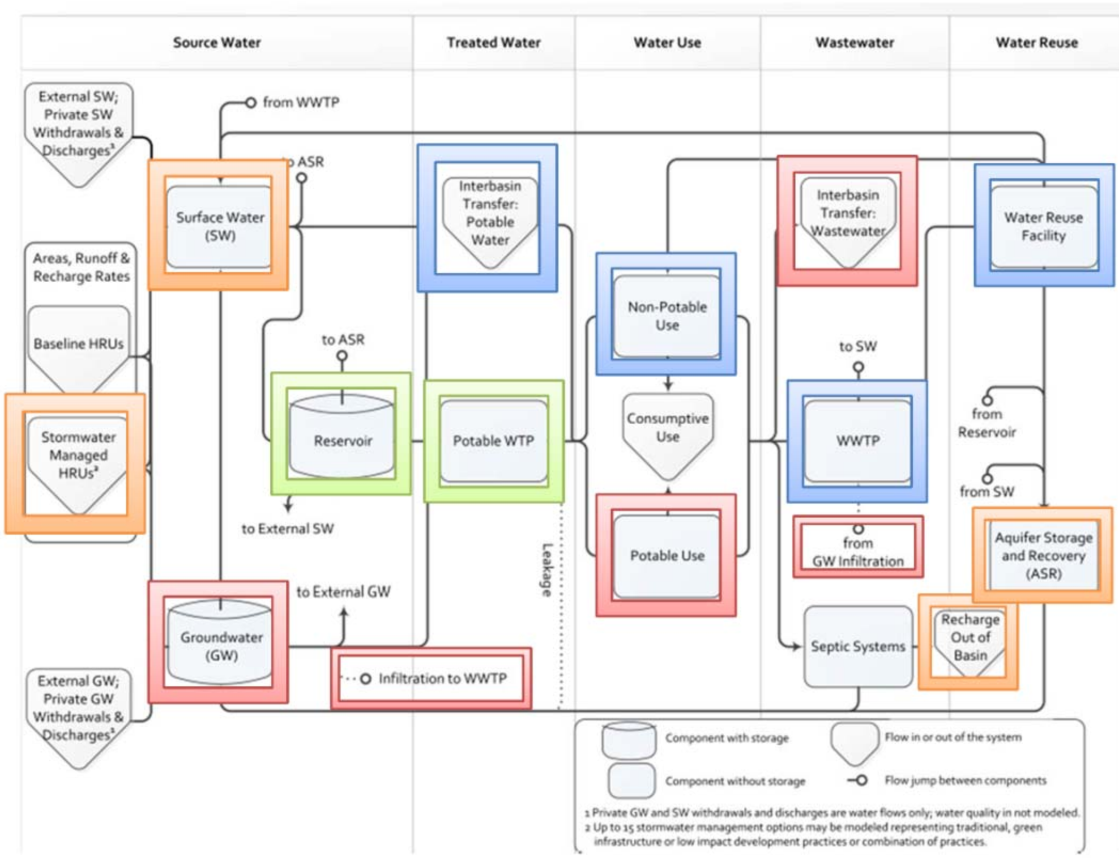


Figure 1-2: WMOST Schematic Diagram with system components evaluated for reduction (red), expansion (blue), complementary increase/ replacement (green), and not included (orange).

WMOST is based in Microsoft Excel and integrates a linear programming (LP) optimization solver to Visual Basic for Applications (VBA). The LP optimization solver determines the most cost-effective set of watershed management alternatives needed to meet all of the input criteria set by the user. Figure 1-3 shows the internal configuration of WMOST, while Figures 1-4 and 1-5 show a sample screenshot of the main and input worksheets. Each of the ‘buttons’ on the main worksheet takes the user to a separate worksheet which requires the input of user data. VBA sets up the input worksheets by the number of HRU types and sets, as well as the number of water user types determined and then named by the user. VBA then reads the data from the input worksheets and enters them into the equations which define the optimization problem, included the mass balance of water, system costs, generated revenue, and study area constraints. The LP optimization solver then produces the most cost effective solution of the combined management alternatives. VBA creates table and graphical output worksheets which are accessed through the main worksheet. Although there is potential for including trade-off and sensitivity analyses of the alternatives in the programming, these were not included in the first version of WMOST. Instead, the user must manually perform them, by varying flow constraints to see the trade-off of alternatives and varying input data to see how sensitive model outputs are to each input (USEPA User Guide, 2013 and USEPA Theoretical Documentation, 2013).

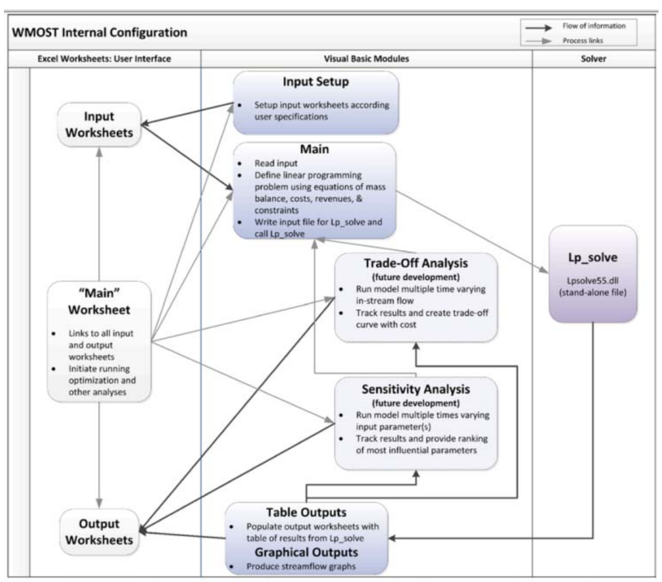


Figure 1-3: WMOST internal configuration (USEPA Theoretical Documentation, 2013)

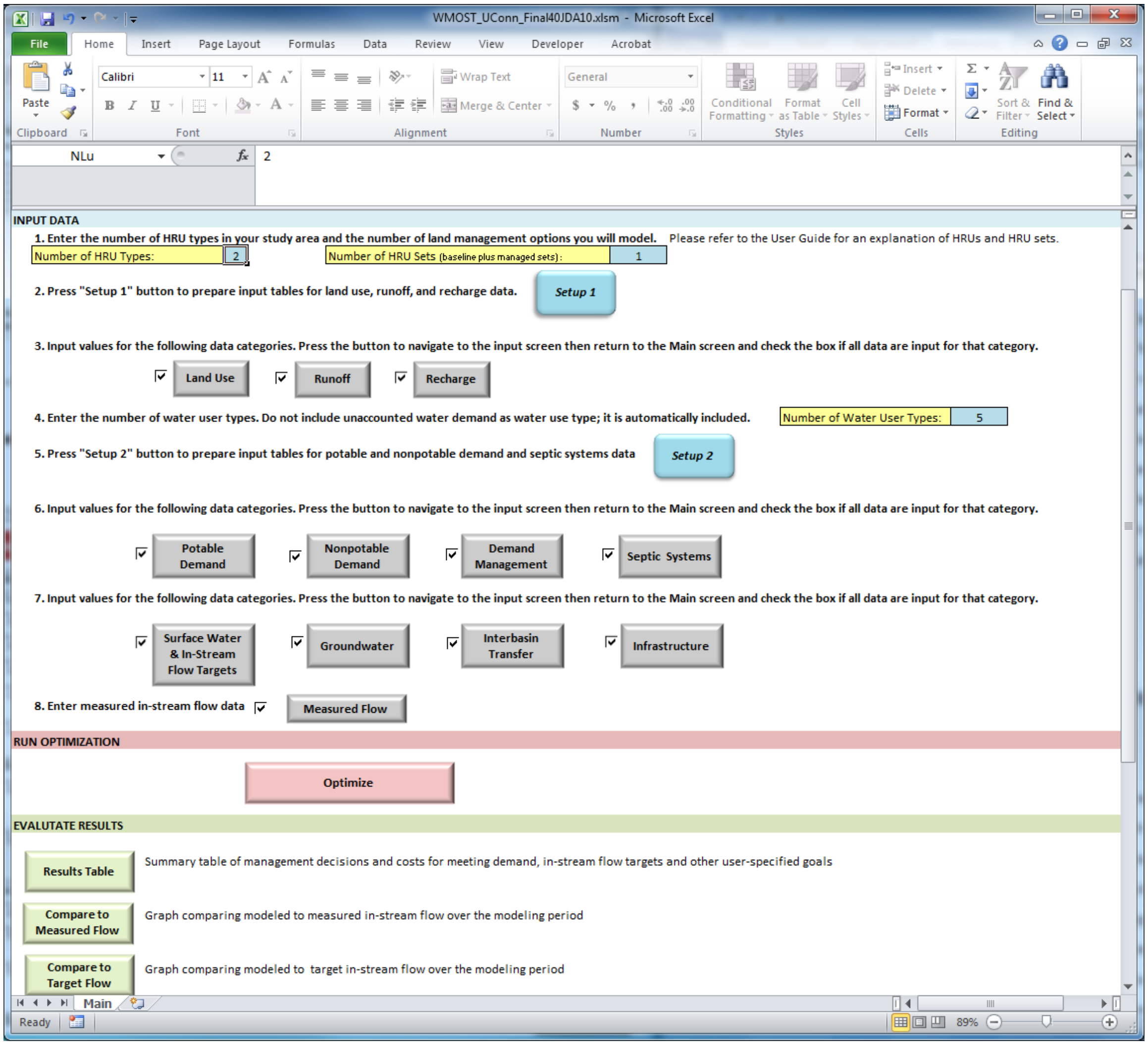


Figure 1-4: Screenshot of main worksheet of WMOST

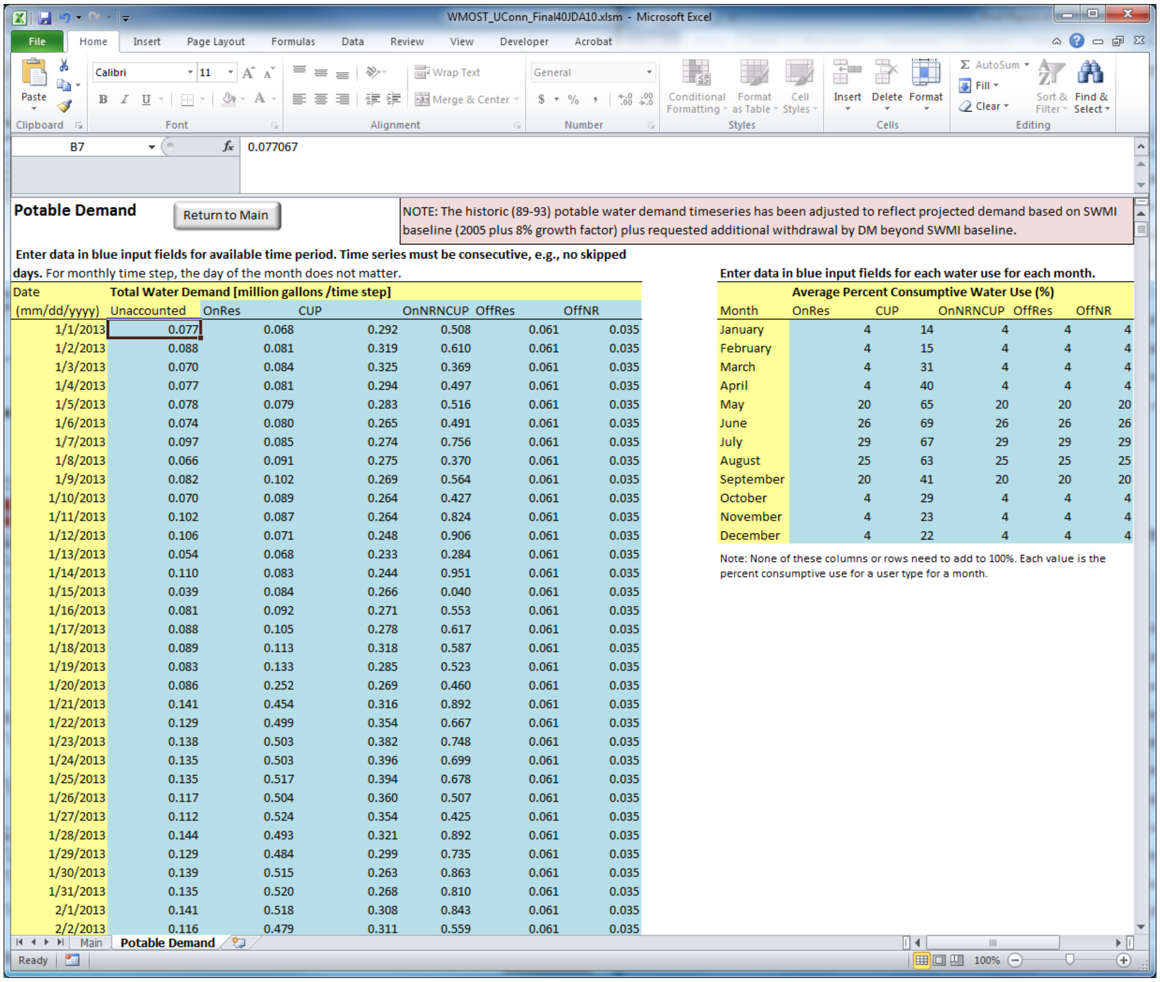


Figure 1-5: Screenshot of main worksheet of WMOST

WMOST includes 20 separate watershed management alternatives for users to select from. Table 1-1 describes the available management options, all of which can be modified or excluded on the user's command, and denotes whether that option was considered for this case study. WMOST models the study area on the daily or monthly time step for the planning period designated by the user and returns the management alternative set optimized for cost.

Table 1-1: WMOST Watershed Management Alternatives		
Watershed Management Alternative	Result	Implemented in Case Study?
Increase land use conservation	Runoff & recharge remain at natural rates	No
Stormwater BMPs or LID employed	Runoff & recharge rates in new development comparable to natural rates	No
Increase surface water storage capacity	Alters timing of pumping, possbily removing need to supply additional sources	Yes
Increase surface water pumping capacity	Reduces demand from groundwater pumping and interbasin transfer	No
Increase groundwater pumping capacity	Reduces demand from surface pumping and interbasin transfer	No
Change in ratio of groundwater and surface water pumping	Changes timing of impact from withdrawal on source	No
Increase potable treatment capacity	Increases availability of water sources to demands	Yes
Decrease leakage in potable water system	Reduces demand from unaccounted for water	Yes
Increase wastewater treatment capacity	Compensates for increased water demands to maintain water quality	Yes
Decrease infiltration to sanitary collection system	Reduces capacity of wastewater treatment	Yes

Table 1-1 (cont): WMOST Watershed Management Alternatives		
Construct water reuse facility or increasing capacity	Produce or increase nonpotable water supply to meet existing demand reducing potable demand	Yes
Construct nonpotable water conveyance system or increasing capacity	Delivers nonpotable water, thereby decreasing potable demand	Yes
Construct aquifer storage & recharge facility or increasing capacity	Increases groundwater recharge for min. outflow or increased pumping capacity	No
Increase price of potable, nonpotable, and waste water	Reduces demand for each and increases relative infrastructure capacity	Yes
Provide direct demand management such as efficient appliance rebates	Reduces demand for potable, nonpotable, and waste water and increases relative infrastructure capacity	Yes
Increase or establish interbasin transfer of potable water	Reduces demand from groundwater and surface water pumping	Yes
Increase or establish interbasin transfer of wastewater	Reduces demand on wastewater infrastructure	No
Set minimum in-stream flow	Meet regulated or scientifically determined stream flow needed for ecosystem health	Yes
Set maximum in-stream flow	Improve ecosystem health by reducing effects of flooding; i.e. streambed modifications and habitat destruction	No

Table 1-2: WMOST Input Worksheets	
	Description
Land Use	HRU name, baseline area, min./max area, initial and O&M cost of conservation for each HRU set, baseline and managed
Runoff	Time series of runoff rates for each baseline and managed HRU sets
Recharge	Time series of recharge rates for each baseline and managed HRU sets
Potable Demand	Time series of water demand for each user type, average percent consumptive use by user type by month
Nonpotable Demand	Maximum percent nonpotable water use by month, average percent consumptive use by user type by month, water conservation check autofilled from input data
Demand Management	Price elasticities by user type, initial and O&M cost for service fee increases, maximum percent change in study period, initial and O&M cost for water efficient appliances rebate and demand reduction
Septic Systems	Customers with public water and septic systems recharging inside and outside of study area by user type
Surface Water & In-Stream Flow	Initial/min./max surface storage volume, initial and O&M cost of storage, time series for private SW withdrawal/discharge and external inflow, min./max in-stream flow and min. outflow
Groundwater	GW recession coefficient, initial/min./max GW volume, time series for private GW withdrawal/discharge and external inflow, min. GW outflow
Interbasin Transfer	Purchase and infrastructure cost for new/increased interbasin transfer of potable and waste water, existing liminits on interbasin transfer by day/month/annum, additional interbasin transfer limits
Infrastructure	Planning horizon, interest rate, potable and sanitary water fees, initial/O&M cost, max capacity, lifetime remaining, and lifetime of new infrastructure for GW/SW pumping, water and wastewater treatment, water reuse, nonpotable distribution, and aquifer storage and recovery, initial/O&M cost of unaccounted for water and infiltration survey & repair
Measured Flow	Measured in-stream flow at reach

Table 1-2 succinctly describes the data required from each input worksheet. Chapter 2 details how each input described in Table 1-2 was determined for this specific case study and how it is used by WMOST to produce the end result. The user must create a series of Hydrologic Response Units (HRUs) with unique stormwater runoff and recharge rates, as well as managed HRU sets with best management practices (BMPs) or low impact development (LID) implemented. The model lumps these HRUs into a single composite watershed with one stream reach comprising the entire study area to perform hydrologic calculations. The user must define the number of different water user types in their study area and describe demands and pricing constraints. Stormwater, groundwater, and streamflow into and out of the watershed must be characterized. The potable, nonpotable, waste, and interbasin transfer water infrastructure must be defined including costs and lifetimes of existing and new construction. Having populated all the natural and manmade water flows, demands, and pricing information, the model is ready to be optimized. The optimization requires that water be conserved, final groundwater and reservoir storage volumes meet the initial volumes, and all constraints on stormwater, groundwater, and streamflow are continuously met over the planning period (USEPA User Guide, 2013). The end results of this modeling procedure include the following:

1. A ‘Results Table’ showing the quantity of each management practice used, annualized costs of each, water and wastewater revenue, and total annual cost (See Figure 1-6)
2. A graph showing modeled and measured in-stream flow (See Figure 1-7)
3. A graph showing modeled and target in-stream flow (See Figure 1-8)

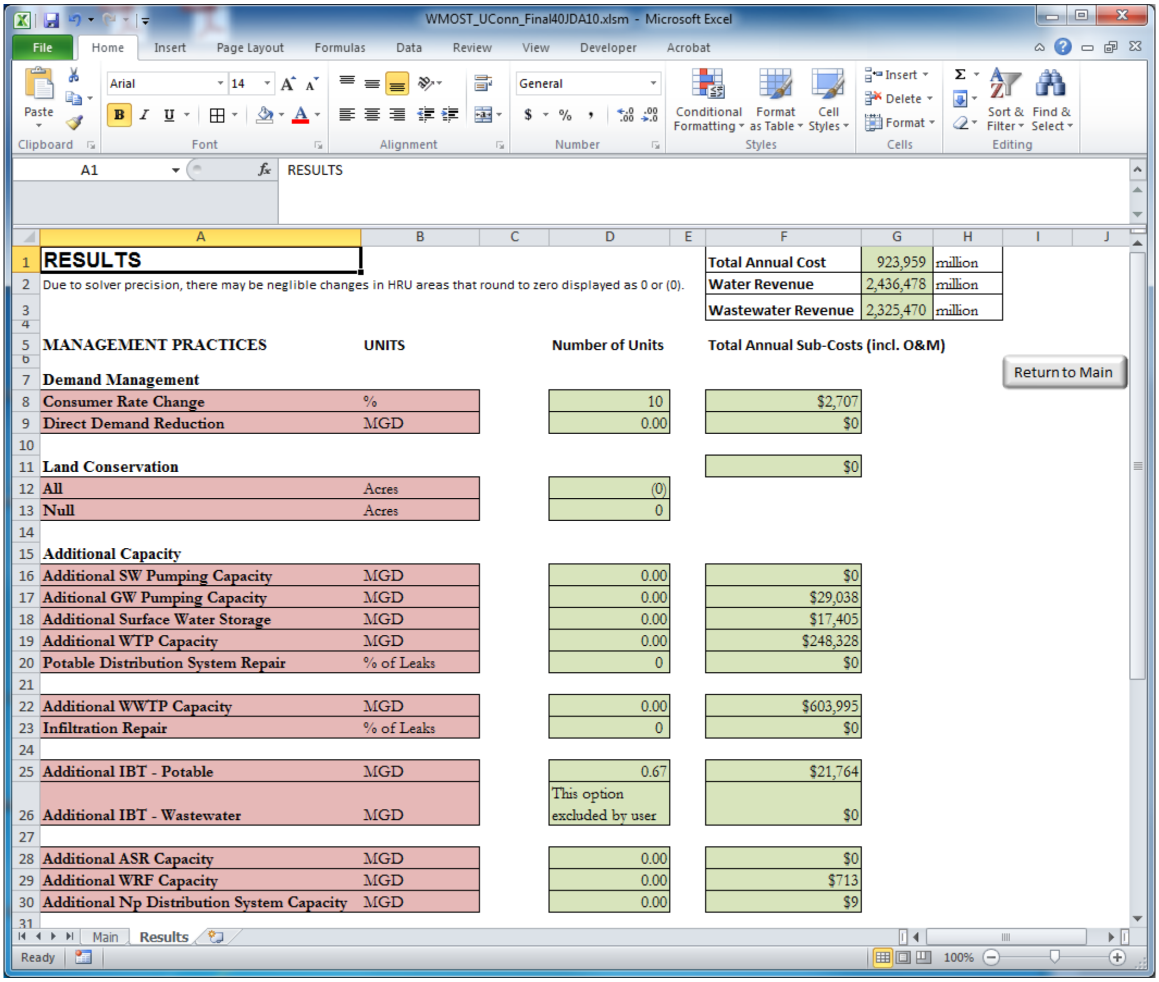


Figure 1-6: Screenshot of ‘Results’ worksheet of WMOST after a model run

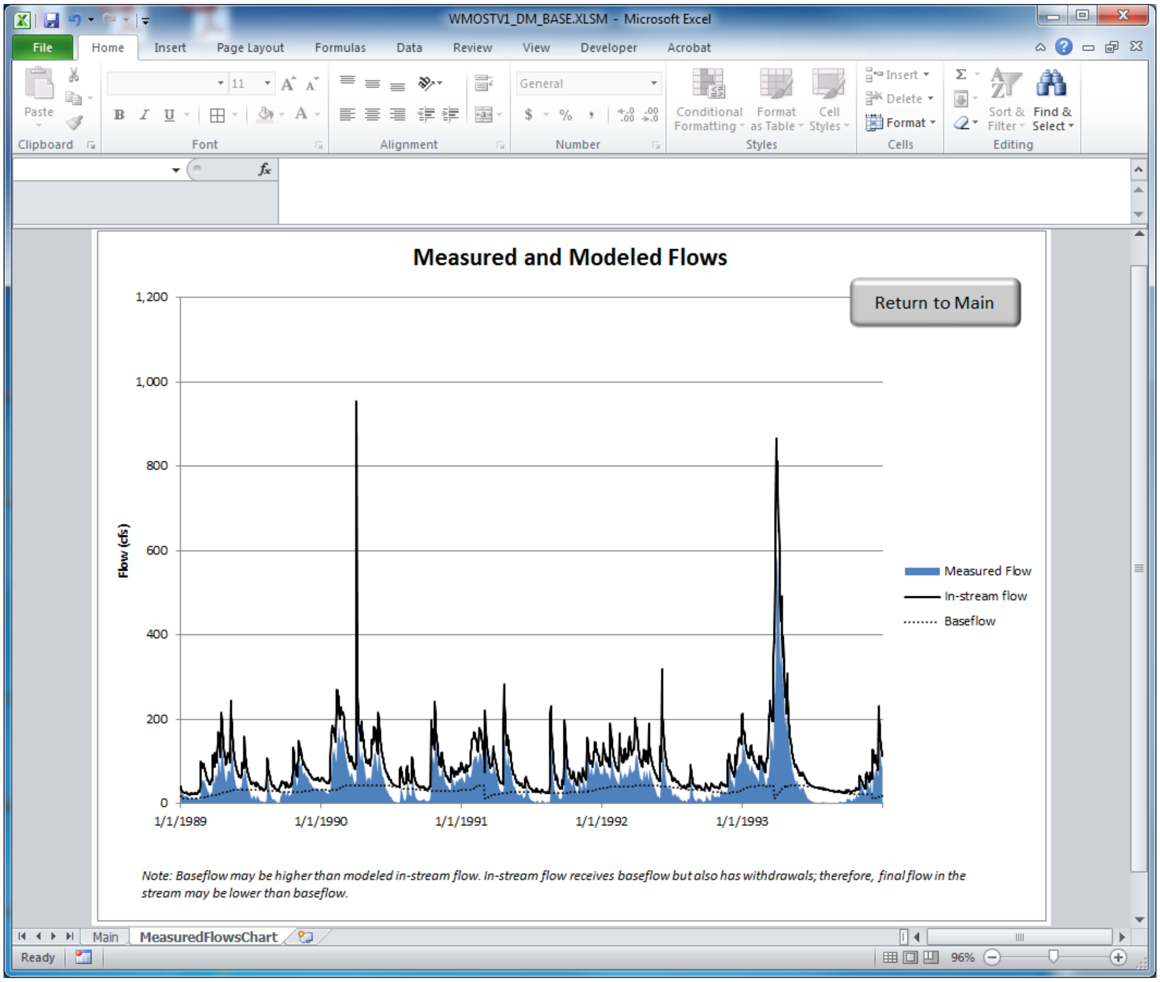


Figure 1-7: Screenshot of 'Compared to Measured Flow' worksheet of WMOST after a model run.

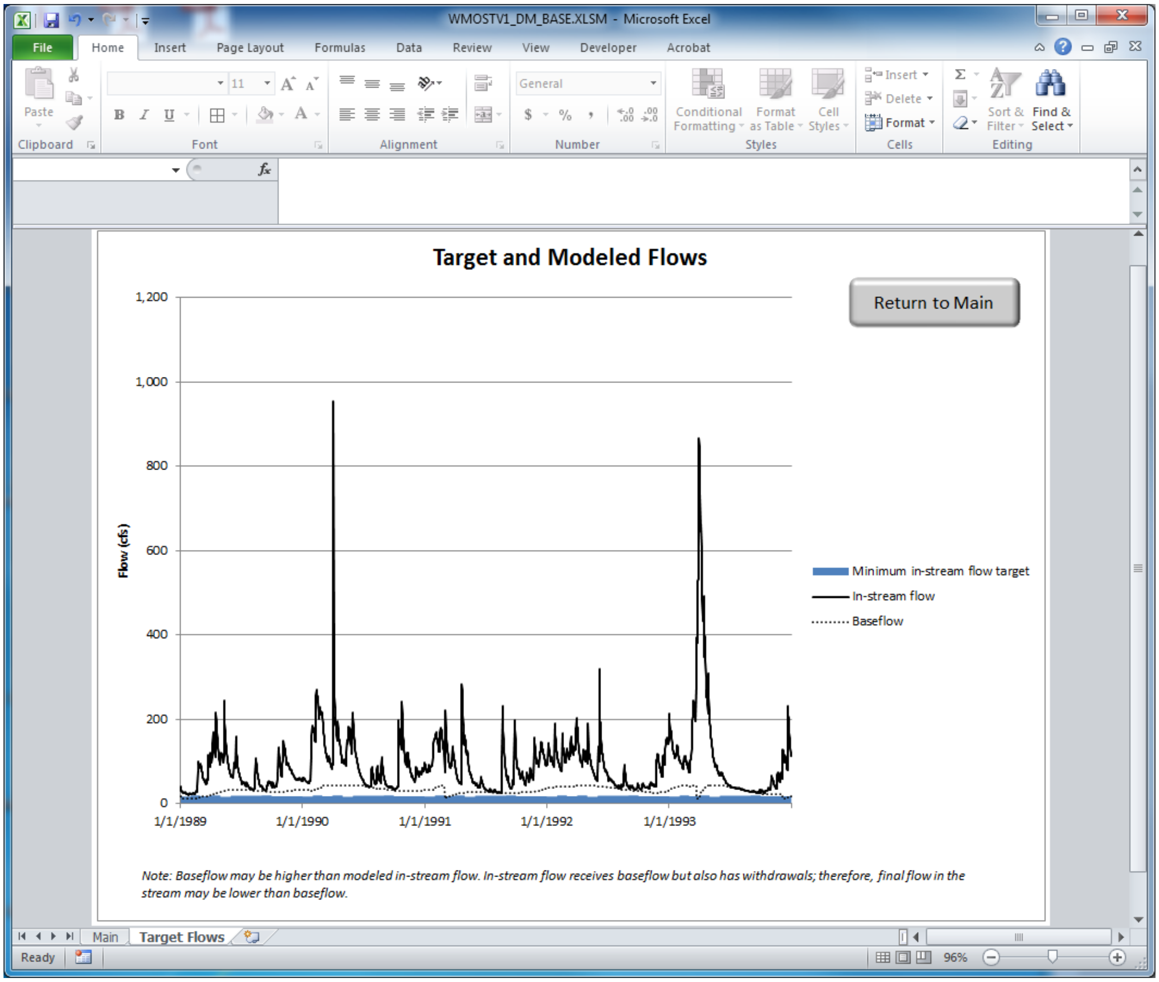


Figure 1-8: Screenshot of 'Compare to Target Flow' worksheet of WMOST after a model run.

Two case study examples were prepared for the release of WMOST to the public to provide guidance in the capabilities and challenges of preparing a watershed management model. The first case study presents an evaluation of the management in the Upper Ipswich River Basin in Massachusetts undertaken to reduce and prevent historic low/no-flow conditions in the Ipswich River. The watershed provides water to all or part of 5 municipalities which only discharge a portion of wastewater to the Ipswich, and human demands peak during the low flow time period in late summer. A single year was modeled using data at the monthly time step. Based on the defined watershed conditions and infrastructure costs, WMOST suggested surface water pumping and aquifer storage and recharge to change the timing of withdrawals avoiding low flows, and directly increasing stream base flow. WMOST also recommended reduced wastewater interbasin transfer by constructing wastewater facilities as well as repairing potable distribution leakages and wastewater infiltration. The second case study evaluated another portion of the Ipswich for Danvers and Middleton modeling the watershed at the daily time step with 5 years of data for a 20 year planning period. Surface and ground water are used to meet water demands in both towns, and Danvers predominantly exports its wastewater out of the Ipswich River Basin. The towns being evaluated only represented part of 18 subbasins contributing to the Ipswich and a significant portion of Danvers drained to another watershed. Land management options were limited in area to the parts of Danvers and Middleton draining to the Ipswich. The modelers had to create synthetic gauge flows, because not all of the municipalities drained to consecutive reaches. WMOST was able to generate streamflow data based on the inputs with a Nash-Sutcliffe Efficiency of 0.93, establishing WMOST's ability to simulate hydrology well, although it did produce higher than actual summer low-flows which are the predominant motivation to create the model. The optimization model was run for the baseline condition and four management scenarios to see how alternative selection changed by assuming summer water use was conserved by 50%, altering minimum in-stream flow, excluding the interbasin transfer of wastewater, and different interbasin transfer costs. WMOST consistently suggested that prices be increased, water rebates be offered for appliances, and potable leakage be fixed, as well as fix wastewater infiltration to reduce overall water demand. Other criteria were selected variably over the scenarios including wastewater treatment, stormwater infiltration, aquifer storage and recharge, interbasin transfer of water, and water reuse facilities (USEPA User Guide, 2013). These case studies provided the guidance to produce the evaluation of management alternatives in the UConn water system, which experiences similar issues with low stream flows an infrastructure capacities.

Study Area Characteristics

UConn owns its potable water supply system and sanitary sewer treatment plant including the necessary conveyance systems, as well as a water reuse facility. The University water supply system consists of eight groundwater pumps, two chemical feed pump houses, six storage tanks, an additional transfer pump house, and 36 miles of transmission and distribution lines. See Figure 1-9 for the schematic layout of the key supply infrastructure (UConn Water Supply Plan, 2011). The University's major wastewater infrastructure include 13 pump stations, gravity sanitary mains, force sanitary mains, the Water Pollution Control Facility, and the newly constructed Water Reclamation Facility. See Figure 1-10 for the schematic layout of the University's wastewater infrastructure (UConn Water and Wastewater Master Plan, 2007).

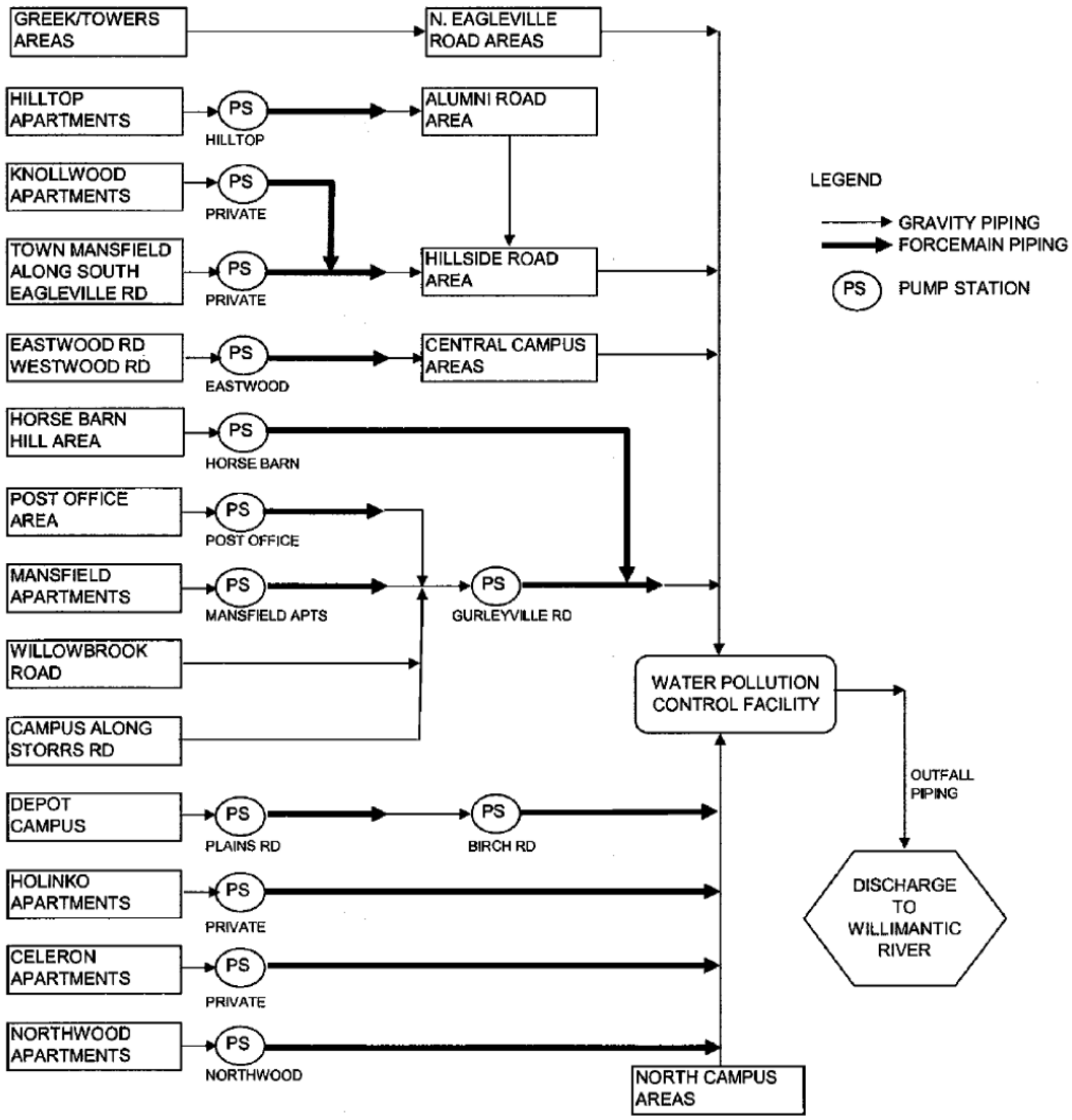


Figure 1-10: Schematic layout of UConn wastewater conveyance system (UConn Water and Wastewater Master Plan, 2007)

The University Facilities Operation staff and the Office of Environmental Policy are responsible for operating, maintaining, monitoring, and evaluating the campus's water and wastewater systems, as well as commissioning contractors as needed to assist in these duties. As the University is experiencing a period of significant expansion and development, it is an opportune time to study the aging infrastructure and evaluate the available infrastructure improvement and expansion options.

The Willimantic River Wellfield is currently registered for a maximum withdrawal rate of 2.3077 MGD by the Connecticut Department of Environmental Protection (CTDEP) through its Wells numbered 1-4. In reality, the wellfield is only capable of producing 1.97 MGD on a peak day and 1.48 MGD for a normal day. This lower value is the one used in this study to represent the safe groundwater pumping yield. The in-stream flow is significantly greater in the Willimantic than the Fenton at each river's respective wellfield locations. In addition, the registered limit of the Willimantic pumps represent about 60% (3.6 CFS) of the lowest flow measurements recorded in the Willimantic River. These facts support the prevailing and future use of the Willimantic Wellfield as the dominant source to supply potable water (UConn Willimantic River Study, 2011).

The Fenton River Wellfield is registered for maximum withdrawal rates of 0.8442 MGD by the CTDEP from its wells 'A-D'. Unfortunately, it is not sustainable to pump at this rate during the University's peak demands and the Fenton River's annual low flow period that coincide with one another between mid-August and mid-October. Low-flow pumping protocols were developed for this time period based on the Fenton River Study. The protocol requires pumping to be reduced as the Fenton River reaches sustained flow below 6.0, 5.0, 4.0 and 3.0 cubic feet per second (CFS). Ultimately, at 3.0 CFS, the Fenton River Wellfield has to be turned off completely to maintain the integrity of the Fenton River system (Warner et al., 2006). During low flow conditions of 1.0 CFS, it has been determined that the use of the singular Well D is practicable based on pumping tests that showed, at a safe yield rate, the in-stream flow at Well A is equal to that at Well D. Utilizing a pumping rate of 0.348 MGD removes exactly the amount of water that is supplied to the river in the length of the wellfield through groundwater inflow and runoff. This conditional use is based on the assumption that there is a resting period between when the entire Wellfield was shut down and that Wells ‘A-C’ remain shut off. The inclusion of this additional supply during the seasonal low flow is helpful in meeting peak day demands as well as removing some burden from the Willimantic River Wellfield which has been responsible for providing 100% of the University’s water demand during low flow periods, after the Fenton River Study was completed in 2006 (UConn Wellfield Management Plan, 2011).

Water Supply Background Information

The completion of this narrative warrants the inclusion of select pertinent terms and logic commonly included in water utility discussions. The base measurement of a supply system is the average day demand (ADD). ADD is the potable water demand for the entire year divided by the number of days in the year. This value provides a rough valuation of the size of a water utility, but no information on temporal variation in the system. To provide a better representation of how supply needs change through the year, monthly average day demands are generally determined. From this data the maximum monthly average day demand (MMADD) is obtained which represents the highest long term system demand a utility can expect. Generally, this value is found during the summer season, when temperatures are high and precipitation is low causing a marked increase in irrigation and cooling demands. The timing and relation of this value to other monthly average days depends on the supply area’s demographics and land use characteristics. Peak day demand (PDD) is the single day of the year where water demand is the highest. The cause of the PDD is usually similar to the MMADD, but in a more extreme, short term form. On the other hand, a municipality may experience their PDD due to an anomalous event water demand event, such as a large structure fire or water main break. These three values form the basis of water utility evaluation, and describe how the water supply sources, treatment facilities, and conveyance infrastructure will be taxed. These demands also have value when looking at wastewater treatment, as potable water ultimately becomes wastewater, although a certain percentage of potable demand is lost to evapotranspiration, and wet weather events cause peak demands in wastewater infrastructure through infiltration and inflow (I/I) to be discussed later.

Storrs Campus Development

The UConn water system will be called upon for additional demands in the coming year for several reasons, as outlined in the many reports on the area's water supply system completed in the last decade. First, the UConn system needs additional water to meet the current 15% MOS for the low flow period, which occurs when the Fenton Wellfield supply contributions are reduced or eliminated and demand on campus is at its peak. In addition, increased supply is needed to meet the 15% MOS for peak day demand in the 2060 demand projection. Next, the University needs increased supplies to satisfy increased demands from the North Campus Technology Park. Although this development has been included in master plans since 2006, the expected water demand based on building square footage was increased between the 2011 Water Supply Plan and the Environmental Impact Assessment of 2012. The University has also committed to supplying a certain amount of water off campus to the Town of Mansfield, some of which is due to increased populations at UConn. Some additional demands such as growth of the Four Corners development and a newly proposed managed care facility were recognized as off campus demands UConn will supply that was not previously committed to Mansfield. Finally, UConn has committed to participating in the Next Generation Connecticut (NextGenCT) proposal. This proposal calls for the expansion of science, technology, engineering, and math (STEM) disciplines at the University over the coming decade, which includes the hiring of around 250 faculty members, accepting 6,500 additional undergraduates, and building/improving the facilities needed to accommodate NextGenCT related additions (UConn Environmental Impact Assessment, 2012). The Water Use Projections section of Chapter 2 fully describes the projected water demands at the University through 2060.

Connecticut Water Company

The CWC has been commissioned to supply additional water supplies to the University through its Northern Operations Western System which supplies around 75,700 people in 11 other northeastern Connecticut municipalities. CWC utilizes the Shenipsit Reservoir and numerous groundwater pumps to provide 14 million gallons (MG) on average days and 16.7 MG for peak days to its Western System customers. Projections by the Department of Public Health project that the Western System, in its present state, has the ability to supply water to the UConn system while maintaining a 15% MOS for average day demand (ADD) through 2060 and for maximum monthly average day demand (MMADD) through 2030. In order to meet MMADD and peak day demand (PDD) projections through 2060, CWC needs to complete strategic capital improvement projects to increase supply within the Western System (UConn Environmental Impact Assessment, 2012).

Chapter 2-Methodology

The EPA has developed the WMOST for water resource managers, planners, and researchers to quantitatively evaluate the water management decisions available to them to meet the regulatory, budgetary, environmental, and social constraints of their study area. The following chapter introduces each of the WMOST input worksheets, parameters that need to be filled in by the user, and how they were obtained or developed for the UConn case study.

There was one major issue in creating the baseline modeling scenario for WMOST that needs to be justified before detailing model formulation. Hydrology was not included in this case study for several reasons. The University drains to two separate watersheds, being the Willimantic and Fenton Rivers. The Fenton River is not gauged sufficiently for the inclusion in the model. This is unfortunate because the Fenton River is the water body of concern for low flow conditions. The Willimantic River is gauged, and its data were used for this modeling exercise, but management alternatives will not be triggered by flow conditions on the Willimantic because University activities aren't capable of producing damaging low flow conditions. No hydrologic model was available at the time of modeling, but to evaluate land management alternatives, runoff and recharge data would be needed for the area draining to the Willimantic. University owned land represents a small portion of that which drains to the Willimantic and has committed to stormwater BMPs through its future development. Given these facts, it was decided that no hydrologic model would be procured for this study, as the outcomes of such a model will have limited effect on the selection of watershed management alternatives. Had the Fenton River been effectively gauged, a hydrologic model would have been warranted as University activities are very capable of causing low flows on the smaller stream.

Land Use

The entire study area is lumped by WMOST into a single watershed and drained to one stream reach. Watershed areal characteristics are collected from the initial land use/ land cover (LULC) areas given by the user. Each LULC is classified as its own HRU with a baseline area, a minimum area, and a maximum area to be maintained in the optimization process. The first set of HRUs is the land conservation set. The minimum and maximum areas can be defined by a number of factors including local zoning, existing or recently planned developments, or limitations in conservation funding. The initial cost to conserve a certain area and the O&M cost to maintain that conserved area need to be included. In addition, the user can define managed sets of HRUs where the user applies a certain BMP or LID to a minimum or maximum area of one or more HRUs. For instance, the user can choose to implement bioretention systems designed to infiltrate 1" of rainfall runoff over the developed area on 0-50% of commercial HRUs and 40%-70% of municipal HRUs. The objective of this management is to reduce runoff and increase recharge in the commercial and municipal land uses to the maximum extent practicable under the system constraints. The costs to implement, operate, and maintain these practices are required from the user (USEPA User Guide, 2013). The University only owns 3,550 Acres, or about 12% of the Town of Mansfield. Most of this percentage is fragmented, undeveloped and/or preserved land (UConn Water Supply Plan, 2011). The University only plans to develop a maximum of 111 acres in the North Campus, 42 acres in Storrs Center, parts of the 84 acres North Eagleville area, and portions of the 234 acre Depot Campus area. The majority of these developments are not explicitly defined at this point and some of the work will be redevelopments of existing built up areas. The University has shown a commitment to requiring stormwater BMPs and LIDs with all North Campus developments required to meet LEED Silver certification and having a maximum floor area ratio of 0.35 (ratio of building floor area to parcel area)(Skidmore, Owings & Merrill LLP, 2012 and UConn Water Supply Plan, 2011). Development outside the North Campus is assumed to carry similar development practices. Combining the planned LIDs with the fact that only a portion of less than 15% of University owned land is expected to be developed in the planning period, it was assumed that including the cost of BMPs or LIDs in this case study would be extremely speculative and produce costs that are already incorporated in building budgets. Therefore, no managed HRU sets were created. Moreover, entering an assumption as to the minimum and maximum land area to be conserved and costs to conserve them would be misguided, as anticipated developments in the planning period are such a small portion of the study area.

Runoff & Recharge

WMOST requires the input of runoff and recharge rate time series data to run its optimization as it does not have the capability to perform these calculations. The User Guide recommends that the user obtain outputs from hydrologic models such as Hydrological Simulation Program Fortran, Soil Water and Assessment Tool, or Storm Water Management Model using the area delineations from the Land Use section. It also suggests that if such models aren’t readily available and can’t be produced for the WMOST exercise, generic rates can be used in their place. These rates must also be determined for the managed HRU sets based on the practices chosen for the management areas under the basic assumption that runoff rates would decrease and recharge charges would increase as BMPs and LIDs are implemented across the watershed.

The UConn WMOST case study presents a unique challenge in its runoff and recharge rate calculations. As previously mentioned, the University drains to two separate stream reaches from its fragmented campus which contains over 3,550 acres. The campus drains to the Shetucket Subbasin of the Connecticut Coastal Basin (U.S. Geological Survey Water Data Report, 2014). Although, the University impacts both rivers through is groundwater pumping and land use decision making, effects on the Fenton River are of greater concern because of its propensity for experiencing excessive low flows concurrent with peak University water demands. It would make sense then, to model the recharge/runoff rates, streamflows, and groundwater flows from the portion of the campus draining to the Fenton. Unfortunately, the only active gaging station on the Fenton is USGS Gaging Station #01121330 at Old Turnpike Road immediately upstream of any campus drainage (see Figure 2-1). It is not possible to directly quantify Fenton River streamflows in relation to the University.

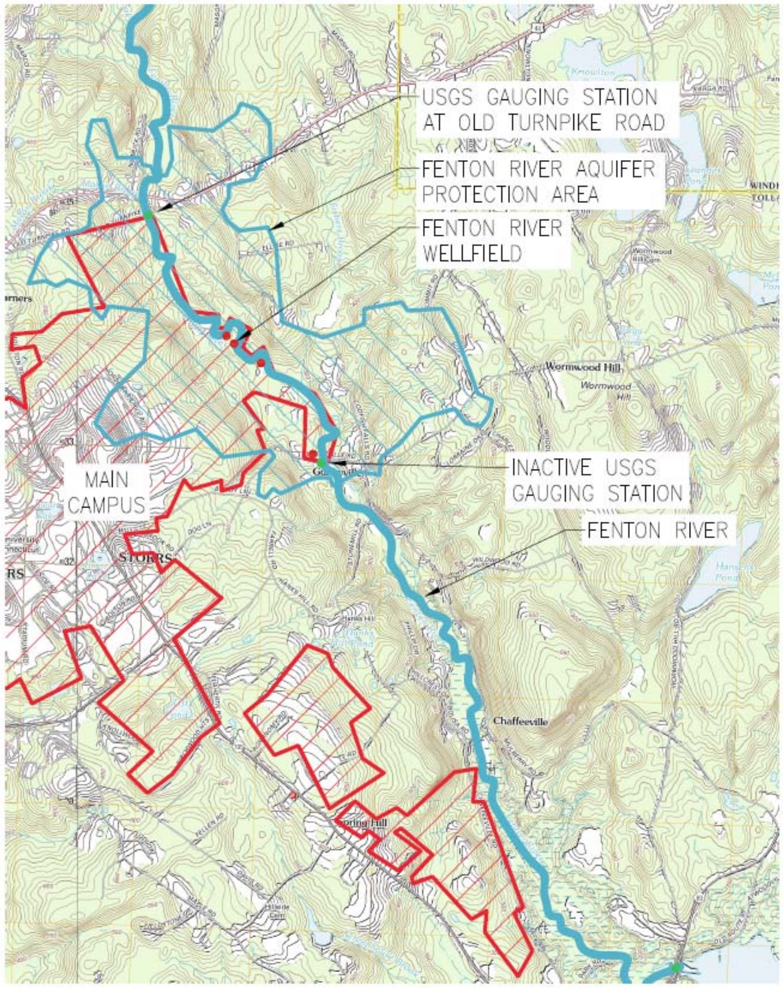


Figure 2-1: Fenton River, USGS 2012 7.5 minute topographic maps overlain with Storrs Campus areas and pertinent hydrologic features (U.S. Geological Survey, 2012 and UConn Water Supply Plan, 2011)

The Willimantic River, on the other hand, does have continuous streamflow data since 2009 from USGS Gaging Station #01119382 at Merrow Road immediately upstream of the campus reach and from USGS Gaging Station #01119500 near Coventry, CT downstream of the furthest campus reach since 1931 (see Figure 2-2). For the purposes of running WMOST, these stream data were used for the external stormwater inflow discussed in the Surface Water section and the in-stream flow used in the Measured Flow section. No prepared stormwater modeling was available for the stream reaches evaluated in this case study.

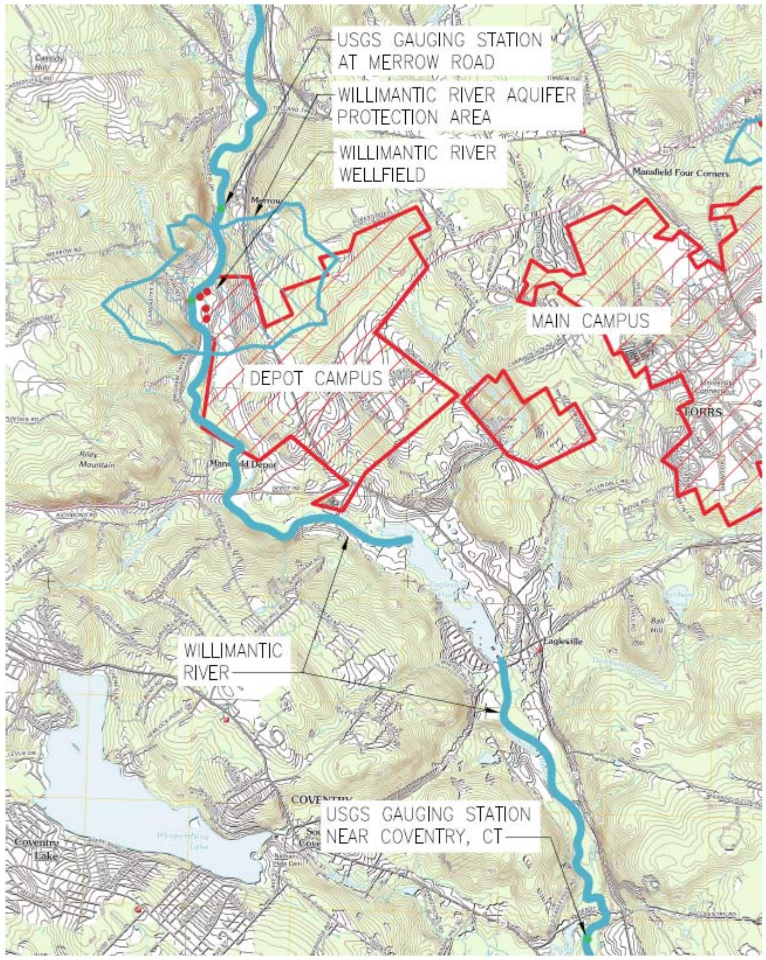


Figure 2-2: Willimantic River, USGS 2012 7.5 minute topographic maps overlain with Storrs Campus areas and pertinent hydrologic features (U.S. Geological Survey, 2012 and UConn Water Supply Plan, 2011)

Based on the Land Use section, it can be inferred that University land use change from future development will have a very small effect on the Willimantic River in the planning period as stormwater BMPs are a staple of design practices and these developments represent a relatively small portion of the drainage area within the stream reach. In addition, groundwater pumping does not have the ability to cause the Willimantic River to run dry, and the University has already established a safe yield well below the registered max withdrawals based on thorough groundwater modeling efforts.

Given the fragmented University contributions, relatively minimal development impacts, and margin of safety on groundwater pumping, it did not seem valuable to devote the resources to procure a hydrologic model at the daily time step for the Willimantic River stream reach. The hydrologic contributions of WMOST are used to ensure that minimum in-stream flows are met by the use of management alternatives including forcing development to increase recharge, reduce and delay the peak runoff, reduce groundwater pumping, and/or reduce surface pumping. For the UConn case study there is no surface water pumping, developments are expected to have minimal effect on streamflow, and the limit of groundwater pumping is set to maintain safe levels of flow. These facts mitigate the need to model the stream at the daily time step to create minimum cost alternatives. In essence, streamflow becomes a token of running the model. The decision to not attempt modeling the Willimantic or Fenton River is justified by the real focus of this case study which is to determine what set of water demand and infrastructure alternatives produce the least cost to the University by optimizing CWC water purchases, which is independent of hydrology under the constraints described in later sections. Had accurate Fenton River streamflow data been readily available, procuring a hydrologic model would have been warranted to perform a trade-off analysis optimizing management alternatives to meet different flow conditions at varying costs. Instead, the groundwater supply is combined and set to different limits for comparison as described in the Infrastructure section.

Potable Demand

Prior to detailing the potable demand, the user must set the number of water user types on the main worksheet, not including unaccounted for water. For this case study, five (5) water user types were selected to represent the study area. See Table 2-1 for a description of each, and Figure 2-3 for a running plot of demands per user relative to total demand. Note, off campus users are not included in the figure because their data is quarterly and a low portion of demands.

Table 2-1: UConn Water User Definitions

Water User Type	Abbreviation	Description	Relative Daily Proportion
Unaccounted	Unacct	Water lost through system leakages at fittings and cracks, system flushing, fire suppression, and unmetered accounts	~8% of total water use
On Campus Residential	OnRes	Dormitories including some cafeterias, variable by student occupancy	7-12% during breaks, ~30% during semester
Central Utility Plant	CUP	Cooling towers, chillers, and boilers for campus climate control	Temperature/ student dependent, 15-40%
On Campus Non-Residential	OnNRNCUP	Academic, administrative, athletic, depot, emergency services, non-CUP utilities	20-63%
Off Campus Residential	OffRes	Select campus adjacent residences and condos, quarterly data only	5-7%
Off Campus Non-Residential	OffNR	Commercial, business, municipal, and institutional bldgs, quarterly data only	2-4%

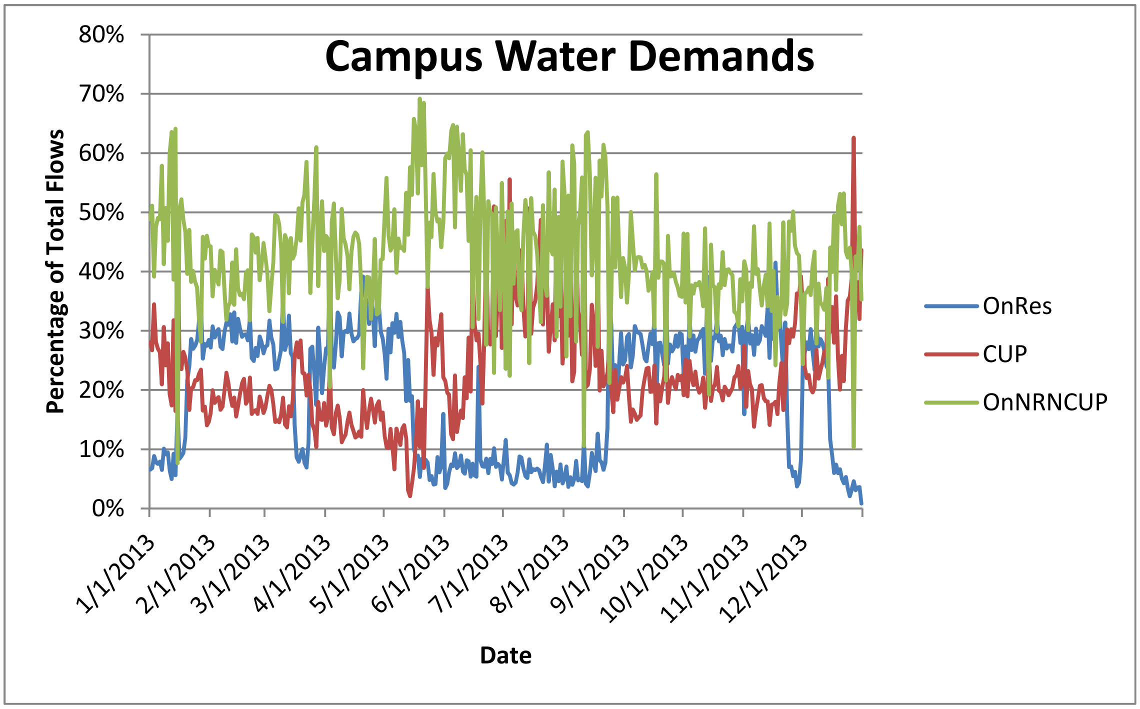
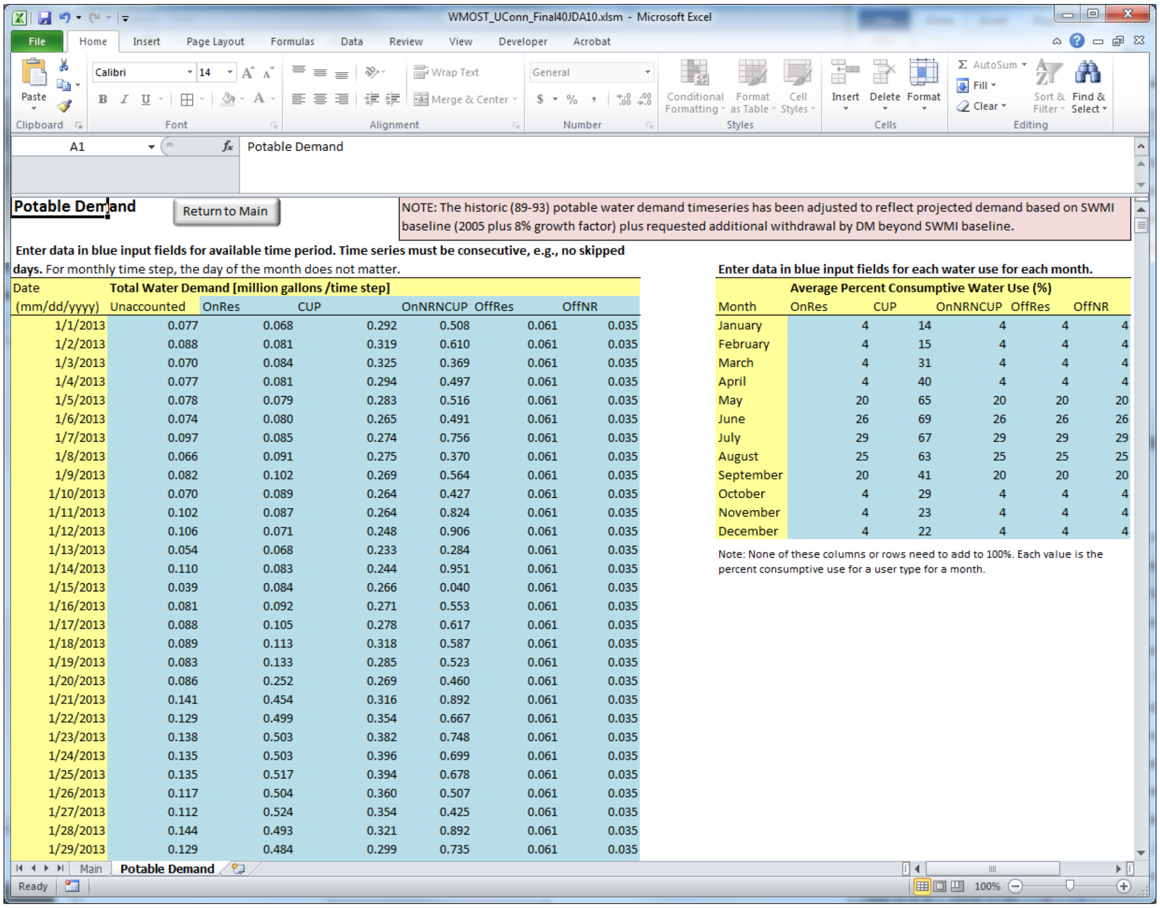


Figure 2-3: Daily water demands between the three major University users

Within the Potable Demand macro, the user inputs the demand data time series for each user type at the time step previously established in earlier macros. In addition, the user inputs the monthly average percent consumptive water use percentage. This value represents the amount of water demand that is not returned to the sanitary system. Typically, it is very low in the winter and significantly higher in the summer. The most common non-consumptive water use in residential users is landscape irrigation, which is either lost to infiltration or evapotranspiration. The largest non-consumptive use is steam losses to the atmosphere from utilities and industrial users that use heating and cooling system processes. See Figure 2-3 for a screenshot of the Potable demand worksheet.



Potable Demand

NOTE: The historic (89-93) potable water demand timeseries has been adjusted to reflect projected demand based on SWMI baseline (2005 plus 8% growth factor) plus requested additional withdrawal by DM beyond SWMI baseline.

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 month does not matter.

Date	**Total Water Demand [million gallons /time step]**					
(mm/dd/yyyy)	Unaccounted	OnRes	CUP	OnNRNCUP	OffRes	OffNR
1/1/2013	0.077	0.068	0.292	0.508	0.061	0.035
1/2/2013	0.088	0.081	0.319	0.610	0.061	0.035
1/3/2013	0.070	0.084	0.325	0.369	0.061	0.035
1/4/2013	0.077	0.081	0.294	0.497	0.061	0.035
1/5/2013	0.078	0.079	0.283	0.516	0.061	0.035
1/6/2013	0.074	0.080	0.265	0.491	0.061	0.035
1/7/2013	0.097	0.085	0.274	0.756	0.061	0.035
1/8/2013	0.066	0.091	0.275	0.370	0.061	0.035
1/9/2013	0.082	0.102	0.269	0.564	0.061	0.035
1/10/2013	0.070	0.089	0.264	0.427	0.061	0.035
1/11/2013	0.102	0.087	0.264	0.824	0.061	0.035
1/12/2013	0.106	0.071	0.248	0.906	0.061	0.035
1/13/2013	0.054	0.068	0.233	0.284	0.061	0.035
1/14/2013	0.110	0.083	0.244	0.951	0.061	0.035
1/15/2013	0.039	0.084	0.266	0.040	0.061	0.035
1/16/2013	0.081	0.092	0.271	0.553	0.061	0.035
1/17/2013	0.088	0.105	0.278	0.617	0.061	0.035
1/18/2013	0.089	0.113	0.318	0.587	0.061	0.035
1/19/2013	0.083	0.133	0.285	0.523	0.061	0.035
1/20/2013	0.086	0.252	0.269	0.460	0.061	0.035
1/21/2013	0.141	0.454	0.316	0.892	0.061	0.035
1/22/2013	0.129	0.499	0.354	0.667	0.061	0.035
1/23/2013	0.138	0.503	0.382	0.748	0.061	0.035
1/24/2013	0.135	0.503	0.396	0.699	0.061	0.035
1/25/2013	0.135	0.517	0.394	0.678	0.061	0.035
1/26/2013	0.117	0.504	0.360	0.507	0.061	0.035
1/27/2013	0.112	0.524	0.354	0.425	0.061	0.035
1/28/2013	0.144	0.493	0.321	0.892	0.061	0.035
1/29/2013	0.129	0.484	0.299	0.735	0.061	0.035

Enter data in blue input fields for each water use for each month.

	Average Percent Consumptive Water Use (%)				
Month	OnRes	CUP	OnNRNCUP	OffRes	OffNR
January	4	14	4	4	4
February	4	15	4	4	4
March	4	31	4	4	4
April	4	40	4	4	4
May	20	65	20	20	20
June	26	69	26	26	26
July	29	67	29	29	29
August	25	63	25	25	25
September	20	41	20	20	20
October	4	29	4	4	4
November	4	23	4	4	4
December	4	22	4	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.

Figure 2-4: WMOST Potable Demand worksheet

‘Unaccounted’ is water lost through system leakages at fittings and damaged pipes, conveyance system flushing, fire suppression, and unmetered accounts. For the purposes of this exercise, unaccounted for water was set to 8% of the total system water production as determined by 2012 calculations from the Office of Environmental Policy. UConn’s unaccounted for water is significantly better compared to industry standards around 15%. The fact that this component decreased from 15% in the 2007-2009 period can be attributed to several actions taken by the University to identify and eliminate the many sources of unaccounted for water. These actions include an aggressive metering program meant to meter as many buildings as fiscally practical, completing regular water audits to identify inconsistencies in supply and demand, and performing leak detection surveys to identify the most cost effective repairs that can be repaired (UConn Water Supply Plan, 2011). One significant contribution to unaccounted for water is the University's irrigation systems. All of the campus irrigation systems at athletic fields and a single turf area are said to be metered. The UConn Water Conservation Plan from 2011 established that in reality only two are reliably metered and, by the publication date, were inconsistently checked, making their readings meaningless. An estimated 13.3 million gallons per year go towards field irrigation, while only 3.5 million gallons per year were determined to be necessary (UConn Water Conservation Plan, 2011). The University plans on expanding its current irrigation use by a maximum of 0.2 MGD during the growing season. A significant portion of growing season demands, depending on the year, coincide with the low flow conditions associated with the months of August and September in the Fenton and Willimantic Rivers, making this additional demand more significant (Coite, 2014). Although irrigation needs are highly dependent on weather, this study assumed irrigation was performed in the manner currently used, which is not optimized for weather. Modeling with the full 0.2 MGD may even fall short of actual future demands when the system inevitably begins leaking during the 50 year study period and as the campus sees increased irrigation needs to compensate for the expected climate change detailed in the Northeast Climate Projection section. Ultimately, 0.2 MGD was applied to the study period during the months of May-September in the OnNRNCUP user type to be described later in this chapter.

'OnRes' is the portion of water produced that is metered by on-campus, residential buildings, some of which provide food services. Water demand in this user type is driven by domestic uses including showering, laundry, dish washing, hand washing, and dining services. On-campus residential demand is highly variable over the course of the year based predominantly on whether class is in attendance. For the 2013 fall semester, the University had 18,032 undergraduate students, 6,244 graduate students, and 4,405 full-time faculty and staff enrolled or employed at the Storrs Campus (UConn, 2013). Undergraduate students typically leave campus during week-long spring and fall breaks, a month-long winter break, and the summer break from mid-May through late-August. Graduate students, faculty, and staff often remain on-campus to continue their research and support the remaining population. During class breaks, on-campus residential water use is significantly reduced. OnRes water demand data were made available at the daily time step for the entirety of 2013. The monthly consumptive water use for this user type varies from 4% for cooler months, where landscape irrigation is minimal, to 20-29% in the growing season between May and September, assuming that irrigation adjacent to residential buildings is captured in the building metering (Vickers, 2001).

'CUP' is the demand determined from the summation of the internal water metering at the Central Utility Plant and was provided for the 2013 calendar year at the daily time step. Water use by the Central Utility Plant varies in response to the local air temperature and whether or not the undergraduate student population is in class. The Central Utility Plant provides steam and chilled water used for climate control on the majority of the main campus buildings. During cooler weather, the Boiler Plant and the #9 Boiler require makeup water to compensate for steam lost in steam supply system leaks, steam traps, and air humidification systems as well as condensate losses in the steam return system. As temperatures fall, heating needs to increase, causing a higher demand for makeup water at the Central Utility Plant. Conversely, as the temperature increases above a certain threshold, chilled water is needed to cool university buildings. This water is supplied by the old and new cooling towers on-campus. These towers chill water through an evaporative cooling process. This process requires evaporation of between 80 and 90% of the incoming water, the remainder of which is sent to the sanitary sewer system, because of the buildup of solids created by the evaporation process (UConn Water Supply Plan, 2011). The final demand on the Central Utility Plant is the Co-Generation Plant which uses natural gas to produce electricity for the University while simultaneously generating steam which is used for heating and evaporative cooling. This system requires makeup water in the same ways as the boilers and chillers described above (UConn, n.d.). The average percent consumptive use for this user type was determined from 2008 monthly sub-metering data at the Central Utility Plant. The percentage representing the cooling tower demand of the total makeup water demand at the Central Utility Plant was multiplied by 0.85 (the midpoint of the 80-90% evaporative losses in the cooling towers). This creates an annual range in consumptive use by month from 13.9% in January to 68.8% in June (UConn Water Supply Plan, 2011). Consumptive losses in the boiler and steam losses aren't accounted for in this process. These losses are represented by steam leakages, humidifying systems, and condensate that does not return to sanitary sewers in the supply and return systems. Both of these values are difficult to quantify, especially in a campus setting, and have not been evaluated in the available UConn literature, so they aren't accounted for in this study.

'OnNRNCUP' is the on-campus, non-residential, non-Central Utility Plant demand which represents academic, administrative, athletic, emergency services, and maintenance buildings. These data were provided for the 2013 calendar year on the daily time step. These facilities are generally climate controlled by the Central Utility Plant and are in use year round, although in a reduced capacity when the undergraduate community is on break. As detailed earlier in the chapter, an additional 0.2 MGD were added to the growing season of May-September to this user type in order to capture the imminently planned expanses in campus irrigation. The monthly consumptive water use for this user type was the same as the OnRes user type as provided by the Vickers text, with the minima in the winter and maxima in the summer.

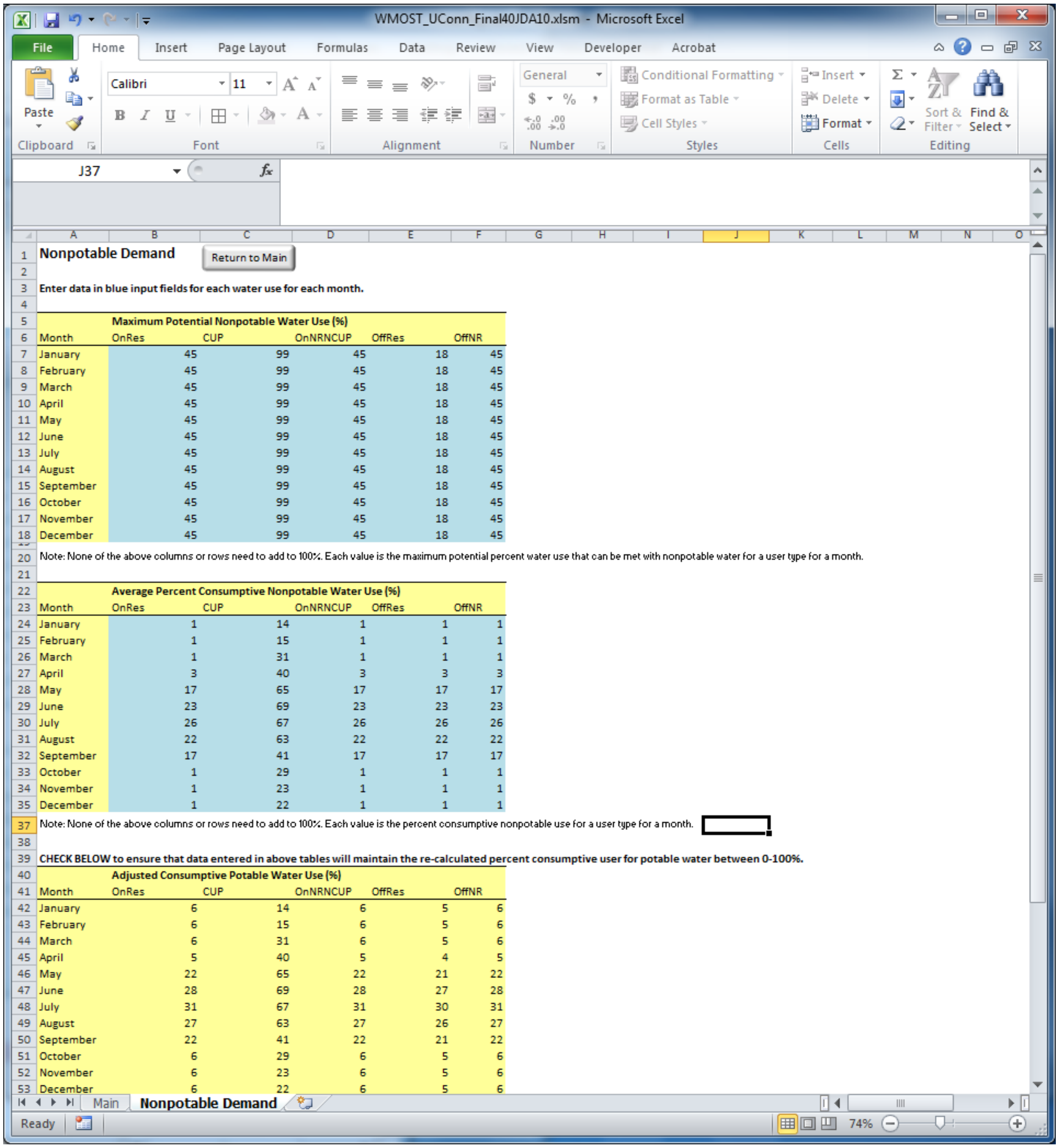
‘’OffRes’ comprises the buildings off-campus that have residential occupants. Many of these buildings are University owned condominium and apartment complexes. These buildings consequently have a high student population. Unfortunately, their meters are only recorded quarterly, and only the 2012 data were available at the time of this study. It’s expected that these residences show a consumption pattern similar to on-campus residential buildings based on the proportion of undergraduate to graduate student occupancy. The variation in this user type demand based on the academic schedule is small compared to overall demand and is therefore ignored (UConn Water Supply Plan, 2011). This water user type has been a large focus of the University’s ongoing metering program, such that it is assumed to be 100% metered for the purposes of this study (UConn Water Conservation Plan, 2011). The annual range of percent consumptive use was kept the same as the OnRes and OnNRNCUP user types.

‘OffNR’ is the user type consisting of off-campus, non-residential buildings including, but not limited to, commercial, industrial, municipal, and institutional buildings in Storrs and Mansfield that are supplied water by the University system. These users are also metered quarterly, but the effects of variable student population are ignored because this user type is small compared to the overall demand and it includes several non-University related customers. The monthly values of percent consumptive use were the same as the OnRes, OnNRNCUP, and OffRes user types.

Nonpotable Demand

The nonpotable demand worksheet shows three tables with the months of the year on the left axis and the user types as the top axis less unaccounted for water as seen in Figure 2-4. The first table is the maximum potential nonpotable water use percentage, which represent how much water, by user type, can be supplied by greywater produced at the Water Reclamation Facility for things such as heating, cooling, irrigation, and toilet flushing. The second table is the average percent consumptive nonpotable water use percentage. This table is used to specify how much of the nonpotable water use does not return to the wastewater system as it is lost to the atmosphere or groundwater. The third table is a check done by WMOST to ensure that the values in the first two tables don’t contradict the previously populated potable demand table. It is a table of the adjusted consumptive potable water use by user type. Should the user enter potential and average consumptive water use percentages that exceed the actual consumptive potable water use, an error occurs as nonpotable water can’t provide more consumed water than is needed by users.

For the Central Utility Plant the max nonpotable water use was set as 99%, since all the makeup water at the plant can be supplied by nonpotable water. The consumptive use was generated from the 2008 evaporative losses data described in the Potable Demand section. The OnRes, OnNRNCUP, and OffNR were set to 45% in the first table as they could use nonpotable water for heating, cooling, and irrigation demands. Their average percent consumptive nonpotable use was set by data pulled from the Vickers text with a maximum of 26% in the summer from evapotranspirative losses through irrigation. OffRes was set at just 18% because nonpotable water use would be limited to irrigation, for family homes and existing residential complexes.



Nonpotable Demand

Return to Main

Enter data in blue input fields for each water use for each month.

Month	OnRes	CUP	OnNRNCUP	OffRes	OffNR
	Maximum Potential Nonpotable Water Use (%)				
January	45	99	45	18	45
February	45	99	45	18	45
March	45	99	45	18	45
April	45	99	45	18	45
May	45	99	45	18	45
June	45	99	45	18	45
July	45	99	45	18	45
August	45	99	45	18	45
September	45	99	45	18	45
October	45	99	45	18	45
November	45	99	45	18	45
December	45	99	45	18	45

Note: None of the above columns or rows need to add to 100%. Each value is the maximum potential percent water use that can be met with nonpotable water for a user type for a month.

Month	OnRes	CUP	OnNRNCUP	OffRes	OffNR
	Average Percent Consumptive Nonpotable Water Use (%)				
January	1	14	1	1	1
February	1	15	1	1	1
March	1	31	1	1	1
April	3	40	3	3	3
May	17	65	17	17	17
June	23	69	23	23	23
July	26	67	26	26	26
August	22	63	22	22	22
September	17	41	17	17	17
October	1	29	1	1	1
November	1	23	1	1	1
December	1	22	1	1	1

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

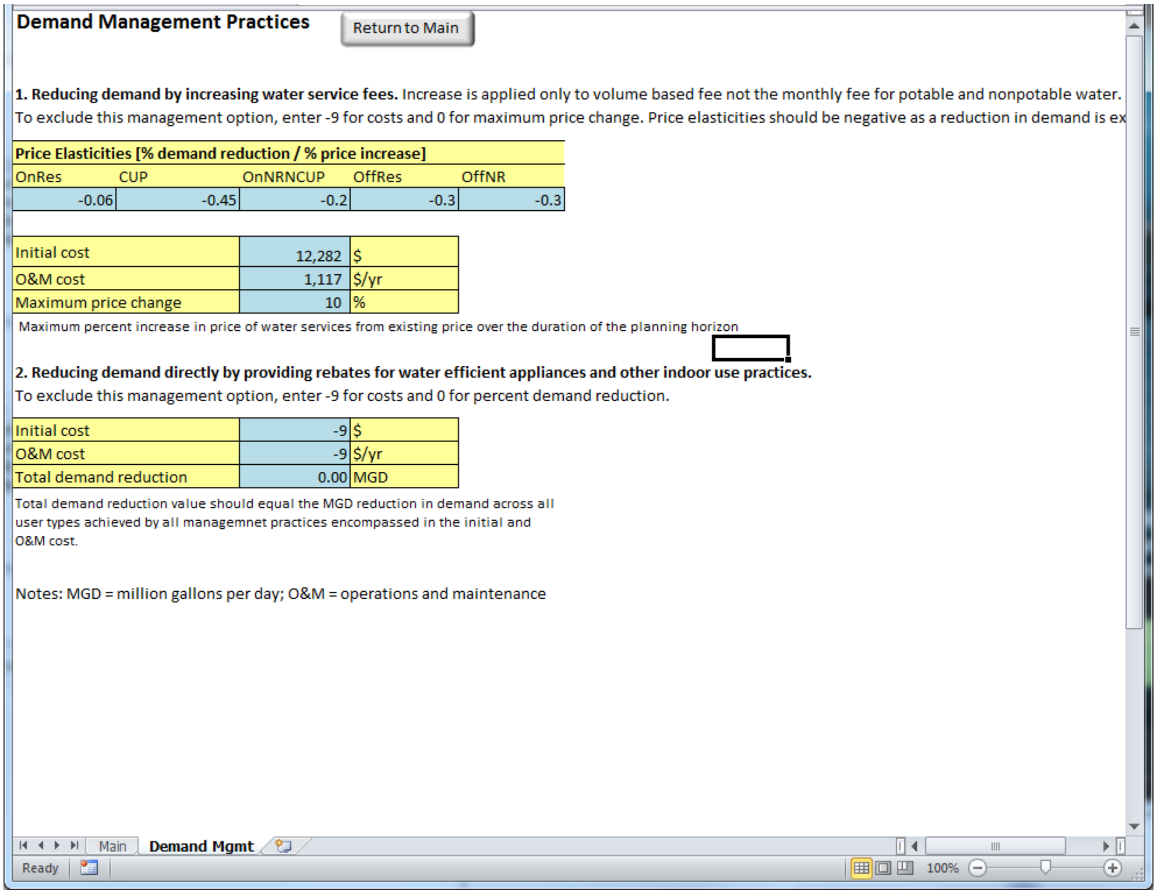
CHECK BELOW to ensure that data entered in above tables will maintain the re-calculated percent consumptive user for potable water between 0-100%.

Month	OnRes	CUP	OnNRNCUP	OffRes	OffNR
	Adjusted Consumptive Potable Water Use (%)				
January	6	14	6	5	6
February	6	15	6	5	6
March	6	31	6	5	6
April	5	40	5	4	5
May	22	65	22	21	22
June	28	69	28	27	28
July	31	67	31	30	31
August	27	63	27	26	27
September	22	41	22	21	22
October	6	29	6	5	6
November	6	23	6	5	6
December	6	22	6	5	6

Figure 2-5: WMOST Nonpotable Demand worksheet

Demand Management

The demand management practices worksheet allows the user to input data that represent indirect and direct potable water demand management. See Figure 2-5 for a screenshot of the demand management worksheet. The first input is price elasticities per user type. Price elasticity is defined as the percent demand reduction per percent price increase passed on to the user for water usage. Values for price elasticities are negative since a price increase should encourage a decrease in usage. This value is dependent on many factors, and is not a linear relationship. For instance, if an individual user is charged a very low price for water relative to other utilities a moderate increase in cost will not cause much decrease in demand. Increasing the cost of water when it's moderately priced should have the strongest effect on their demand, as they are realizing there are more cost effective options than simply paying for their current water use. This is true to a point where increasing the billing rate of water when it is already very high, will not have as much of an effect since the user would have already undertaken the easily available demand reduction options and are nearing the quantity of water absolutely needed to subsist (Pioneer Institute, 2007) . To account for this, WMOST allows users to set a maximum price change over the study period. Ideally, this value would be at the price where the users could not alter their actions any further to reduce water usage (USEPA, 2013). For the purposes of this study, a maximum price increase of 50%, or 1% for every year in the study period, was implemented. In addition, an initial cost to the price changes and O&M cost have to be entered to cover the cost of an initial study for the best pricing structure and administrative costs, as well as the cost for regular studies to monitor and modify price structuring over the planning period. No local data were available for estimating these costs, so the values used in the base WMOST case study were scaled to the size of UConn's system, leading to an initial cost of $11,000 and annual cost of $1,000 (USEPA User Guide, 2013).



Demand Management Practices Return to Main

1. Reducing demand by increasing water service fees. Increase is applied only to volume based fee not the monthly fee for potable and nonpotable water. To exclude this management option, enter -9 for costs and 0 for maximum price change. Price elasticities should be negative as a reduction in demand is ex

Price Elasticities [% demand reduction / % price increase]				
OnRes	CUP	OnNRNCUP	OffRes	OffNR
-0.06	-0.45	-0.2	-0.3	-0.3

Initial cost	12,282	$
O&M cost	1,117	$/yr
Maximum price change	10	%

Maximum percent increase in price of water services from existing price over the duration of the planning horizon

2. Reducing demand directly by providing rebates for water efficient appliances and other indoor use practices. To exclude this management option, enter -9 for costs and 0 for percent demand reduction.

Initial cost	-9	$
O&M cost	-9	$/yr
Total demand reduction	0.00	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.

Notes: MGD = million gallons per day; O&M = operations and maintenance

Figure 2-6: WMOST Demand Management Practices worksheet

Estimates of price elasticities are not consistent within the literature, but values from -0.2 to -0.5 are justifiable based on New England based research and national meta-analyses. These elasticity ranges would apply for OnRes, OnNRNCUP, OffRes, and OffNR as since they predominantly include domestic water uses. The Central Utility Plant, on the other hand, would fall into a water intensive industrial use pattern. Elasticities for industrial practices are strongly dependent on the relation of water costs to overall costs, with feasible ranges between -0.1 to almost -1.0, representing a reduction of 1% for every 1% price increase (Pioneer Institute, 2007). Unfortunately, the University cannot even expect to fall within the above values for two reasons. First, the end water users (students, faculty, and staff) are not paying for their water. Water is paid for through a facilities operational fund which is sourced through tuition and capital funds such as UConn 2000 and 21st Century UConn, meant for reinvesting state funds in the public school system (UConn Water Supply Plan, 2011). Second, the University will only pay 60% of the normal unit rate charge for water purchased from Connecticut Water Company since it is a public entity (UConn Final Record of Decision, 2013). For these reasons, reducing the campus water usage by price increases becomes an indirect measure in terms of changing end user habits, and a mitigated measure, due to the reduced University price. In order to meaningfully test the effect of elasticity on demand management, a series of elasticities were established and tested. See Table 2-2 for the elasticities used.

In general, the elasticity for OnRes was the least because students are directly responsible for the majority of water usage. Based on the 2007 water audit, domestic residential uses top 20% of the total water budget compared to only 8% for the dining services, which includes the eight dormitory cafeterias and the 12 retail and café services in OnNRNCUP buildings. The University can and has progressively taken measures in residential buildings to reduce water usage through the installation of conservative fixtures and sponsored dormitory competitions to reduce per capita use. Ultimately, the inhabitants of these buildings will be unaffected by price increases so price elasticities are the lowest in this user type. OnNRNCUP water demands should be more responsive to price increases, as the University has more control over usage. In addition to the installation of water conserving fixtures, the University can improve metering and proficiency of athletic irrigation, reduce wasteful habits in the agricultural and dairy operations, as well as improve the efficiency of experimental and mechanical infrastructure that needs cooling. CUP has significantly higher than the other user types and falls within the range of industrial users. To compensate for the reduced rate of pay for water procured from CWC, the price elasticities were set and then multiplied by 0.6. OffRes and OffNR are maintained at a price elasticity significantly higher than their University parallels, as they must pay for their own water at the full unit rate, although some University owned buildings operate as dormitories.

Table 2-2: Price Elasticity Scenarios

	OnRes		CUP		OnNRNCUP		OffRes	OffNR
	Un-adjusted	Adjusted x0.6	Un-adjusted	Adjusted x0.6	Un-adjusted	Adjusted x0.6		
Baseline	-0.1	-0.06	-0.75	-0.45	-0.2	-0.12	-0.3	-0.3
Low	-0.05	-0.03	-0.5	-0.3	-0.1	-0.06	-0.2	-0.2
High	-0.2	-0.12	-1	-0.6	-0.3	-0.18	-0.4	-0.4

As the actual cost of water is such an important element of this case study, a sensitivity analysis was performed on the baseline scenario. Originally, the maximum price percent change was set at 50%, or 1% for each year of the planning period. To quantify how this factor influences the outcome of the model, two additional model scenarios were run where the maximum price change was set at 25% and 75%. The maximum percent price change is applied to both the price of potable and nonpotable water, but is not applied to the purchase cost of interbasin transfer. WMOST assumes that the purchase price for interbasin transfer is set for the planning period. Although price increases aren’t planned at this time, CWC has the ability to increase water rates as needed subject to approval by the State of Connecticut Public Utilities Regulatory Authority (PURA). To see how CWC price increases affect the modeling effort, WMOST was rerun with the cost of interbasin transfer increase by 50%.

The second portion of demand management is direct demand management. This includes many of the options already discussed and is difficult to quantify given the nature of the study. Direct demand management is meant as the use of rebates to encourage system users to install water efficient appliances and reduce indoor water use in general. Off campus users who would benefit from such rebates are a very small portion of the overall demand. The University cannot give itself rebates for its own conservation measures. In addition, studies by NEWUS on the conservation measures implemented over the last decade suggest a plateau in the effectiveness in expanded conservation. The University has already greatly reduced average demands and successfully metered the majority of users as referenced by the impressive 8% rate of unaccounted for water. For these reasons and the lack of access to the status of all the conservation measures implemented on campus, the use of direct demand was excluded from this study (UConn Water Supply Plan, 2011).

Septic Systems

WMOST requires the modeler to input information on the use of septic systems within the study area to help define interbasin transfer by groundwater and passive groundwater recharge. The percentage of each user type on public water that are recharging within the study area and those recharging outside of the study area are delineated. For this study, no users on public water use septic systems outside of the study area. However, 22.6% of the OffRes user type within the study utilizes septic recharge (UConn Water Supply Plan, 2011). Overall, this is a small reduction in sanitary sewer creation that needs to be omitted from Water Pollution Control Facility calculations and is accounted for in this section. See Figure 2-6 for a screenshot of the Septic System Users worksheet.

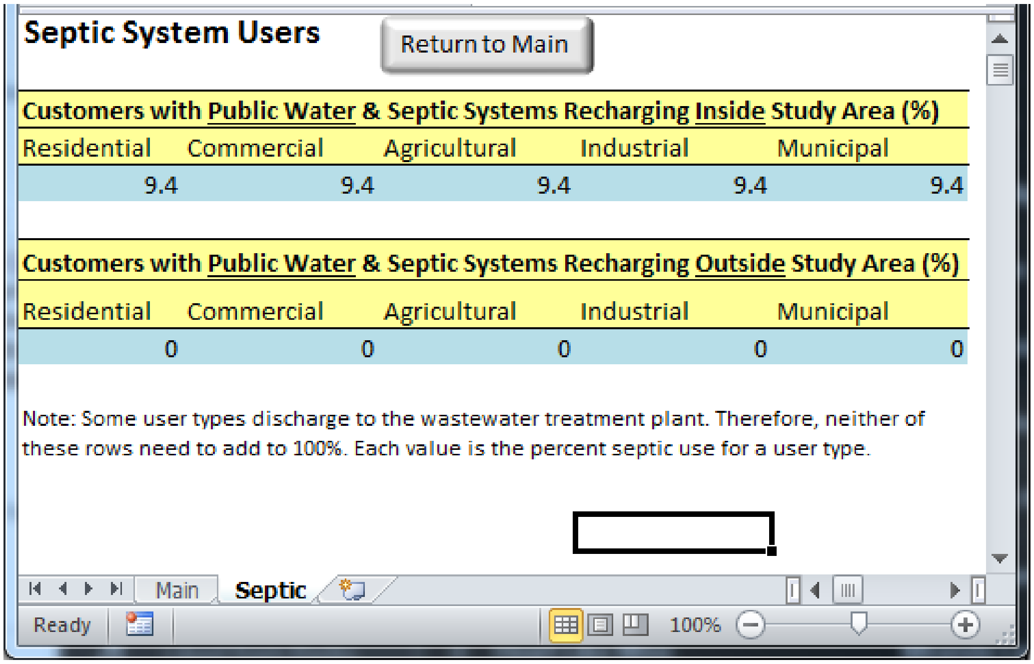


Figure 2-7: WMOST Septic System Users worksheet

Surface Water: Streamflow and Surface Storage

The study area's surface water infrastructure and constraints need to be defined next, the components of which are shown worksheet in the screenshot in Figure 2-6. First, the user describes the storage components of the water supply system including costs. The University currently has 6.62 MG of usable water storage capacity across the campus. Minimum target storage volume was set at 1.19 MG (the 2013 average day demand), so that all water supplies could be turned off for 24 hours without losing system pressure or failing to meet demands. The initial construction cost for new/additional storage was set at $2.5 million per million gallons determined from the installation of the new 1 MG tank costing $2.5 million. The O&M cost of storage facilities is minimal, and was therefore set at a minimal 0.1% of the initial cost. New/ additional capacity was not excluded from this study, as WMOST allows for. Increased storage capacity is not an expected result of this case study as the University is already considered to have more than sufficient storage (UConn Water and Wastewater Master Plan, 2007). The external inflow was the daily discharge at the Merrow Road gauging station. No private stormwater withdrawals or discharges were included. Had the hydrology been paramount to the outcome of the model, stormwater discharge within the stream reach observed, but not from UConn land would be been include here. Once again, no minimum or maximum in-stream flows or minimum stormwater outflows were included in this modeling effort, as the hydrologic modeling effort would not have been able to recreate the precise groundwater pumping restrictions determined from the Willimantic and Fenton River flow studies.

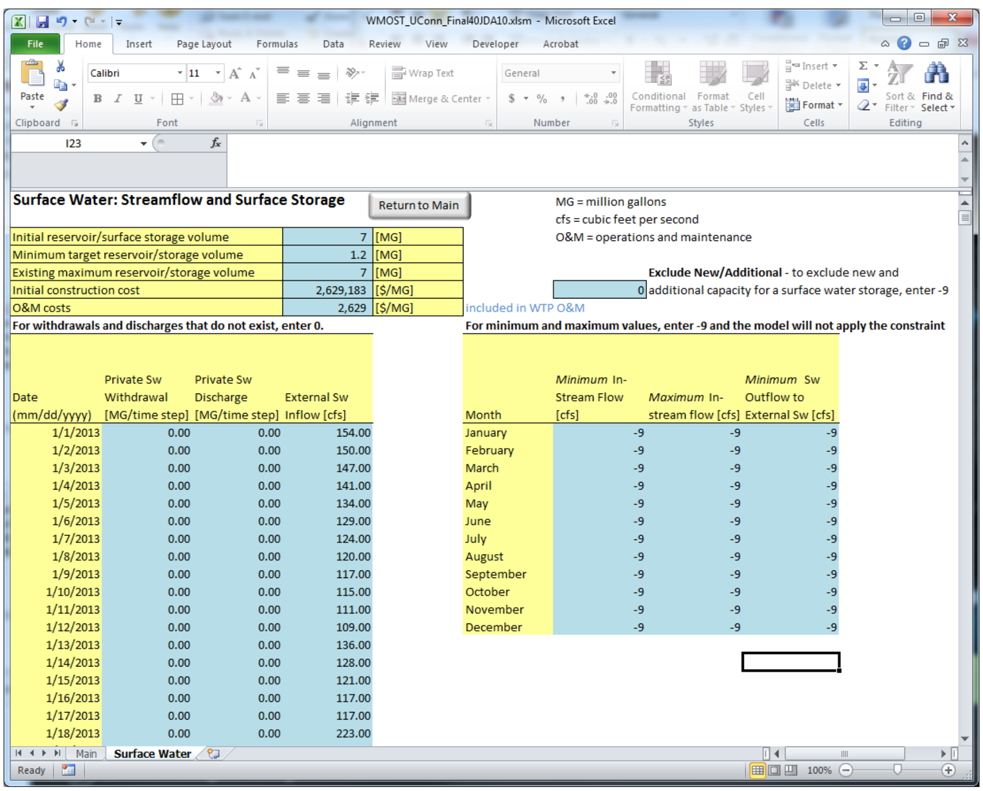


Figure 2-8: WMOST Surface Water: Streamflow and Surface Storage worksheet

Groundwater

WMOST requires the user to define groundwater flow based on a several parameters and time series. The user must define a groundwater recession coefficient, initial groundwater volume, and the minimum and maximum groundwater volume. The groundwater recession coefficient is defined as the fraction of the groundwater volume that flows to the stream reach per time step. Groundwater water volumes are the amount of water held in the soil pore spaces between the saturated and unsaturated soils during the planning period. WMOST also needs a time series of private groundwater withdrawal, private groundwater discharge, and external groundwater inflow. Private groundwater withdrawal is the summation of private wells within the study area and other municipal pumps. Private discharge would be pumping into the groundwater table through recharge wells and septic systems. External inflow is the flow from other subbasins into the one being studied. Last, the user fills the minimum external groundwater outflow, which is the amount of flow out of the study area that may be required by a planning body, which does not exist in the UConn study area. WMOST determines the groundwater volume on the daily time step by taking the private withdrawals and discharges and combining them with values input by the user such as recharge from the various land uses, leakage from the water conveyance system, recharge from an aquifer storage facility, groundwater pumping, inflow to the sewer conveyance system and groundwater outflow (USEPA User Guide, 2013).

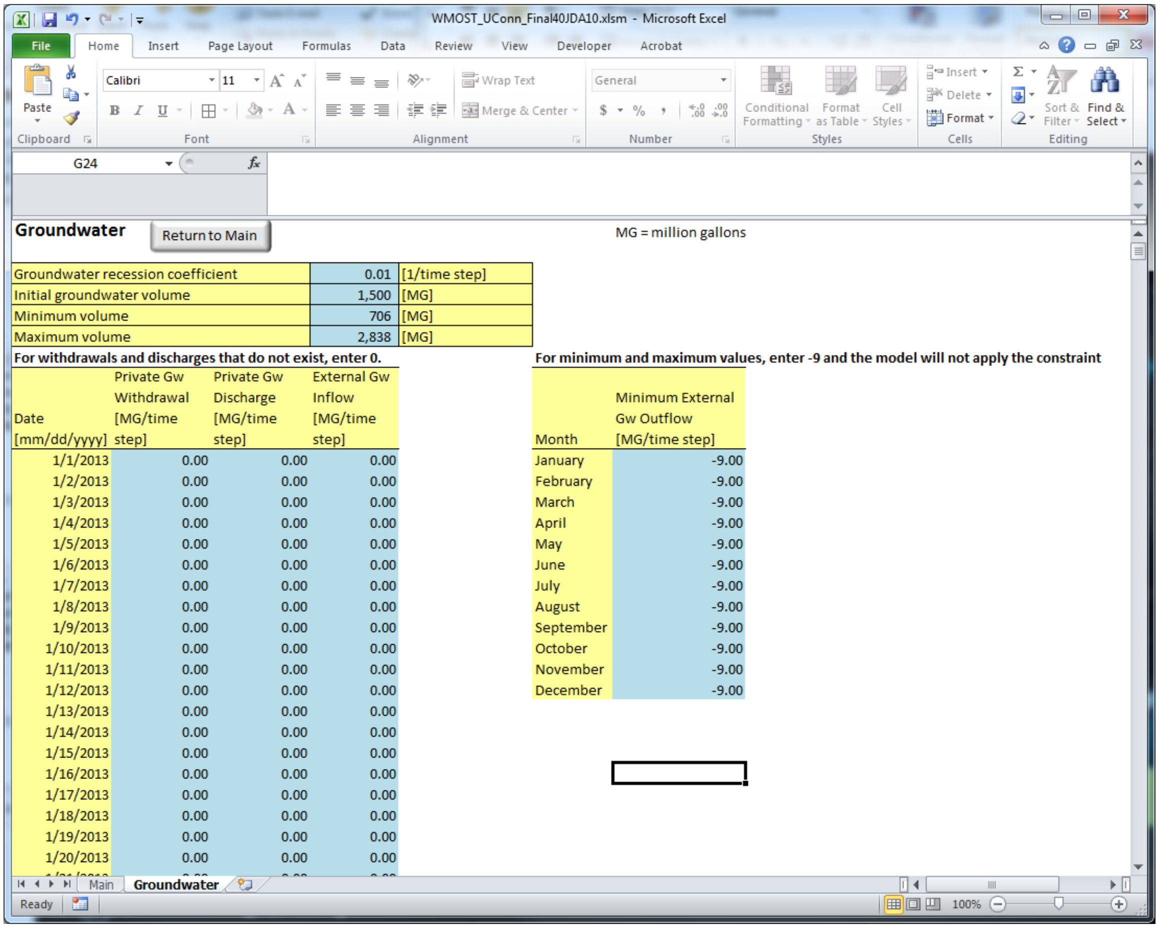


Figure 2-9: WMOST Groundwater worksheet

As previously discussed, hydrologic modeling in the study area is challenging for a number of reasons, especially the nearly equal division of runoff between the Willimantic and Fenton watersheds which are both pumped from. Since the Willimantic River has the needed streamflow data, it would make sense as the watershed to model. Pumping from the Fenton River and residential pumps would be modeled as private withdrawals and external inflow along the Willimantic would be quantified from monitoring well data. Recharge would only be included from portions of campus and Mansfield draining to the Willimantic. Although this seems relatively straightforward, the recharge and runoff rates section justified the simplification of the hydrologic modeling. It is not worthwhile to attempt to delineate Willimantic groundwater conditions, when the

Fenton River is the one susceptible to low flows and safe yields of groundwater pumping have been determined by comprehensive modeling efforts in earlier studies. Therefore, the groundwater information in this study had to be set in such a way that the supply of groundwater would not limit the amount of safe yield groundwater pumping rates detailed in the Infrastructure section. The groundwater volumes from the Danvers and Middleton case study in WMOST were maintained, since it is a geologically comparable watershed in Massachusetts with a groundwater volume ranging from 706-2838 MG, flow to the stream reach is 7-28 MG as determined by the 0.01 per day recession coefficient. Groundwater pumping is set at a maximum of 2.3242 MGD which is well below the values maintained from the original case study. To prevent limiting groundwater availability, no private groundwater withdrawal or discharge was defined; these values would have been speculative at best given the limited private well data available at the time of this case study.

Interbasin Transfer

The interbasin transfer worksheet allows the WMOST user to input data used to determine the applicability of importing potable water from another distributor and exporting wastewater to another municipality for treatment (see Figure 2-8 for a worksheet screenshot). The user enters the quoted cost per unit of new or additional potable and waste water to be transferred and the capital cost associated with initiating the new or additional interbasin transfer. In addition, WMOST has the user to enter existing limits on interbasin transfer on a daily, monthly, and our annual scale. Most importantly in this case study, the user enters the capacity limits on additional interbasin transfer in terms of MGD for both potable and waste water (USEPA User Guide, 2013).

For the purposes of this study, transfer of sanitary sewage was not evaluated, as there are no plans to by the University to do so. As previously described, the University has completed the regulatory steps to initiate the purchase of potable water, as necessary, from CWC. As detailed above, the cost per unit of water for UConn will only be 60% of the residential customer charge rate by CWC. Therefore, the University will pay $3.62 per hundred cubic feet of water consumed, which is equivalent to $4,839.25 per million gallons (the price rate entered to WMOST). Residential users will pay $25 quarterly for meter reading and what equates to $6.90 per hundred cubic feet ($9,223.98 per million gallons), assuming 60,000 gallons of use per year per household, a value determined by the PURA. Commercial users will be charged $6.25 per hundred cubic feet ($8,355.06 per million gallons), in addition to the meter reading charge (UConn Environmental Impact Assessment, 2012). To actually model the cost of the interbasin transfer an aggregate cost had to be created. The average demand of each user was multiplied by their respective unit cost. The sum of these values was divided by the total demand to acquire a value of 5,524.65 per million gallons of demand in the base year of study. This obviously creates a concern as demands increase at different rates within the 5 user groups causing the weighted average price to change. To compound this issue, CWC water rates can change in the future with the approval of PURA. As mentioned in the Demand Management Practices section, a WMOST model run was completed with CWC water costs increased by 50%, which represents a 1% increase every year over the study period.

The capital cost of increasing interbasin transfer was equal to the construction cost of 2000’ of water supply pipe and a meter pit, as agreed upon by the University and CWC. A recent water main replacement cost the University $0.23 million for 1280’ of 12” ductile iron pipe. This equates to roughly $180 per linear foot, while the meter pit was assumed to cost $5,000, for a total cost of $364,375 at 3 MGD. The maximum supply of interbasin transfer from CWC is 3 MGD so the capital cost is $121,458/MGD of. There are no existing limits on interbasin transfer on the daily, monthly, or annual scale as neither water or wastewater are transferred at this time.

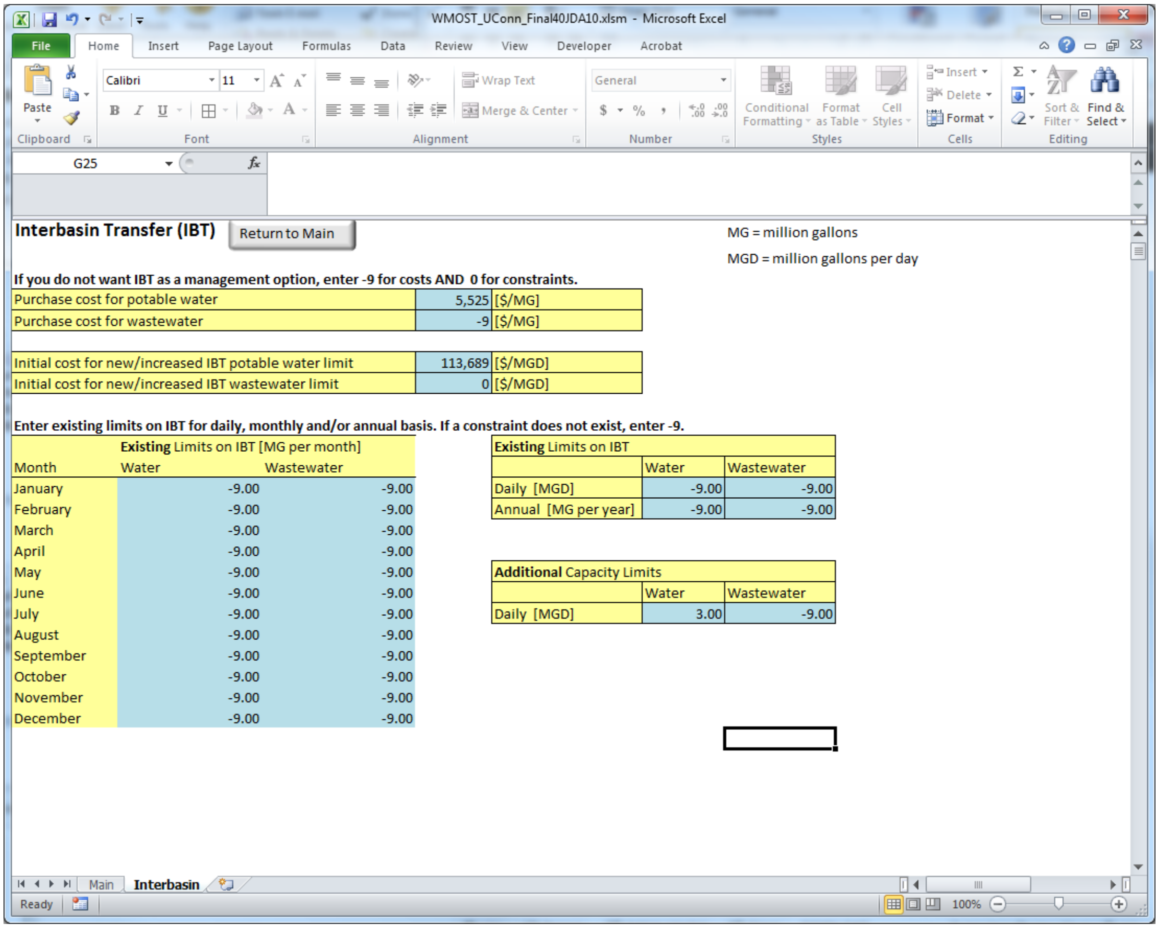


Figure 2-10: WMOST Interbasin Transfer (IBT) worksheet

Infrastructure - Water Services

To define the physical system of the water utility, WMOST presents the modeler with an infrastructure worksheet (see Figure 2-9 for a screenshot of the Water Services portion of the Infrastructure). This window requires the input of 53 parameters which help determine the annualized cost of operating, maintain, and upgrading the water and wastewater infrastructure owned by the utility being studied. Annualization allows the user to compare all costs incurred in different amounts at different times over the planning period with a dollar value from one year, which in this case is a 2010 US dollar. To annualize costs, the user first enters the planning horizon and interest rate.

For this study, a 50 year planning period ($Tplan$) was used as the University has completed its water demand studies based on water use from 2010-2060. The interest rate (i) is generally set at 5% to represent the rate at which loans are acquired to pay for infrastructure improvements and is used to annualize the three different types of infrastructure costs that are incurred. The annualized cost of any investment is described by the following equation:

$$C_{c,a} = F \text{ x } C_c$$

Where $C_{c,a}$ is the annual capital cost, C_c is the capital cost at construction, and F is the annualization factor. There are three types of annualization factors.

The first type of factor is used to annualize the cost of new construction, such as building a new water reclamation facility, over its own lifetime. If the cost of the plant is $1 million ($C_c$) with an engineering design lifetime of 40 years ($TNEW$) the following equation is used:

$$F_{new} = \frac{i\ x\ (1+i)^{Tnew}}{(1+i)^{Tnew}-1} \qquad F_{new} = \frac{0.05x\ (1+0.05)^{40}}{(1+0.05)^{40}-1}$$

$$F_{NEW} = 0.0583 \text{ and } C_{c,a} = 0.0583 \text{ X } \$1{,}000{,}000 = \$58{,}300$$

Therefore, the cost to construct this facility is equal to $58,300 per year for 40 years.

The second annualization factor is the replacement cost of an existing piece of infrastructure. For instance, assuming the same water reclamation facility has a remaining lifetime of 35 years ($Texist$), only part of the cost of replacing the facility is incurred in the planning period. The equations for this process are as follows:

$F_{exist} = \frac{i\ X\ (1+i)^{TNEW}}{(1+i)^{TNEW}-1}$ x $\frac{Tplan-Texist}{Tplan}$ $F_{exist} = \frac{0.05x\ (1+0.05)^{40}}{(1+0.05)^{40}-1}$ x $\frac{50-35}{50}$

F_{exist} = 0.01749 and $C_{c,a}$ = 0.01749 X $1,000,000 = $17,490

The last annualization factor is the cost of implementing a management practice once and distributing it over the entire planning period. This is comparable to the cost of completing an I/I survey. At a fee of $100,000, the annualization is as follows:

$F_{plan} = \frac{i\ x\ (1+i)^{Tplan}}{(1+i)^{Tplan}-1}$ $F_{plan} = \frac{0.05x\ (1+0.05)^{50}}{(1+0.05)^{50}-1}$

F_{plan} = 0.0548 and $C_{c,a}$ = 0.01749 X $100,000 = $5,480

Interest rates are temporally variable and vary based on the loan source and expected use. For instance, the use of Connecticut's State Drinking Water Revolving Fund was proposed as a source of financing for the UConn alternatives for interbasin transfer at an interest rate of just 3% (UConn Final Record of Decision, 2013). Therefore, the baseline model was altered to see how management alternative selection would be modified with a 3% interest rate and the opposite scenario where the interest rate was 7%.

In addition to interest rate, management alternatives selection is also a function of the duration of the planning period. For instance, it makes sense to maximize groundwater pumping and nonpotable water use in the near term, because these facilities simply impart O&M costs to the utility as they are already constructed. Any element of water supply infrastructure that needs to be replaced during the planning period increases the cost for UConn to provide its own water which makes interbasin transfer a more economical supply. To evaluate the effect of planning period on alternative management, the baseline model was modified with shorter planning periods. A 10 year planning period was modeled, to evaluate how quickly UConn will need to start purchasing significant amounts of water from CWC. As detailed below, no infrastructure components need to be replaced in the next 10 years, so there will be no capital cost incurred in this time period for new construction. To observe the effect of a significant capital replacement cost on management selection the replacement major renovation/ replacement of the WWTP is observed with two model scenarios. As described in the Wastewater Services section below, this facility is only expected to have 21 years of additional usable life. After this point in time, the capital cost of replacement is annualized to the other years of the study. To capture this phenomenon, the baseline model was rerun with a planning period of 20 and 30 years which was expected to yield a tipping point in management alternative decisions. As an additional evaluation point, the model was run with a planning period of 40 years, to see if there are any additional major shifts in management selections between 30 and 50 year planning periods. To ensure continuity between the different planning period costs, the maximum price percent change was set to 1% for each year of the planning period modeled, i.e. 10% for the 10 year planning period model scenario.

Next the user defines the utility's water services. The user can enter a fixed monthly fee and/or unit rate price per 100 cubic feet of potable water usage. The University bills off campus users in two ways. Unmetered users, which are typically single-family homes, are billed $340.00 per year. Metered users are charged 3.05 per 100 cubic feet with an additional $25 charge per quarter to check meters ($8.33 per month) (UConn Water and Sewer Fee & Rate Schedule, 2012). As of 2011, there were only 17 identified unmetered users on the UConn system and a plan was in place to meter these residents (UConn Water Supply Plan, 2011). Therefore, it's assumed that these residents are now metered and billed as such. The cost of water use by University buildings is convoluted in that water is paid for through a facilities operational fund as described earlier. The price for water to the University was set equal to the cost for off campus users to ensure that the fiscal motivation to provide water to off-campus users is equal to that of on-campus users.

Then the groundwater infrastructure is defined. Capital cost for additional capacity was set at the unit rate of the pump replacement cost. Under normal circumstances, the eight wells are capable of safely producing 2.3242 MGD within their registration limits, at 1.48 MGD and 0.8442 MGD for the Willimantic and Fenton Wellfields, respectively. The replacement cost of all the wells, including re-drilling the wells and pump replacement, was determined to be $400,000, equating the replacement cost to $172,102 per MGD of groundwater pumping (UConn Water and Wastewater Master Plan, 2007). WMOST allows the user to exclude each management option including expanding groundwater pumping. As the wellfields are already near their safe yields and CTDEP registration limits, pumping expansion was excluded from the case study, which justifies using the cost of simply replacing wells after their useful lifetime is reached as the capital cost. The O&M cost of the pumps was set at 10% of the capital cost converted to MG (dividing by 365 days per year) or $203 per MG. The remaining lifetime on the pumps and wells was determined by using a weighted average of the well capacity and well age. The lower horsepower pumps in the Fenton Wellfield have much longer useful lifetimes than the high horsepower pumps in the Willimantic Wellfield. These pumps push the weighted average age at replacement to 50.3 years after installation. This made the weighted average remaining lifetime on the pumps 22.0 years.

For this case study, the existing capacity on groundwater pumping was varied in multiple model runs to see how interbasin transfer from CWC would be affected. Groundwater pumping at 2.3242 MGD was the baseline scenario. The next scenario modeled was assuming low flow conditions on the Fenton. As described earlier, the operation of Well D is possible under low flow conditions in the Fenton River. Although this typically only occurs during the late summer and early fall, it was used as the supply year round for the entire planning period, to simulate a scenario where the University decides to lower its annual impact on the Fenton ecological system. Therefore, an existing maximum pumping capacity was set at 1.828 MGD, with 1.48 MGD from the Willimantic and 0.348 MGD from the Fenton equal to Well D production during low flow. The second pumping scenario modeled was the exclusion of the Fenton Wellfield with an existing capacity set at 1.48 MGD. This scenario expands upon the previous, where impact on the Fenton River ecological system is completely removed.

System surface water pumping is defined next in WMOST. UConn doesn't use any kind of surface water pumping. Groundwater pumping induces infiltration from the Fenton and Willimantic Rivers when local groundwater is insufficient. No surface flows in the study area are deemed viable for use in the University system (UConn Wellfield Management Plan, 2011). Therefore, the option to construct/ increase surface water pumping was exempted for this case study.

The potable water conveyance and treatment must be outlined next. NEWUS is currently responsible for running the UConn water supply system, including performing biennial water surveys and making the necessary repairs. The latest available NEWUS contract sets the total annual fee for water facilities O&M at $437,850 per year. This value does not cover emergency and non-routine projects which are billed separately. These types of costs cannot be projected from the available information (University of Connecticut and New England Water Utility Services Inc., 2006). The details of this contract were used to determine the costs outlined in the next two paragraphs.

An important component to reducing water demand is identifying and repairing the unaccounted for water, especially potable water distribution system leakage. This is an ongoing effort performed by NEWUS and includes biennial surveys for leaking components and costs of repairs. To quantify this effort in WMOST, the maximum percent of unaccounted for water able to be fixed was set at 99% since identifying and fixing 100% of leaks is not feasible. The initial cost for survey and leak repair was set at a token value $1. The justification for this is that survey and repair is a recurring task which is more accurately modeled as an annual O&M cost, rather than an annualized lump sum from the beginning of the planning period. The NEWUS contract includes $50,000 for capital repair and replacement and personal services for $242,310 among other charges which cover the water treatment, pumping, and leakage costs. It is assumed that more personnel hours are needed for operating the treatment pumps and more capital cost is needed for leak repair. Therefore, O&M cost of distribution system leaks was set at 75% of the capital repair and replacement budget and the equivalent of one year's salary for a single staffer assumed to be $60,000 totaling $97,500 per year over the entire planning period. The remainder of the contract total, is the cost of operating and maintaining the water treatment detailed below.

The University does not utilize a true Water Treatment Plant and will not need expanded treatment for water supplied from CWC. The University does employ three chemical feed facilities and chlorination systems with pumps, all of which were built in 1993. The 2007 Water and Wastewater Master Plan valued replacement for each of these facilities and described the fact that the Willimantic Wellfield and Towers High Head treatment facilities were in need of replacement while the Fenton Wellfield treatment system was in good condition. The three feeds, assumed to be capable of treating the maximum combined registered pumping capacity of the wells at 2.3242 MGD, were valued at $1.1 million, giving a replacement cost of $473,281 per MGD. To see how water treatment costs effect the selection of management alternatives, WMOST was rerun with the replacement cost set to 75% and 125% of the baseline value, equal to $354,961 and $592,851 per MGD. The Master Plan also assigned a 20 year functional lifetime to the treatment facilities which is a reasonable interpretation given the poor condition of two of the three chemical feeds after just 14 years. The Willimantic supply feeds were replaced and combined in 2010 while the Fenton supply feed remains operational at 21 years old. The current age and remaining lifetime on the existing infrastructure were set to 10.1 years and 9.9 years, respectively, using a weighted sum of ages by contributing pump capacity to each feed (UConn Water and Wastewater Master Plan, 2007). The O&M costs were equal to the remainder of the cost in the NEWUS contract. After distribution system costs, the NEWUS contract totals $340,350 which is equivalent to $401 per MG (University of Connecticut and New England Water Utility Services Inc., 2006).

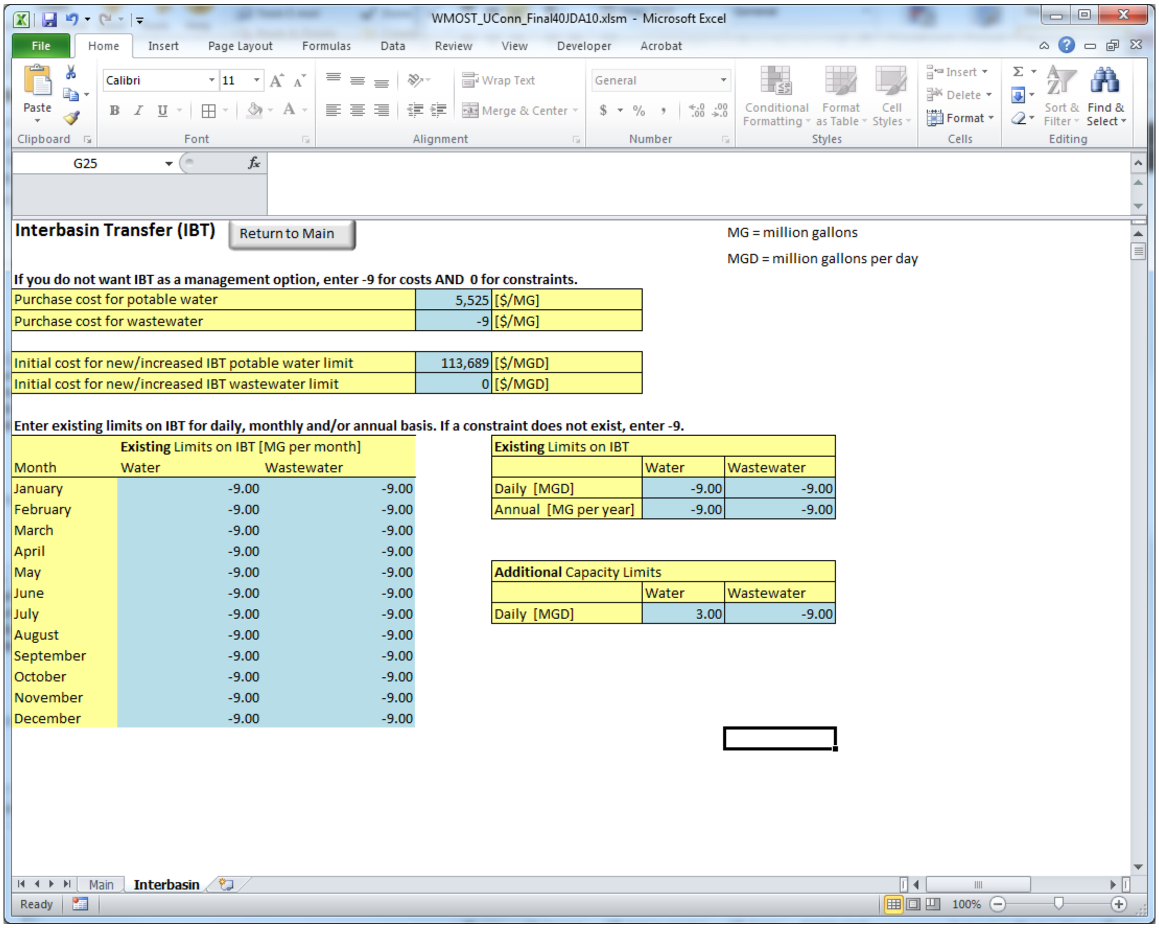
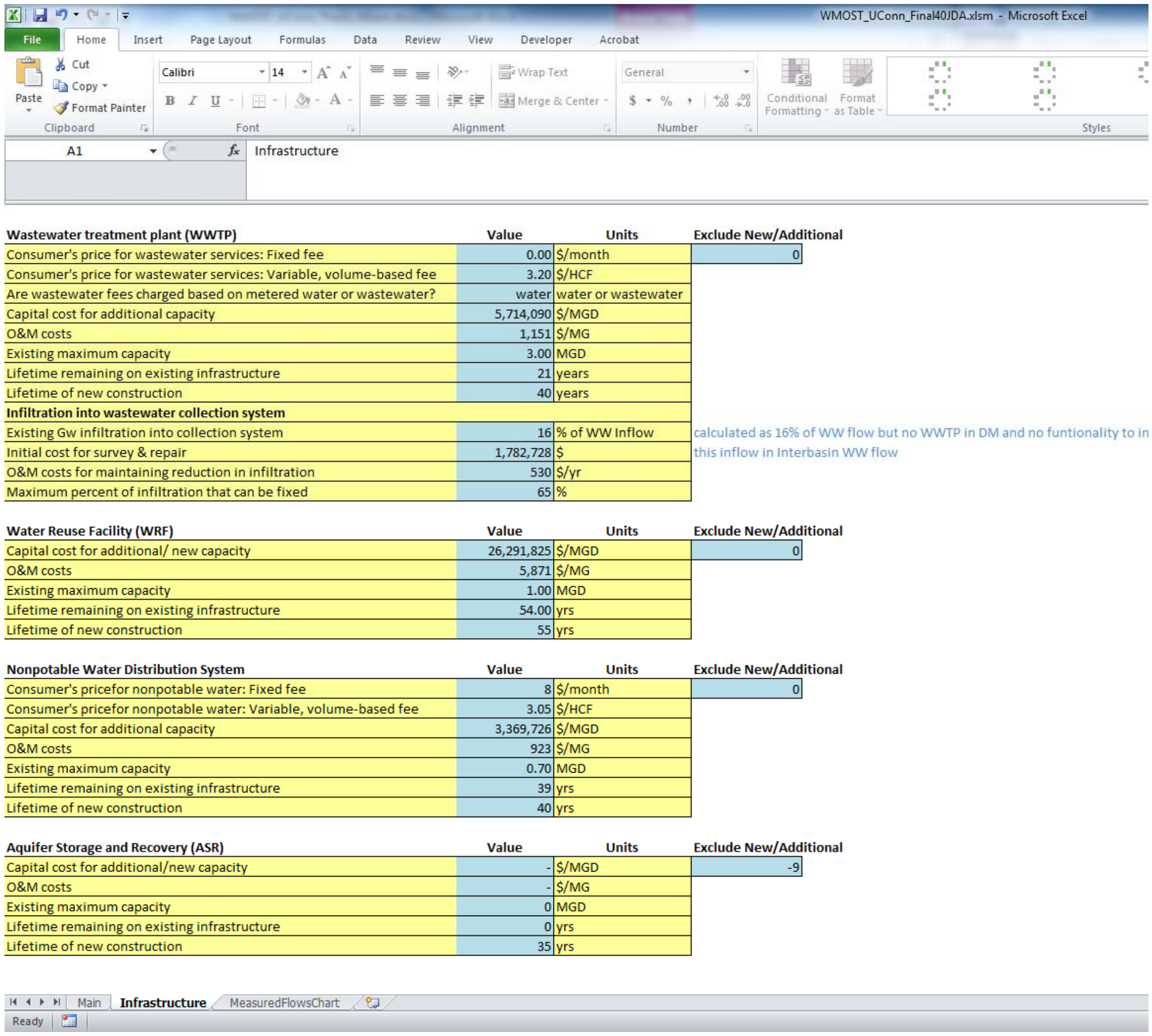


Figure 2-11: WMOST Infrastructure – Water Services worksheet

Infrastructure - Wastewater Services

The wastewater infrastructure is the next set of items to be populated in WMOST (see Figure 2-10 for a screenshot of the Wastewater Services portion of the Infrastructure worksheet). Consumer's price for wastewater is set first. UConn charges $357 for sewage flows from unmetered water customers and 105% of the water charge for metered sewage generation, or $3.2025 per 100 CF (UConn, 2012). Again, the bulk rate charge was used, as it was assumed that the unmetered homes have been metered. The sewage billing rate is not expected to change, as CWC begins to provide water to the UConn system. The Water Pollution Control Facility (WPCF) is currently sized for 3 MGD of flow. In reality, it's only receiving 1.0-1.5 MGD on average, which allows it to handle very high levels of infiltration and inflow (I/I) during wet weather events, and keeps it from needing significant expansion with increases in water demands. The WPCF's estimated replacement cost in 2007 was estimated to be $16.3 million with a useful lifetime of 40 years from 1995. This leaves the WPCF with 21 years of remaining lifetime at a replacement cost of $5.43 million per MGD (UConn Water and Wastewater Master Plan, 2007). The cost to operate and maintain the wastewater facilities, including pump stations around campus, was indirectly determined by taking the recommendations of the 2014 WPCF staffing study of 8.5 Full Time employee equivalents plus 1.9 for times where the regular staff aren't working normal hours, such as weekends and holidays. Therefore, 10.5 full time equivalents of experienced staff were assumed to be needed (UConn WPCF and Collection System Staffing, 2014). It was assumed that the average employee would make $60,000, as this information was not available, which creates an O&M budget of $0.63 million for 1.5 MGD or $1,151 per MG.

In addition, the wastewater collection system is evaluated by WMOST which is generally a significant concern; especially when evaluating an aging infrastructure system close to groundwater elevations. As previously stated, the WPCF has a significant MOS in terms of average flows, but nears peak flows often which is an artifact of groundwater infiltration to the system and inflow from cross connections with stormwater infrastructure. As with water supply leaks, the maximum percent of sewer infiltration and inflow that can be remediated is less than 100%. In fact, it's much more difficult and expensive to identify and fix such issues. An I/I study completed by URS Corporation in 2011 on campus recommended that only 95% of stormwater inflow and 65% of *identified* infiltration sources could be cost-effectively mitigated. WMOST evaluates the wastewater treatment facilities based on their average capacity, as it only asks the user to procure the groundwater infiltration as a percentage of total sewage flows. This value is significantly lower than the percentage of I/I during wet weather events. The URS study identified $1.839 million in sewer rehabilitation that would remove a total of 0.169 MGD of groundwater infiltration to the sanitary collection system of the total 1.029 MGD average received at the WPCF during the study period. Therefore, the initial cost was input as $1.839 million, while the percentage of sewer flows from infiltration was set at 16.4% of the 1.029 MGD. As for moderating peak flows, the University would have to undertake a cross connection elimination initiative to remove direct stormwater connections from catch basins, drain manholes, and roof leaders to the sewer collection system. These flows account for almost 1 MGD during wet weather events at replacement cost of only $0.244 million (UConn I/I Study - Sanitary, 2011). This cost is not evaluated by WMOST, but is relatively small, and could be lumped in the O&M costs. The O&M costs were set at just 10% of the initial cost of repair, equivalent to $504 per year. The initial cost of this work is very high and would significantly isolate infiltration. A maintenance program at more than 10% would be unjustified given that routine cleanings were previously recommended at $0.417 million over a 10 year maintenance period (UConn Water and Wastewater Master Plan, 2007).



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	3.20	$/HCF		
Are wastewater fees charged based on metered water or wastewater?	water	water or wastewater		
Capital cost for additional capacity	5,714,090	$/MGD		
O&M costs	1,151	$/MG		
Existing maximum capacity	3.00	MGD		
Lifetime remaining on existing infrastructure	21	years		
Lifetime of new construction	40	years		
Infiltration into wastewater collection system				
Existing Gw infiltration into collection system	16	% of WW Inflow	calculated as 16% of WW flow but no WWTP in DM and no funtionality to in	
Initial cost for survey & repair	1,782,728	$	this inflow in Interbasin WW flow	
O&M costs for maintaining reduction in infiltration	530	$/yr		
Maximum percent of infiltration that can be fixed	65	%		

Water Reuse Facility (WRF)	Value	Units	Exclude New/Additional
Capital cost for additional/ new capacity	26,291,825	$/MGD	0
O&M costs	5,871	$/MG	
Existing maximum capacity	1.00	MGD	
Lifetime remaining on existing infrastructure	54.00	yrs	
Lifetime of new construction	55	yrs	

Nonpotable Water Distribution System	Value	Units	Exclude New/Additional
Consumer's pricefor nonpotable water: Fixed fee	8	$/month	0
Consumer's pricefor nonpotable water: Variable, volume-based fee	3.05	$/HCF	
Capital cost for additional capacity	3,369,726	$/MGD	
O&M costs	923	$/MG	
Existing maximum capacity	0.70	MGD	
Lifetime remaining on existing infrastructure	39	yrs	
Lifetime of new construction	40	yrs	

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

Figure 2-12: WMOST Infrastructure – Wastewater Services worksheet

Infrastructure - Nonpotable Services

Last, the user needs to populate data to define the nonpotable water system, which includes any water reuse facility, nonpotable water distribution system, and aquifer storage and recover (which is excluded from this study). The University finished constructing, and put online, a 0.5 MGD water reclamation facility, which can easily be expanded to 1 MGD in the future. Although it is operated at 0.5 MGD, it is capable of producing 0.7 MGD without significant changes in O&M. At this time, all reclaimed water is used at the CUP, but the University plans to develop other uses, as it seeks to conserve water while the campus continues its planning developments. The capital for new/additional capacity is not straightforward for this piece of infrastructure. The new facility was constructed for a price of $25 million to run at 0.5 MGD, but can easily be expanded to 1 MGD (Coite, 2014). This creates a step cost function. As the useful lifetime of the plant is set to end in the planning period (equivalent to the WPCF at 40 years for new construction), setting the cost at $50 million per MGD creates a large annualized cost that would cause WMOST to recommend abandoning the facility after its useful lifetime terminates. Even $25 million per MGD would drive WMOST to suggest this abandonment. In reality, with proper O&M the plant would not need to be completely replaced after 40 years, but would undergo the renovations to expand to 1 MGD and make the necessary upgrades to maintain operation barring a significant loss of function or demand. Therefore, the remaining lifetime of the reclaimed water facility was set to be longer than the planning period, so WMOST would not annualize replacement costs, only taking into account the cost of O&M. Initially, Woodard and Curran is contracted to operate and maintain the facility with a 3 year, $4.5 million contract, at which point the University will decide whether or not to assume the operational role (Perez, 2013). This cost is equivalent to $5,870.84 per MG of reclaimed water assuming the current max operational production of 0.7 MGD.

As the reclamation facility only provides water to the CUP, existing nonpotable infrastructure is minimal. In the future, nonpotable demands will be met with new ‘purple pipe’ mains, sent to large areas of demand such as the North Campus Tech Park development. The cost to the consumer for nonpotable water consumer was set to the same as potable, as the convoluted payment situation is the same where the University is paying itself, but some constraint to consumption needs to be established. The capital cost for new/additional capacity was determined by quantifying the cost of installing a main to the North Campus and future demands from the buildings constructed there. The water main replacement cost detailed in the interbasin transfer section set a price of 180' per linear foot of 12" ductile iron pipe installed. The North Campus development will not have nonpotable demands requiring such large piping, but the majority of the cost is from the excavations, road closures, and engineering so the unit rate is still applicable (Coite, 2014). The North Campus development nonpotable main will need to run from the reclamation facility north under North Hillside Road to the new developments approximately 4000', which is equal to $0.72 million. Demands for the North Campus are not expressly defined at this point, but can be estimated by multiplying the expected Tech Park water demand of 0.444 discussed later, and multiplying them by the 45% maximum potential nonpotable water use defined in the Nonpotable Demand section. This equates to roughly 0.2 MGD of demand, setting the purple pipe cost at $3.6 million per MGD. The existing maximum capacity was set at the 0.7 MGD, as this is the estimated maximum flow that can be achieved from the reclamation facility to the CUP. The lifetime remaining on existing infrastructure and new construction were assumed to be greater than the length of the planning period, as failures entire pipe corridors are rare (UConn Water Supply Plan, 2011). Rather, small leaks and isolated breaks occur, the cost of which are covered in the O&M costs. O&M costs are also expected to be minimal, assuming good engineering design. The costs were set at 5% of the capital cost split between 365 days per year as used in the base WMOST case study (USEPA User Guide, 2013).

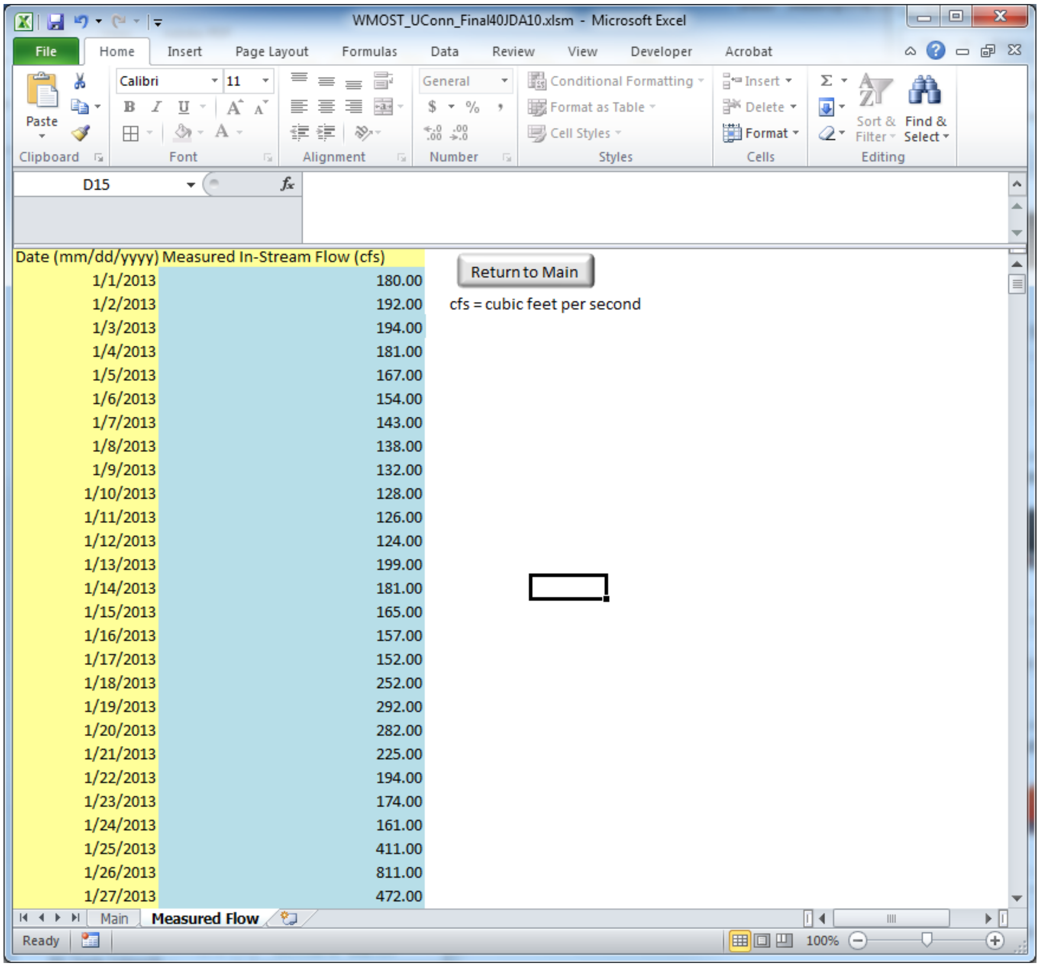
One final aspect of filling in all of the cost parameters in WMOST is accounting for inflation from the time that the various costs were determined and converting them to a universal dollar value in time. For instance, the replacement costs of infrastructure from the Water and Wastewater Master Plan are from 2007. Assuming a cost of $10,000 was estimated from 2007 for a replacement, the 2010 equivalent would be $10,516.73 as determined by the Consumer Price Index tool from the Bureau of Labor Statistics. This difference is over 5% in a span of 3 years. Therefore, all costs were converted to the expected value at the beginning of the planning period in 2010. See Table 2-3 for all of the costs detailed in Chapter 2, the year data was obtained to determine costs, and the value after conversion to U.S. dollars in 2010.

Table 2-3: Conversion of Costs to 2010 U.S. Dollars

	Original Costs			2010 Converted Costs	
Component	Initial	O&M	Year	Initial	O&M
Increasing Water Service Fees	$11,000	$1,000	2005	$12,281.70	$1,116.52
Reservoir Storage ($/MG)	$2,500,000	$2,500	2007	$2,629,182.50	$2,629.18
Increased Interbasin Transfer ($/MGD)	$121,458	$0	2013	$113,689.25	$0.00
Groundwater Pumps ($/MGD)	$172,102	$47	2007	$180,995.27	$49.59
Water Treatment Plant ($/MGD)	$473,281	$401	2007	$497,736.98	$421.93
Distribution System Leakage	$1	$97,500	2007	$1.05	$102,538.12
Wastewater Treatment ($/MGD)	$5,433,333	$1,151	2007	$5,714,089.62	$1,151
Infiltration Survey and Repair	$1,839,000	$504	2011	$1,782,728.44	$529.87
Water Reuse Facility ($/MGD)	$25,000,000	$5,870.84	2013	$23,400,875.00	$5,495.31
Nonpotable Distribution ($/MGD)	$3,600,000	$986	2013	$3,369,726.00	$923.21

Measured Flow

The final component that WMOST needs to run its watershed optimization is the measured streamflow at the reach defined by the study area. As discussed in the runoff and recharge and the groundwater sections, for this case study the hydrology was not explicitly modeled as it would not have been able to replicate the unique conditions in the study area. To run the model though, the daily discharge at the USGS gauging station near Coventry, CT was input. Measured flow is used as a comparison, to the modeled flow generated by the study area from withdrawals and discharges to the streamflow. See Figure 2-10 for a screenshot of the Measured Flow worksheet.



Date (mm/dd/yyyy)	Measured In-Stream Flow (cfs)
1/1/2013	180.00
1/2/2013	192.00
1/3/2013	194.00
1/4/2013	181.00
1/5/2013	167.00
1/6/2013	154.00
1/7/2013	143.00
1/8/2013	138.00
1/9/2013	132.00
1/10/2013	128.00
1/11/2013	126.00
1/12/2013	124.00
1/13/2013	199.00
1/14/2013	181.00
1/15/2013	165.00
1/16/2013	157.00
1/17/2013	152.00
1/18/2013	252.00
1/19/2013	292.00
1/20/2013	282.00
1/21/2013	225.00
1/22/2013	194.00
1/23/2013	174.00
1/24/2013	161.00
1/25/2013	411.00
1/26/2013	811.00
1/27/2013	472.00

Figure 2-13: WMOST Measured Flow worksheet

Water Use Projections

The University has completed two reports and an Environmental Impact Evaluation, filed in accordance with the CEPA, that address the water supply concerns of the Storrs campus, each containing information on the existing and projected water demands. The 2011 UConn Water Supply Plan goes in depth on the projected campus and Mansfield demands that cannot be met with the existing system, while the 2012 Environmental Impact Evaluation regarding the Potential Sources of Water Supply, justifies modifications to the predetermined future demands and details three potential alternatives for interbasin transfer of potable water. Figure 2-11 shows the water demands determined by the many studies, compiled and updated for the Record of Decision. Please note that the Projected ADD in the Adjusted Demand and the Margin of Safety for 2045 and 2060 are reversed.

Projected Average Day Demands

Year	Tech Park	Off-Campus	NextGenCT	Adjusted Demand[1]	Margin of Safety (MOS)	Adjusted Demand plus MOS	Existing Supply[2]	Required Additional Supply[4]
Projected Average Day Demand (gpd)								
2015	0	0	24,125	1,564,133	234,620	1,798,753	1,830,000	0
2030	126,480	242,000	138,500	2,353,855	353,078	2,706,933	1,830,000	876,933
2045	333,900	369,000	138,500	2,928,274	439,241	3,091,516	1,830,000	1,261,516
2060	333,900	453,500	138,500	2,795,900	419,385	3,215,285	1,830,000	1,385,285
Projected Peak Day Demand (gpd)[3]								
2015	0	0	43,425	2,116,623	317,493	2,434,116	1,970,000	464,116
2030	168,219	321,860	239,700	3,051,082	457,662	3,508,744	1,970,000	1,538,744
2045	444,087	490,770	239,700	3,495,860	524,379	4,020,239	1,970,000	2,050,239
2060	444,087	603,155	239,700	3,626,942	544,041	4,170,983	1,970,000	2,200,983

1. "Adjusted Demand" includes estimated existing demands plus "committed" demands, plus Tech Park, Off-Campus (including the Four Corners service area, the proposed managed care facility, and other additional demands in the EIE), Next Generation CT (including residential, STEM, and other academic demands) and a water demand deduction applied for recycling reclaimed wastewater at the UConn Central Utility Plant. Additional water deductions through the use of reclaimed water in other applications are expected to materialize over the planning period; however, these have not been quantified and have not been included in the adjusted demands. Therefore the adjusted demands presented herein are assumed to be conservatively high.
2. Reflects Willimantic Wellfield supply pumped at safe yield (1.48 mgd), and Fenton Wellfield to include Well "D" at 0.35 mgd.
3. Peak Day Existing Supply reflects Fenton Wellfield offline, no Well "D" supply, and Willimantic Wellfield is producing at diversion registration limit.
4. The "Required Additional Supply" figures are the volumes for the requested action. Potential water demands along the preferred pipeline in Tolland and Coventry were developed in the EIE and will be on the order of 33,000 gpd in addition to the above figures. Water demands in Mansfield between the Coventry town line and Mansfield Four Corners will be nominal, as the overlay zones will restrict withdrawals from the pipeline.

Figure 2-14: WMOST Measured Flow worksheet (UConn Final Record of Decision, 2013)

For input to WMOST, the demand increases were prorated to show a continuous increase over the planning period and redistributed to the appropriate WMOST user types created (see Table 2-4 for projected demands). For instance, the NextGenCT projected ADD's for 2030 (0.139 MGD) were prorated back to their 2010 value of zero and then split between OnRes and OnNRNCUP for that time period. The justification for this is NextGenCT development is not fully defined between 2015 and 2030 as only select projects are undergoing planning and design. Currently, it is a plan which includes the expansion of STEM disciplines at the University and providing the facilities to accommodate that expansion, which would include both residential and nonresidential demand increases (UConn Final Record of Decision, 2013). The latest North Campus Tech Park Master Plan outlines three build out scenarios, two of which don't include residential housing, with a third allocating 22% of development to residential uses. This scenario was included to accommodate the possibility that more housing is needed, but for this study it was assumed that the development is nonresidential. Therefore, Tech Park demand projections were all placed in the OnNRNCUP user type. The expanded facilities on campus are all assumed to have access to steam and chilled water supplied by the CUP, as detailed in the Master Plan (Skidmore, Owings & Merrill LLP, 2012). Unfortunately, no data were available as to how much CUP demand could be attributed to residential and nonresidential buildings on campus. Therefore, projected CUP demands were determined by multiplying the projected OnRes and OnNRNCUP demands by the ratio of OnRes and OnNRNCUP demands to CUP demands in the 2013 data. The following equations, where each component is the annual sum of that demand, clarify this projection:

$$\text{CUP from Projected OnRes} = \frac{\text{CUP}}{(\text{OnRes} + \text{OnNRNCUP})} \times \text{Projected OnRes}$$

$$\text{CUP from Projected OnNRNCUP} = \frac{\text{CUP}}{(\text{OnRes} + \text{OnNRNCUP})} \times \text{Projected OnNRNCUP}$$

For each gallon of non-CUP demand, roughly 0.3436 gallons were required from the CUP. Unaccounted for water was determined by maintaining the University's current ability to limit losses to 8% of the total demand, therefore it is simply 8% of the sum of projected demands.

The town of Mansfield and off-campus University facilities are also expected to grow over through 2060, and those detailed below will be supplied by the University system. The Off Campus demands in Figure 2-10 include the Four Corners development, a proposed managed care facility, and other additional demands not identified in the Water Supply Plan (UConn Environmental Impact Assessment, 2012). Furthermore, the Adjust Demand listed in Figure 2-10 includes so-called “committed demands” which the University agreed to provide as part of the Water Supply Plan equivalent to 0.358 MGD through 2060 (UConn Water Supply Plan, 2011). Both the Off Campus and committed demands are roughly split between residential and nonresidential uses over the planning period. Therefore, the demands were combined and then divided equally between OffRes and OffNR user types and prorated over the planning period; see Table 2-4 (UConn Final Record of Decision, 2013).

Table 2-4: Projected Demand Increases in MGD							
	Unacct.	OnRes	CUP	OnNRNC	OffRes	OffNR	Sum
2010	-	-	-	-	-	-	-
2011	0.0040	0.0024	0.0074	0.0191	0.0107	0.0107	0.0543
2012	0.0080	0.0048	0.0148	0.0381	0.0214	0.0214	0.1086
2013	0.0121	0.0072	0.0221	0.0572	0.0321	0.0321	0.1629
2014	0.0161	0.0097	0.0295	0.0763	0.0428	0.0428	0.2172
2015	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2016	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2017	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2018	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2019	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2020	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2021	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2022	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2023	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2024	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2025	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2026	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2027	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2028	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2029	0.0201	0.0121	0.0369	0.0954	0.0535	0.0535	0.2714
2030	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2031	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2032	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2033	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2034	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2035	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332

Table 2-4 (cont): Projected Demand Increases in MGD							
	Unacct.	OnRes	CUP	OnNRNC	OffRes	OffNR	Sum
2035	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2036	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2037	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2038	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2039	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2040	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2041	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2042	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2043	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2044	0.0839	0.0693	0.1195	0.2786	0.2910	0.2910	1.1332
2045	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2046	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2047	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2048	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2049	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2050	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2051	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2052	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2053	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2054	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2055	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2056	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2057	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2058	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2059	0.1172	0.0693	0.1910	0.4866	0.3590	0.3590	1.5820
2060	0.1247	0.0693	0.1910	0.4866	0.4058	0.4058	1.6831

To further evaluated water use demands, the water demand projections were altered to quantify the effects of demands being greater than or less than expected. Typically, water use projections are determined conservatively. Should water use projections exceed actual future demands, the amount of water that needs to be purchased from CWC would be lessened and purchases would not be needed until a later date. Therefore, the model was rerun with the water use data multiplied by 0.85. Conversely, Water use projections could end up being less than the actual on campus demands, and a 15% margin of safety is usually considered when evaluating water supplies. To model a 15% MOS on the projected demands and the situation where projected demands exceed projections by 15%, the model was run with a 1.15 multiplier on the water use demands. The last WMOST modeled demand was providing a 15% MOS on the situation where projected demands are exceeded by 15%. Although this scenario is excessive for planning efforts (a 1.3225 multiplier on projected demands), it describes the worst case scenario in terms of demand and provides an extra management selection set for comparison.

Intra-annual Water Use Characterization

As discussed in the Potable Demand section, water demands are highly dependent on a number of factors, especially student attendance characteristics and temperature. Given that this case study investigates a 50 year planning period, a discussion of how climate change will affect water demands is warranted. To project water demands with climate change, a better understanding of the relationship between demands, student residency, and temperature are needed. This section breaks down the 2013 daily water demand data by water user in an attempt to describe the predominant factors in how much water will need to be purchased from CWC. The temperature data were acquired for the daily time step of 2013 from National Climatic Data Center. The data are from the Global Historical Climatology Network database for Storrs. The data are a composite of historical data from 20 nearby weather stations that was subjected to quality assurance reviews. Raw data are in form of the maximum and minimum daily temperatures observed in degrees Celsius. For the assessments below, the daily average temperature was determined as simply the average of the maximum and minimum (Burroughs, 2009). Figures 2-12, 2-13, and 2-14 show the water demands of the user types OnRes, CUP, and OnNRNCUP relative to the average temperature of that day.

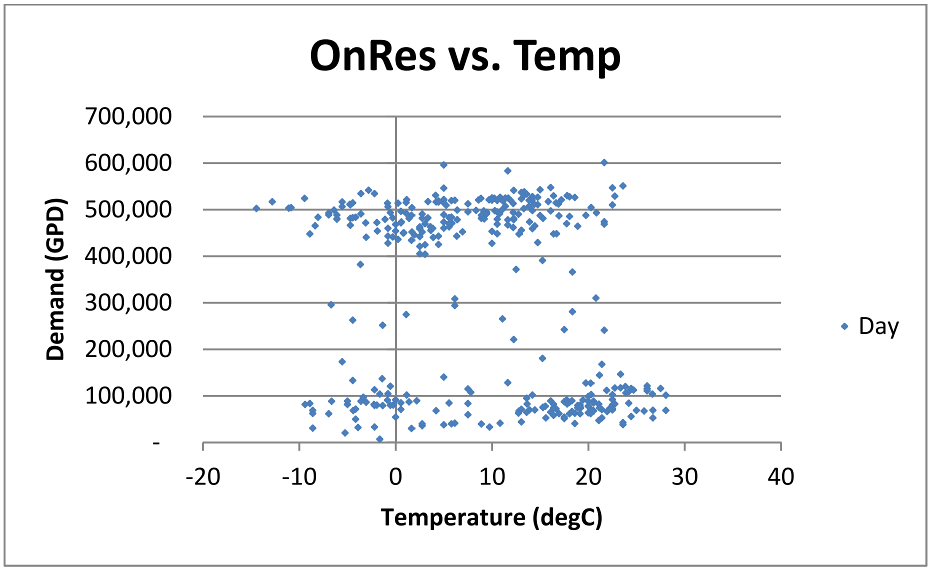


Figure 2-15: OnRes daily demand compared with daily average temperature

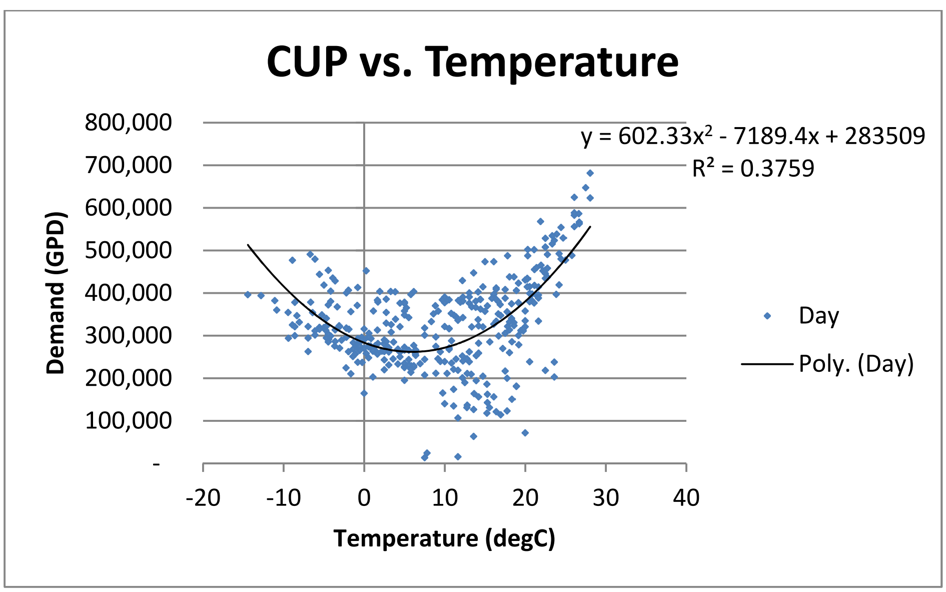


Figure 2-16: CUP daily demand compared with daily average temperature

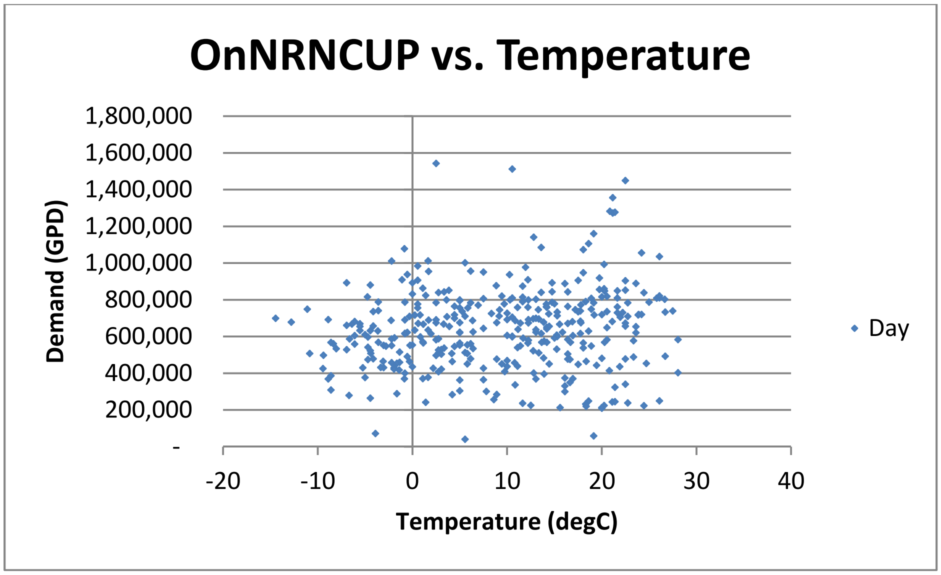


Figure 2-17: OnNRNCUP daily demand compared with daily average temperature

Both the OnRes and the OnNRNCUP user types are weakly correlated to the temperature, with coefficients of determination (R^2) values less than 0.1 for linear and parabolic function fits. This is explained by the fact that the majority of temperature dependent water demand is from the Cup which provides chilled water and steam to the majority of the buildings on campus which fall into these user types. Figure 2-13 is moderately correlated to the temperature as evidenced by the R^2 value of 0.38 with a parabolic function fit to the data. Clearly, water demand increases when temperatures are low, as steam production, and consequently steam loses, increase. Similarly, water demand increases as temperature increases because chilled water production increases, thereby by increasing losses to the evaporative cooling process. These figures assume that user demand in homogenous over the course of the year. Figure 2-12 visually shows that another factor is controlling the demand for that user type. Intuitively, this occurrence is known to be caused by the fact that in 2013, students only spent 203 days in class (weekdays and weekends), while 162 days were academic breaks of at least one week. Figures 2-15, 2-16, and 2-17 show the water demands of the user types OnRes, CUP, and OnNRNCUP relative to the average temperature of that day separated between with the academic sessions separated from the breaks.

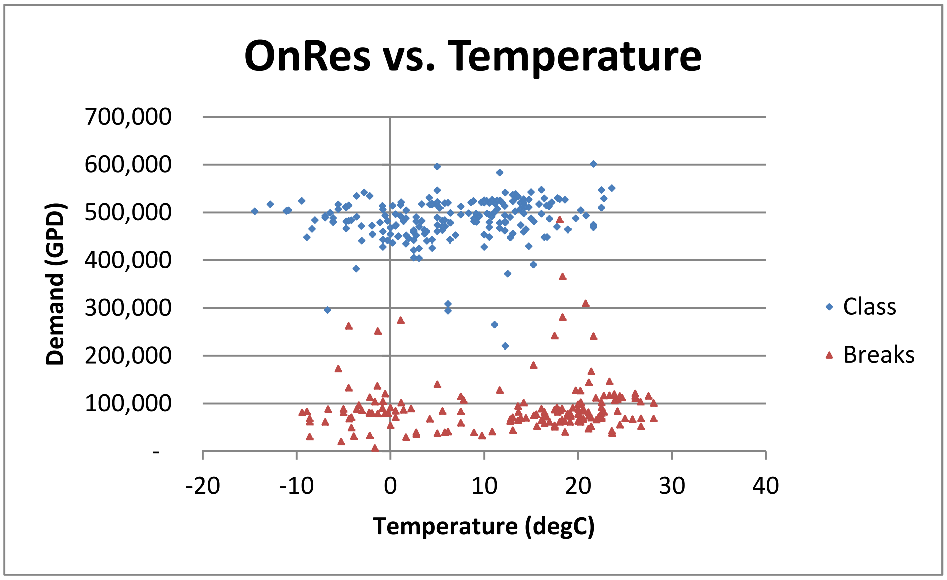


Figure 2-18: OnRes demand compared with average temperature with breaks separated

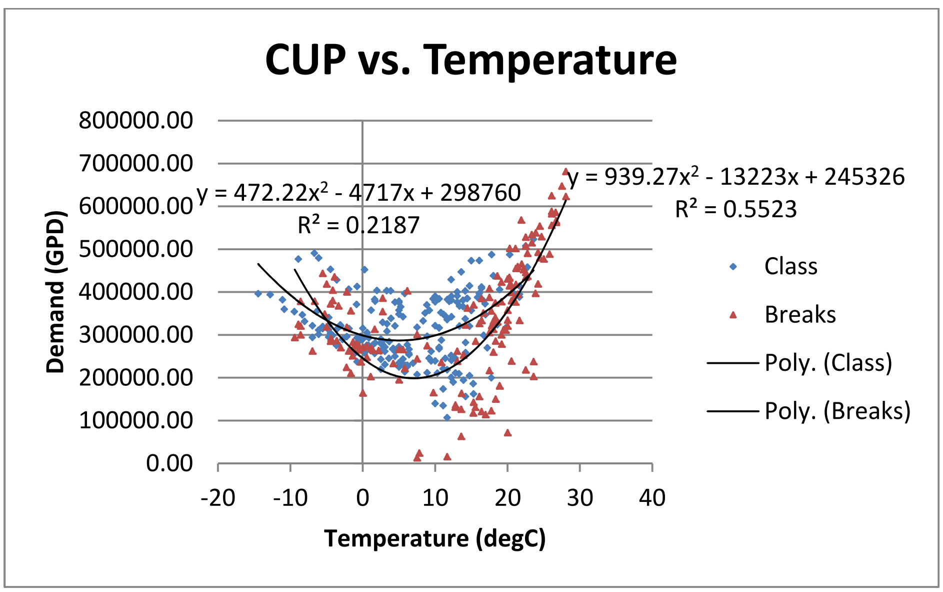


Figure 2-19: CUP demand compared with average temperature with breaks separated

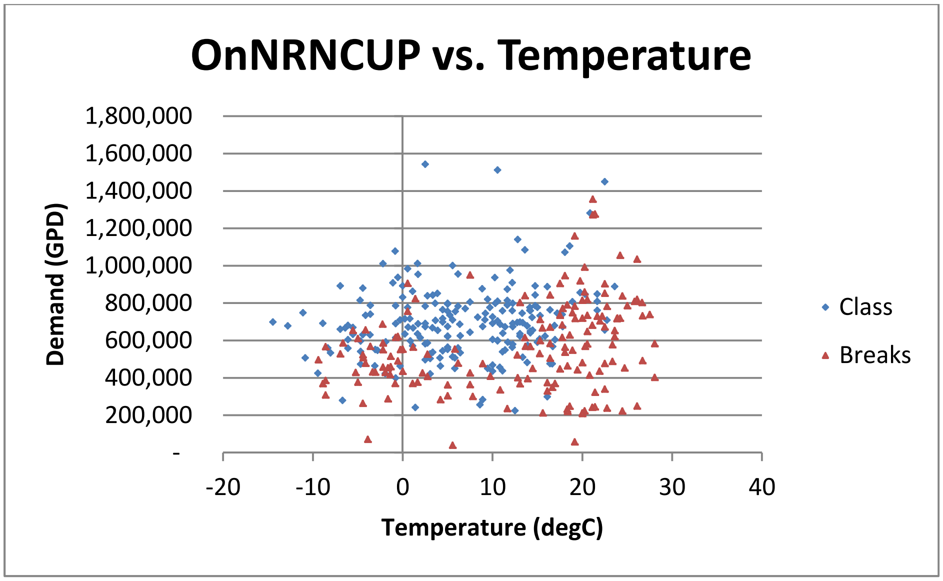


Figure 2-20: OnNRNCUP demand compared with average temperature with breaks separated

These figures more clearly show the true water demand characteristics of the UConn system. Figure 2-15 unmistakably shows that water demands in campus residential buildings are dependent on whether students are in class or not. The average demand is 520% greater (0.484 MGD compared to 0.093 MGD) when students are not on break. The remaining water demand is the product of mostly graduate students, faculty, and staff that do not leave campus during such breaks. The same amount of water is used by this user type regardless of temperature, because heating and cooling water demands are generally offsite at the CUP. Figure 2-16 clarifies CUP and, consequently, heating and cooling demands. During class, CUP demands are not as well correlated with temperature, and show a parabolic function having less variation with temperature. On the other hand, CUP demands during breaks are much better correlated with an R^2 value of 0.55. The OnNRNCUP user type shows little to no correlation with temperature in Figure 2-17, regardless of whether students are in class or not. As is the case for OnRes, temperature dependent water demands are mostly at the CUP.

One visually apparent statistical anomaly generated from the above procedure is that temperature is generally either above the threshold for air conditioning or below the threshold for indoor heating during class breaks. This is intuitively supported, as breaks are predominantly in the summer and winter. To a lesser degree, temperature during classes is generally below the air conditioning threshold. Logically, the CUP scatterplot shows this dichotomy well. Figure 2-18 shows the relationship between cold temperatures, less than 8 degrees Celsius daily average and water demand during class and breaks and Figure 2-19 shows demands with warm temperatures, more than 18 degrees Celsius daily average.

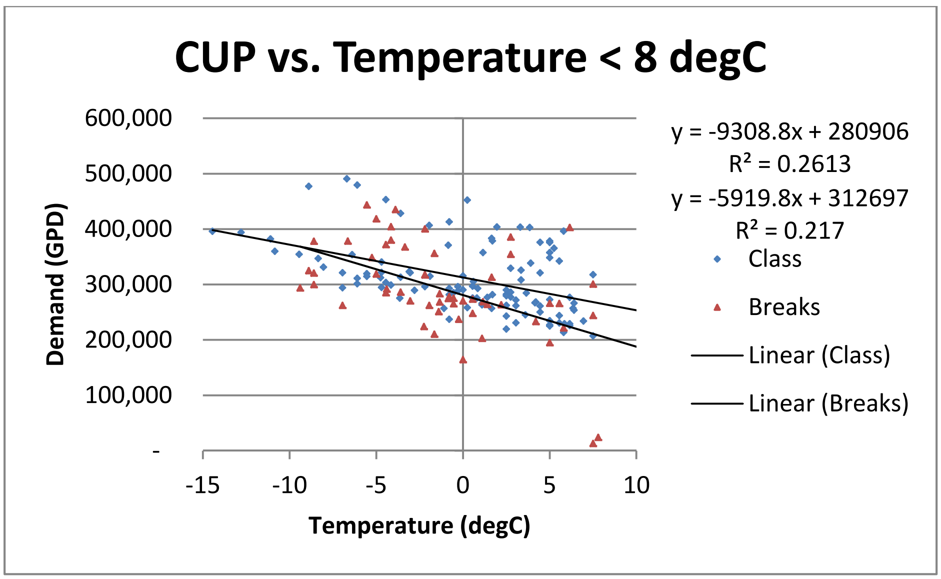


Figure 2-21: CUP demand compared with average temperatures less than 8 degrees

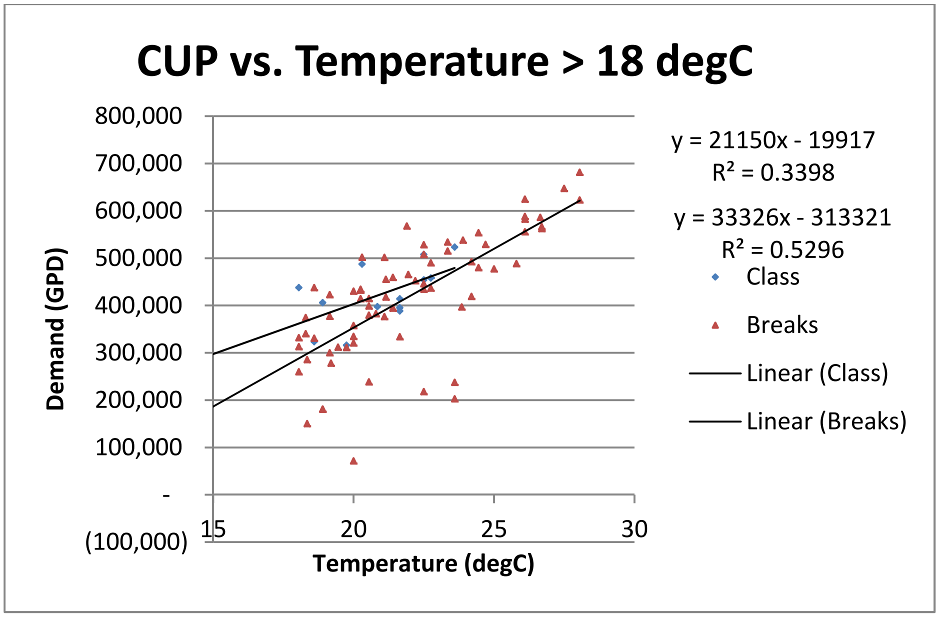


Figure 2-22: CUP demand compared with average temperatures greater than 18 degrees

Figure 2-18 shows a negative linear relationship with low to moderate correlation between water demand and temperature. The correlation for classes and demand is similar to that of the non-segregated temperature ranges, while correlation during breaks decreases from 0.55 to 0.26. Figure-19 shows a positive linear relationship with more moderate correlations. It also shows the limited sample size of warm weather days during the semester at just 13. The relationship still shows an increased correlation than the full year, parabolic fit with an R^2 value of 0.34 compared to 0.22. During breaks the R^2 value is very similar at 0.53 relative to the 0.55 value for the entire year fit.

Northeast Regional Climate Projections

Northeast climate projections were provided for the study area from the research of Professor Guiling Wang and PhD student Kazi Farzan Ahmed. Using statistical downscaling and bias correction, the researchers created a multi-model dataset for the period 2045-2065 with at a spatial resolution of 1/8 degree for the A2 emission scenario established by the Intergovernmental Panel on Climate Change (IPCC) Special Report Emissions Scenarios (SRES) (Ahmed et al., 2013). This scenario is based on high population projections to 15 billion in 2100 under globally heterogeneous conditions where economic development and technical change for improved CO_2 emissions are slower than other scenarios and vary regionally, as they do currently (Working Group III, 2014). The monthly averages, in degrees Celsius, were determined over the 20-year simulation period for this exercise. To compare to this data, 30-year monthly averages from the GHCN station were calculated for the period 1984-2013. The historical temperature data were subtracted from the 2045-2065 averages to determine monthly temperature projections through the study period. Temperature increases ranged from 0.736 degrees in December to 2.68 degrees in June with an average increase in 1.82 degrees. This equates to a 0.0364 degree increase per year over the planning period. The total temperature increase was then added to the running temperature data for 2013 and the equations determined to represent the CUP demands during the academic semester and the class breaks were reapplied to the newly projected temperature. During class, the increase in temperature caused the CUP demand to increase by just 1.31%. An increase of 6.45% occurred in the Cup demands during breaks, with an overall annual increase of 3.66%. These results make sense intuitively for two reasons. As previously discussed, the CUP demands are less responsive to temperature when class is in session, and most of the mild weather days occur during the early fall and late spring semesters. In addition, there are more warm weather days during class breaks than cold weather days, which have a steeper response curve than their cold weather counterparts which see decreased demand with increased temperature. Overall, the effect of temperature is relatively small compared to the uncertainties and variability of water demands on all time scales. This is compounded by the fact that warming's predominant effect is on the CUP which represents less than 25% of the monthly average demand for the entire system. It was not deemed necessary to model WMOST with a 3.66% increase in potable water demand on the CUP demand due to climate change. To see how a greater increase in temperature would affect the model, water demands were projected with a 5 degree increase in annual temperature. This resulted in an increase in an overall demand of 13.47% with 22.32% occurring during breaks. There would also be an increase in demand from the OnNRNCUP user group, but this relationship is not well defined. The temperature, and corresponding water demand, increases are projected to gradually occur over the planning period, such that the 13.47% increase would not be seen until the end of the case study. Therefore, a WMOST scenario with 13.47% would be conservative. Although the University will see noticeable increases in water demand from climate change, no individual scenario run was performed to capture the increase. The 15% MOS scenario will provide the management alternative response for 15% increases applied to each year of the planning period providing a sufficient comparison for the effect of climate change on the watershed.

Chapter 3-Results and Discussion

Modeled Scenarios

In total, 8 different scenario sets and 19 individual model runs were evaluated with WMOST each having a variation in one or more related parameters to quantify how sensitive model outputs were to the different parameters set by the user. Table 3-1 shows the sets that were modeled and differences in the management alternative unit quantities, annualized costs, and annualized revenues. The first line describes the baseline scenario. For the baseline, the consumer rate change (50%), potable leak repair (99%), and infiltration repair (65%) alternatives were selected at the maximum value possible derived in model setup. With increased water demand, WWTP plant capacity needs to increase by 7%, and 0.55 MGD of CWC purchases are needed to meet projected demands. No additional surface water storage, water treatment, water reuse, or nonpotable capacity is needed. WMOST does show costs of these management alternatives, but with no units of the alternatives added. This is explained by the fact that even if a system component, such as groundwater pumping, isn't selected to be evaluated for higher yields, it still incurs costs for O&M as well as capital costs if it needs to be replaced within the planning period. As previously discussed, each value returned, cost or units of an alternative measure, is the annualized value over the planning period and is not representative of any one year. Each scenario set is broken down in the following paragraphs, and related to the described baseline.

The price elasticity set was modeled under relatively high and low elasticities compared to the baseline. It's important to note that a 0.6 multiplier was applied to on-campus user elasticities, as UConn will only be charged 0.6 of the normal price for CWC water. The low elasticity run caused a 95% increase in WWTP capacity; caused by an increase in overall water demand. This demand increase was compensated for by a 33% increase in CWC transfers and a 9% increase in water reuse. Increases in cost were seen in all supply and treatment components because of increased water usage. Conversely, a 29% decrease in WWTP capacity and a 16% decrease in CWC water were seen in the high elasticity scenario, while a 2% increase occurred in water reuse occurred. Other than water reuse and the corresponding nonpotable distribution, all elements that increased with the low elasticity scenario were lower in the high elasticity scenario compared to the baseline, albeit to a lesser degree. Revenues and costs reacted accordingly, with the high elasticity scenario having the lowest cost and revenue while the low elasticity scenario had the highest of both. This was the expected result, because lower price elasticity implies that consumers will be less responsive to cost increases. It also follows that the change from the baseline was greater in the low elasticity scenario, because with the 0.6 multiplier on the University users, elasticity is near zero. As elasticity and responsiveness increase from near zero, they approach a lower consumption state increasingly quickly.

Table 3-1: Summary of WMOST selected alternatives, annualized costs, and annualized revenues by scenario

			Units of Selected Management Alternatives									Annualized Cost and Revenue Summary				
	Scenarios	Value	Consumer Rate Change (%)	Additional WTP Cap (MGD)	Leak Repair (%)	Additional WWTP Cap (MGD)		Infiltration Repair (%)	Additional IBT (MGD)		Additional Nonpotable Cap (MG)	Total Annual Cost (MUSD)		Water Revenue (MUSD)		Wastewater Revenue (MUSD)
Baseline	Medium		50	0	99	0.21	0%	65	0.55	0%	0	2.105	0%	4.260	0%	2.978
Price Elasticity	Low	Table 2-2	50	0	99	0.41	95%	65	0.73	33%	0	2.318	10%	4.535	6%	3.171
	High	Table 2-2	50	0	99	0.15	-29%	65	0.46	-16%	0	2.023	-4%	4.122	-3%	2.882
Max Price Change	Low	25%	25	0	99	0.4	90%	65	0.74	35%	0	2.331	11%	3.803	-11%	3.191
	High	75%	75	0	79	0.02	-90%	65	0.40	-27%	0	1.909	-9%	4.615	8%	2.765
Interest Rate	Low	3%	50	0	99	0.21	0%	65	0.61	11%	0	1.891	-10%	4.260	0%	2.979
	High	7%	50	0	99	0.21	0%	65	0.5	-9%	0	2.344	11%	4.260	0%	2.977
Demands	Low	Base x0.85	50	0	0	0	-100%	65	0.34	-38%	0	1.741	-17%	3.621	-15%	2.531
	MOS	Base x1.15	50	0	99	0.69	229%	65	0.98	78%	0	2.651	26%	4.899	15%	3.425
	MOS+15%	Base x1.3225	50	0	99	1.27	505%	65	1.58	187%	0	3.433	63%	5.665	33%	3.962
GW Pumping	Fenton Low	1.48+0.348 MGD	50	0	99	0.21	0%	65	1.04	89%	0	2.468	17%	4.260	0%	2.978
	No Fenton	1.48 MGD	50	0	99	0.21	0%	65	1.39	153%	0	2.903	38%	4.260	0%	2.978
Increase Price of IBT	Low	Base x0.50	50	0	99	0.21	0%	65	0.5	-9%	0	2.148	2%	4.260	0%	2.938
	High	Base x1.00	50	0	99	0.21	0%	65	0.44	-20%	0	2.191	4%	4.260	0%	2.897
Planning Period	Short	10-year	10	0	0	0	-100%	0	0.05	-91%	0	0.9216	-56%	2.436	-43%	2.318
	Near Mid	20-year	20	0	0	0	-100%	65	0.53	-4%	0	1.175	-44%	3.017	-29%	2.636
	Far Mid	30-year	30	0	99	0.20	-5%	65	0.47	-15%	0	1.725	-18%	3.583	-16%	2.889
	Long	40-year	40	0	99	0.29	38%	65	0.61	11%	0	2.056	-2%	4.089	-4%	3.063
WTP Capital Cost	Low	Base x0.75	50	0	99	0.21	0%	65	0.55	0%	0	2.081	-1%	4.260	0%	2.978
	High	Base x1.25	50	0	99	0.21	0%	65	0.55	0%	0	2.131	1%	4.260	0%	2.978
			Annualized Cost of Selected Management Alternatives													
			Consumer Rate Change (%)	Additional GW Cap (MGD)	Additional Surface Storage (MG)	Additional WTP Cap (MGD)		Leak Repair (%)	Additional WWTP Cap (MGD)		Infiltration Repair (%)	Additional IBT (MGD)		Additional WRF Cap (MGD)		Additional Nonpotable Cap (MG)
Baseline	Medium		$ 1,789	$ 46,446	$ 17,405	$ 386,616	$ 101,513	$ 101,513	$ 1,342,000	$ 109,568	$ 63,818	$ 109,568	$ 1	$ 5,113	$ -	$ 31,047
Price Elasticity	Low	Table 2-2	$ 1,789	$ 47,867	$ 17,405	$ 398,703		$ 101,513	$ 1,449,030		$ 63,818	$ 201,006	$ 1	$ 5,582	$ 0	$ 31,121
	High	Table 2-2	$ 1,789	$ 45,640	$ 17,405	$ 379,755		$ 101,513	$ 1,302,220		$ 63,818	$ 74,549	$ 1	$ 5,205	$ 0	$ 31,061
Max Price Change	Low	25%	$ 1,789	$ 48,007	$ 17,405	$ 399,893		$ 101,513	$ 1,451,150		$ 63,818	$ 211,350	$ 1	$ 5,415	$ 0	$ 31,094
	High	75%	$ 1,789	$ 45,078	$ 17,405	$ 374,974		$ 81,357	$ 1,232,850		$ 63,818	$ 55,990	$ 1	$ 4,944	$ (0)	$ 31,020
Interest Rate	Low	3%	$ 1,594	$ 42,696	$ 17,405	$ 370,225		$ 101,513	$ 1,174,840		$ 45,381	$ 110,255	$ 1	$ 3,618	$ (0)	$ 23,019
	High	7%	$ 2,006	$ 50,613	$ 17,405	$ 404,420		$ 101,513	$ 1,528,250		$ 84,309	$ 108,654	$ 1	$ 6,811	$ 0	$ 39,996
Demands	Low	Base x0.85	$ 1,789	$ 44,549	$ 17,405	$ 370,469		$ -	$ 1,168,690		$ 63,818	$ 38,335	$ 1	$ 4,746	$ (0)	$ 30,989
	MOS	Base x1.15	$ 1,789	$ 49,385	$ 17,405	$ 411,620		$ 101,513	$ 1,606,240		$ 63,818	$ 361,827	$ 1	$ 5,880	$ 0	$ 31,167
	MOS+15%	Base x1.3225	$ 1,789	$ 51,657	$ 17,405	$ 430,952		$ 101,513	$ 1,923,320		$ 63,818	$ 806,709	$ 1	$ 4,759	$ (0)	$ 30,991
GW Pumping	Fenton Low	1.48+0.348 MGD	$ 1,789	$ 40,144	$ 17,405	$ 356,379		$ 101,513	$ 1,342,000		$ 63,818	$ 508,576	$ 1	$ 5,113	$ -	$ 31,047
	No Fenton	1.48 MGD	$ 1,789	$ 33,946	$ 17,405	$ 320,039		$ 101,513	$ 1,342,000		$ 63,818	$ 986,560	$ 1	$ 5,113	$ -	$ 31,047
Increase Price of IBT	Low	1.5	$ 1,789	$ 46,446	$ 17,405	$ 386,616		$ 101,513	$ 1,300,862		$ 63,818	$ 109,568	$ 1	$ 5,201	$ 0	$ 39,568
	High	1.75	$ 1,789	$ 46,446	$ 17,405	$ 386,616		$ 101,513	$ 1,251,535		$ 63,818	$ 87,839	$ 1	$ 5,305	$ 1	$ 48,450
Planning Period	Short	10-year	$ 2,707	$ 29,038	$ 17,405	$ 248,328		$ -	$ 603,995		$ -	$ 66,817	$ 2	$ 9,975	$ (1)	$ 1,569
	Near Mid	20-year	$ 2,102	$ 32,496	$ 17,405	$ 340,062		$ -	$ 611,245		$ 92,327	$ 72,158	$ 1	$ 4,983	$ (1)	$ 784
	Far Mid	30-year	$ 1,915	$ 38,895	$ 17,405	$ 363,262		$ 101,513	$ 1,035,660		$ 75,724	$ 83,254	$ 1	$ 6,397	$ (1)	$ 1,006
	Long	40-year	$ 1,832	$ 44,569	$ 17,405	$ 384,978		$ 67,876	$ 1,280,760		$ 67,876	$ 146,393	$ 1	$ 5,609	$ (1)	$ 4,319
WTP Capital Cost	Low	Base x0.75	$ 1,789	$ 46,446	$ 17,405	$ 362,132		$ 101,513	$ 1,342,000		$ 63,818	$ 109,568	$ 1	$ 5,113	$ -	$ 31,047
	High	Base x1.25	$ 1,789	$ 46,446	$ 17,405	$ 411,856		$ 101,513	$ 1,342,000		$ 63,818	$ 109,568	$ 1	$ 5,113	$ -	$ 31,047

The maximum price change set was run with 25% and 75% values compared to the baseline's price change of 50%. The 25% change caused a 90% increase in WWTP capacity and 21% increase in CWC water, while maxing out system repairs. Similar to the low elasticity, all water supply and treatment system components saw a price increase. The 75% price change had a greater impact than the high elasticity scenario, causing a 90% decrease in WWTP capacity and 16% decrease in CWC purchases. Interestingly, only 79% of the water supply system leaks were selected to be repaired, showing that purchasing water was cheaper than system repairs. In this set, the low and high scenarios were much closer in their divergence from the baseline, showing a more linear relationship between system costs and maximum percent price change as compared to price elasticities.

The interest rate set compared a 3% and 7% rate with the baseline 5%. Interest rates a more well defined than elasticities and price changes which are speculative without a site specific study on user's reactions to price changes. Interest rates were only expected to affect infrastructure elements that needed to be replaced during the planning period as interest rates aren't applied to O&M costs. These variations were enough to trigger a shift in how much water was supplied from CWC relative to the WRF. The low interest rate favored an increase in interbasin transfer of 11% from baseline, because the annualization of the initial cost of construction becomes less of a factor relative to the unchanging O&M cost of the WRF over time. Should the WRF have any initial cost of construction, i.e. the system remaining life was less than the planning period; this shift would not be expected to the same degree. The high interest rate caused an 9% decrease in CWC water compensated by increased water reuse. These scenarios resulted in a 10% decrease and 11% increase in annualized cost for the 3% and 7% scenarios respectively. The majority of these cost differences were from the replacement of the WWTP equal to 77% and 78% of the total cost change for the low and high interest rates, respectively.

The water demand set compared three scenarios to the baseline, being 85%, 115%, and 132% of the baseline. The 85% scenario resulted in no water supply leak repair or WWTP capacity increases, a 38% decrease in CWC purchases, and a 7% decrease in water reuse. As would be expected, costs and revenues decreased by 17% and 15%, respectively. For the MOS/ 15% un-projected demand increase, WWTP capacity increased by 229% of the baseline or 23% of the existing capacity, CWC purchases increased 78%, water reuse increased by 15%, costs increased 26%, and revenue increased by 15%. For the relatively unrealistic 15% MOS on the 15% unanticipated increase in demand scenario, WWTP capacity increased by 42% from the existing capacity, CWC purchases increased 187% to actually exceed groundwater pumping by a small amount, water reuse decreased by 7%, costs increased 63%, and revenue increased by 33%.

Two scenarios were modeled for the groundwater pumping modification set. In this set, the baseline has the greatest amount of pumping. The low flow condition only utilizing the Willimantic and Well D on the Fenton and the no Fenton condition were modeled against the baseline with decreases in groundwater supply of 21% and 36% respectively. As expected, the only variations from the baseline for either scenario are in the amount of CWC purchases, groundwater costs, and water treatment costs. CWC purchases increased by the exact amount of groundwater pumping reductions and caused total annual costs to increase 17% and 38%. No changes occurred in water reuse and nonpotable infrastructure, meaning water purchases were more cost effective than WRF expansion.

Two scenarios were modeled for the CWC purchase price set. The cost of interbasin transfer was increased by 50% and 100% to see how management alternative selection may vary with price increases. These values are completely hypothetical given the fact that they CWC isn't openly planning on seeking rate increase approvals from the PURA. These changes were expected to decrease CWC purchases, increase water supply components, increase nonpotable water components, and decrease wastewater components. WMOST followed these expectations closely with CWC decreases of 9 and 20%, 2% and 4% increases in water purchases, 1% and 3% decreases in wastewater revenue, and 2% and 4% increases in cost. CWC purchases will inevitably increase as the need to make capital investments in infrastructure to maintain their current level of service to eastern Connecticut.

The effect of planning period length on the overall selection of alternatives was explored by running the WMOST model at 10 year planning intervals. In the 10 year planning period, water reuse is selected for a 95% increase from baseline essentially adding 1 MGD of capacity to the WRF and nonpotable distribution meeting 100% of the maximum nonpotable water use demand, while CWC purchases are 91% less than the baseline at 0.05 MGD to meet the remaining demands. In the near term, it is more effective to greatly increase water reuse, but this isn't possible in reality. Nonpotable distribution was costs were set based on new construction to the North Campus development, which is significantly less than supplying individual buildings across the fragmented campus. Longer term runs were closer in alternative selection to the baseline with CWC purchases within 15% of the 50 year value. No water leakage repair is suggested in the 20 year period, and CWC purchases are 4% less than the 50 year. Then in the 30 year period, water repair increases to 99% causing CWC purchases to go 15% lower than the 50 year period. WWTP expansion is also suggested at 95% of the baseline value Revenues and costs show definitive trends with planning period which can be seen in Figure 3-1.The annualized cost and water revenue maintain a linear increase with planning period through 40 years. Wastewater revenue decreases between the 40 and 50 year period. Cost plateaus between the 40 and 50 year periods, while water revenue increases to a lesser degree through 50 years. The logic behind the revenues plateauing is that projected water demands don't increase by a large amount in later planning periods. The plateau in cost is also most likely an artifact of demand stabilizing, requiring less infrastructure replacement between the 40 and 50 year planning periods.

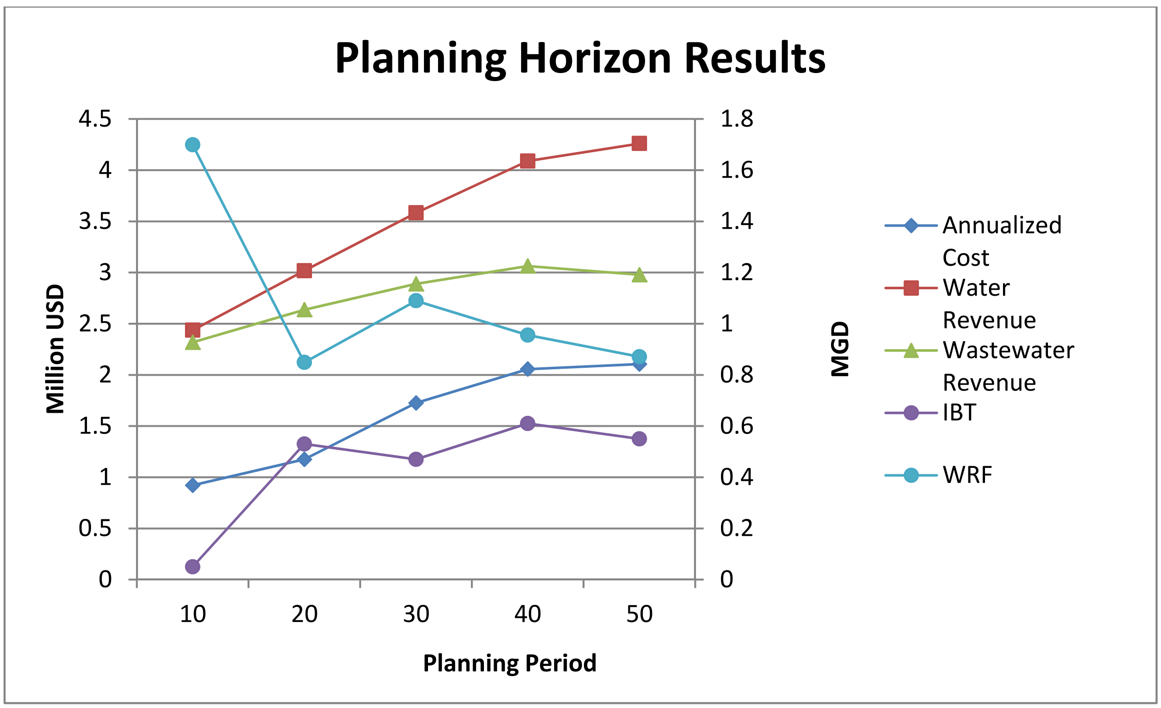


Figure 3-1: Comparison of costs, revenues, CWC and WRF water between planning periods

The water treatment facilities capital costs were evaluated at 75% and 125% of the baseline cost for the last scenario set. Neither scenario changed the selection of alternatives, and only caused a 1% decrease and 1% increase in cost, respectively. Assuming that the cost of the water treatment facilities is on the correct order of magnitude, the costs they incur are of minimal importance to the outcome of the study as compared to the other scenarios which were evaluated.

Through the modeling efforts, certain management options have been shown to be appropriate for the most cost effective operation of the system. These include fixing as much of the leakage from the water supply system, as this is less expensive than expanding water treatment facilities and increasing purchases from CWC. Similarly, implementing the 65% maximum on infiltration repairs in the wastewater conveyance system is selected before significantly increasing WWTP capacity. This result indicates it is more cost effective to repair over 50% of infiltration issues to reduce demands on the plant, than to increase capacity by the volume of infiltration from the repairs, which intuitively makes sense. Had this not been the result, then WMOST would be falsely suggesting I/I studies are futile and plant capacities should simply be increased.

Overall, CWC purchases ranged from 0.34 and 0.40 MGD for the 15% reduced demands and high max price change scenarios up to 1.58 and 1.39 MGD for the MOS+15% and no Fenton groundwater scenarios , respectively. These results suggest that if the University wants to minimize CWC purchases, water demands need to be maintained within or below projected values with one method of doing this being conveying a fiscal cost to the end users at the school to force conservative habits. Additionally, the low flow Fenton scenario produces CWC purchases of 1.04 MGD. This indicates that if all other components are well defined in the model, reducing or removing the Fenton Wellfield in the long term will cost an average of $363,000 to $798,000 per year. Water supply studies completed in recent years have suggested that the University will need to purchase 1.385 MGD to meet ADD and 2.200 MGD to meet peak demands from CWC by 2060. This modeling effort confirmed that these values may be overly conservative with the correct application of management alternatives. The baseline scenario computed water purchases of 0.55 MGD and the MOS+15% scenario, which is similar to the 1.35 peak day factor used in the Water Supply Plan, calculated a purchase rate of 0.98 MGD. These ranges suggest that several management alternatives are effective means of reducing demand on interbasin transfer even though the water projections for this study are 0.47 MGD greater than figures determined for the Record of Decision.

WMOST Discussion

Although WMOST was ultimately a helpful model, it did have some limitations that could be implemented in future versions. Some of the items described in this section have already been identified by the authors as priorities for future development.

The first issue encountered in this case study was the application of WMOST to a dual watershed system where both watersheds receive runoff from the study area and supply potable water in comparable volumes. Although there are workarounds for modeling dual watersheds which were explored in the earlier phases of preparing this case study, they ultimately fall short of reaching the necessary accuracy to provide valuable insight. This was especially true in the UConn system where land conservation has little effect on overall stormwater characteristics, the water body of interest was not gauged, and such extensive water supply studies had already been completed delineating well supported guidelines on pumping capabilities.

One of the most important and concerning limitations of the WMOST model is the inability to apply demand changes during the planning period. There are numerous reasons why water demand may change over a planning period, not limited to population changes, commercial and industrial development, irrigational demand shifts, and conservation efforts. Water utilities and municipalities generally have the data to quantify such changes in potable demand and consequently wastewater production. The WMOST user has the ability to project water demands through the planning period as needed. The issue with demand projections is WMOST significantly slows down as the number of years of input data increases. Modeling a 50 year planning period with a single year of runoff, recharge, surface flows, groundwater flows, demand, and measured flows takes 1-2 minutes. For this case study, water demand is expected to change constantly through the 50 year planning period. To model these water projections, the user has to input all of the time series data for the continuous 50 years and run the model. WMOST was not capable of performing this task, as it required any unsupportable volume of computing. The model had to be run with projections out to 40 years, with a 50 year planning period causing a single model run to take several hours and occasionally fail. Fortunately, the majority of projected demand increases occur within the first 40 years of planning so the results were not greatly affected. The ability to include projection data without greatly hindering the run time of the model would make WMOST significantly more practical. The time and computer usage significantly limited the ability to perform sensitivity and trade-off analyses on this case study, as well.

WMOST sets the relationship between price elasticity and demand as a linear function, allowing the user to set an elasticity and then a maximum price percent change. This is not inherently correct. In reality, the demand price elasticity curve compares to an ‘S’ shaped function (See Figure 4-2). As price increases from a very low value, demand only slightly decreases as seen in Slope 1. At some transition point, water becomes expensive enough to encourage significant changes in use habits. Then as price increases, demand decreases significantly more, as seen in Slope 2. At the second transition point price continues to increase, but the user has reached an absolute minimum water use level. Further price increases have little effect on demand because all feasible water conservation efforts have been undertaken. This model is greatly simplified and not directly relatable to all users. There may be several inflection points and possibility steps in the function where certain conservation efforts become fiscally viable to the user. Allowing users to define their own price elasticity functions would better reflect the users in their study area. Consequently, this would require more in-depth study as to how users would react to price changes.

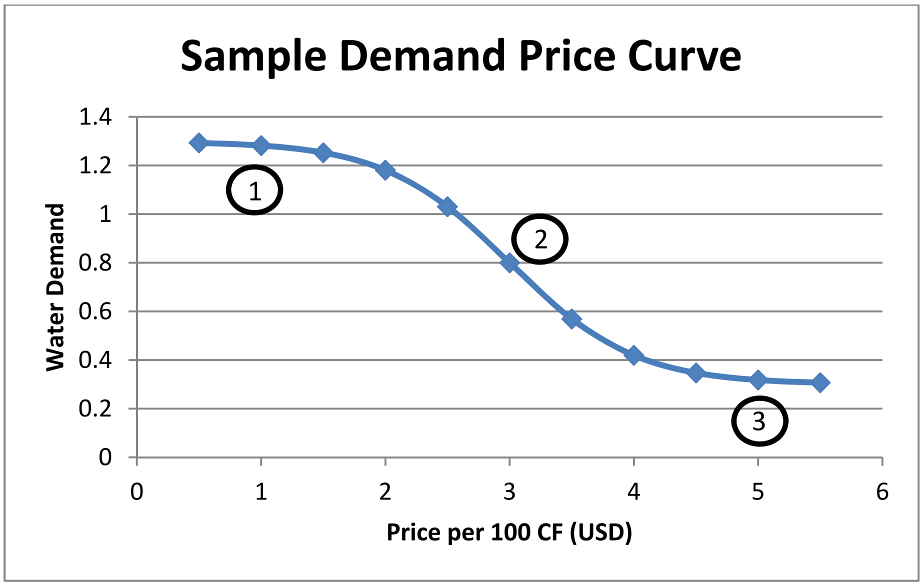


Figure 4-2: Sample model of demands reactions to price changes

There are also several other prices peculiarities that came up when completing this case study, which were difficult to account for in WMOST. Although these problems were unique, the ability to accommodate them would add significant flexibility to the model for other users. First under the interbasin transfer worksheet, the ability to define a maximum price percent change and the application of price elasticities for user groups would increase the practicality of the model as interbasin transfer is also subject to price increases. WMOST assumes the price of interbasin transfer is constant over the planning period which isn't regularly the case. Although for this case study a maximum price change for CWC supplies is not set, the ability to compare purchase amounts with difference price increase scenarios would be beneficial. Instead, the price of interbasin transfer was increased by 50% in a separate scenario to see how these adjustments would affect management alternative selection. Additionally, there are two issues with the application of price changes. WMOST models the price changes as one time price increases from the existing rates. The Danvers case study uses a 20% maximum price increase for a 20 year modeling period. Water rates are generally set, or need to be approved, by a regulatory agency. A 20% increase in price is plausible, but this increase would occur as several smaller price increases and/or be phased in over multiple years.

WMOST allowed the user to input limitations on existing interbasin transfer of water and wastewater at the daily, monthly, and annual timescales. This is a comprehensive constraint set that would also be very useful for proposed interbasin transfer. Although there is no monthly or annual limitation on UConn purchases on CWC water, there could have been monthly limitations as CWC experiences its peak demands and lowest supply flows during the late summer just as the University does. The contract between CWC and UConn was not available for this case study, but could very well include a monthly limitation that is lax during the spring, but at or below the daily limit that was agreed upon during the late summer. This would allow CWC to maintain its own supply margin of safety without having to prematurely initiate its planned capital improvements.

WMOST annualizes the costs of capital and O&M costs of the planning period, to present a single price for each management alternative, overall cost, and water and wastewater revenues to the user. Although this approach simplifies the process of evaluation for the user when evaluating different management scenarios, it does have its downfalls. An example would be the use of management alternatives like leak and infiltration repair in the water supply and wastewater collection systems, respectively. These alternatives are input as one-time costs with O&M costs to maintain the repairs. In reality, such repairs are completed over long time spans to lower capital costs. For this study, the effects of this cost input is not as significant as it would be in a short term planning effort, as evidenced by the outcome of the 10 and 20 year planning period scenarios which did not perform potable leak repair and 10 year planning not suggesting wastewater infiltration repair. In addition to the distribution of capital costs, the inability to view how alternatives, such as interbasin transfer, are distributed over the planning period is prohibitive. Acknowledging that WMOST is not meant as an annual implementation or system operation model, such an output would be very helpful. For this case study, the ability to see the timing and amount of CWC purchases would be particularly useful.

As previously discussed, WMOST does not have the ability to perform sensitivity or trade-off analyses, but the authors have recognized this as a priority for future development. Sensitivity analysis allows the user to know how important each parameter is to the final outcome of the model. Should a model parameter, such as a price elasticity, be found to carry a disproportionate weight on the cost and revenue relative to another parameter, such as the cost of conservation efforts, then the researcher would know that more effort should be put forth to ensure that the price elasticity values are as appropriate to their case study as possible. A trade-off analysis allows the user to see at what cost a certain parameter or constraint is affecting the outcome of their model. The user could see, for instance, how much it costs and what management alternatives change in meeting a conservatively selected groundwater pumping rate. If the difference between maintaining 115% and 105% of the minimum in-stream flow causes a 1% increase in cost, then the user may decide to maintain that 115% flow. As WMOST simply selects the lowest cost alternative, it cannot recognize that a relatively small increase in price creates an intangibly valuable increase in environmental sustainability. The ability to input a cost for such sustainability would be a progressive step for WMOST, as researchers are currently exploring ways to assign monetary value to environmental resources.

Along the lines of the ability to run sensitivity analysis, the option to apply a margin of safety and peaking factors to groundwater pumping, water demands, and wastewater treatment would be beneficial in completing a comprehensive water management study. Water demands vary over the daily, monthly, and annual scales. Water utilities generally attempt to maintain a 15% margin of safety on all of these demands, and also use peaking factors to ensure that peak demands within these timeframes can be met with peak production, which may exceed registration limits on pumping. The margin of safety and peaking demands also cause greater demand in the treatment facilities, compounding the cost of maintaining a supply buffer. Additionally, wastewater systems are subject to greatly increased flows from wet weather inflows which need to be specifically designed for. This case study was completed with the majority of water demands supplied at the daily time step, which precludes the need for peaking factor adjustments by WMOST, but the option to apply a margin of safety would save the user from a step of preprocessing which carries the risk of human error. A simple percentage window that would multiply all demands would make evaluating a margin of safety, and alternate water projection scenarios. Another table could be used to apply peaking factors for each month to daily values. If the user only has monthly data, the peaking factor could be used to create a more realistic continuous water demand for each month. The simplest model would multiply the peaking factor by the middle day of the month and then apply a lesser and lesser factor to each day further from the middle of the month while maintaining the monthly average supplied by the user. This would create a month where the demand on the first and last day of the month is the monthly average multiplied by one less half the peaking factor. Since peaking factors reach lows in the spring and fall, two other models could be created where the peaking factor is applied to the last day of the month and one less the peaking factor to the first day of the month. This would simulate months where the demands are generally increasing over the course of the month as occurs in early summer and winter. The exact opposite model would then be used to simulate months in late summer and winter where demands are generally decreasing over the month. Such a change would allow modelers to easily increase accuracy with minimal effort and compensate for data at monthly or quarterly timescales, such as the off campus users in the UConn system.

Future Development

The watershed management alternatives explored in this study are already under way which provides a clear path for infrastructure decisions on campus. The University should continue to fix as much leaking infrastructure as possible. It should also research how it can motivate its water end users to conserve resources. Additionally, evaluating steam loses within the climate control system, will supply valuable information towards the cost effectiveness of repairing steam infrastructure which requires significant potable makeup water. Similarly, a quantification of exactly how much water is lost in steam distribution compared to decentralized steam production could be completed. The distribution of electricity may be a cost effective water conservation strategy when related to steam loss. Concurrent to such a system is evaluating how much water would be saved by reducing electricity consumption, which is created by the Cogeneration

Plant and requires large amounts of water for cooling. Reducing energy consumption would effectively reduce the need for makeup water, as would electricity generation by solar power. A comprehensive study would determine the most cost effective way to generate electricity and steam for the study, and may yield a significant source of savings. Additionally, a study could also be done to evaluate how valuable certain flow levels are to the Fenton River. Such a study may reveal that the costs to reduce or remove Fenton River pumping are justifiable given their environmental benefit.

Chapter 4-Conclusions

This modeling effort provided a real world case study at the University of Connecticut for the newly released EPA WMOST, which was able to detail the most cost effective watershed management alternative scenario based on the physical, regulatory, and social constraints of the study area with system characterization created from the input of University staff, infrastructure assessments, and literary sources. Under the baseline set of parameters, the University is poised to purchase 0.55 MGD from CWC on average over the 50 year planning period.

The application of WMOST to this case study proved difficult for several reasons, although the modeling effort did provide valuable results. Through the creation of 9 scenarios with 19 different model runs, management alternatives were successfully optimized for cost effectiveness over the planning period. WMOST confirmed that previous projections for CWC purchases were realistic, if not overly conservative even though projected demands were underestimated according to the procedure followed within this effort. This occurred because of WMOST's ability to account for management practices aimed at reducing potable water demands to save money that hadn't previously been evaluated on a single platform.

By evaluating the modeled scenarios, a range of management alternatives can be recommended to create a near optimized system for UConn. An average of 0.55 MGD will need to be purchased from CWC, while implementing the repair of 99% of water supply system leakages. The WPCF will need an additional 0.21 MGD of capacity, while infiltration to the conveyance system should be eliminated to the greatest extent possible. Around $2.1 million will need to be invested in water and wastewater infrastructure including O&M and replacement costs. WMOST indicated a very strong relationship between demand management practices and annualized system costs, which suggests the University should find ways to make water use fiscally relevant to users on campus to keep demands at or below current projections. Finally, if the University seeks to minimize its impact on the Fenton River, it can downscale or remove the wellfield at the annualized cost of $363,000 or $798,000, respectively.

WMOST was found to be prohibitively difficult to run with long term water demand projections. Long term planning efforts in evolving watersheds becomes a laborious task which could ultimately force planners to make concessions for the sake of time and effort. Performing manual sensitivity and trade-off analyses compounded the long term planning issues with very time consuming and demanding computer processes. In addition, obtaining and manipulating realistic hydrologic conditions for WMOST input was difficult, especially for this study, leading to its exclusion from the modeling effort. WMOST also lacked flexibility in pricing structures, forcing users to create composite prices for water and wastewater, perform sensitivity analysis to price elasticities and maximum price percent changes, and perform multiple scenarios to project interbasin transfer pricing changes.

This modeling effort effectively showed that WMOST is a capable watershed management screening model. Ultimately, it had some drawbacks which forced the user to bridge gaps between available data and actual model inputs. Given the final conditions of the model without hydrology, a more simple logistics model would have been able to perform the modeling effort. Such a model would have taken more setup time and effort on the part of the researcher, but would have produced a model tailor made to the issues at hand in the UConn system. Such a modeling effort would most likely reveal a similar result to WMOST, suggesting the University seek a few key alternatives to minimize purchases from CWC. Future research into water conservation, should include evaluation of the steam supply system as well as creating a monetary value for streamflow in the Fenton River.

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