The Water-Energy Simulator (WESim)

User Manual

WateReuse Research Foundation

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About the WateReuse Research Foundation

The mission of the WateReuse Research Foundation is to conduct and promote applied research on the reclamation, recycling, reuse, and desalination of water. The Foundation's research advances the science of water reuse and supports communities across the United States and abroad in their efforts to create new sources of high-quality water through reclamation, recycling, reuse, and desalination while protecting public health and the environment.

The Foundation sponsors research on all aspects of water reuse, including emerging chemical contaminants, microbiological agents, treatment technologies, salinity management and desalination, public perception and acceptance, economics, and marketing. The Foundation's research informs the public of the safety of reclaimed water and provides water professionals with the tools and knowledge to meet their commitment of increasing reliability and quality.

The Foundation's funding partners include the Bureau of Reclamation, the California State Water Resources Control Board, the California Energy Commission, and the California Department of Water Resources. Funding is also provided by the Foundation's Subscribers, water and wastewater agencies, and other interested organizations.

The Water–Energy Simulator (WESim)

User Manual

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Cosponsors

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Contents

List of Figures vi
List of Tables vii
List of Acronyms viii
Foreword ix
Acknowledgments x

Chapter 1. Introduction..1

Chapter 2. Terminology 3
2.1 Water System Components 3
2.2 Scenarios, Water Systems, and Water System Facilities..............................5

Chapter 3. Model Specifications...9
3.1 Minimum System Requirements 9
3.2 About User Mode and Development Mode..9

Chapter 4. Getting Started...11
4.1 Model Overview...11
4.2 Enabling Macros...11
4.2.1 Changing the Security Settings...11
4.2.2 Enabling Macros...13

Chapter 5. Model Inputs 15
5.1 Start Page...15
5.2 Scenario Manager...16
5.3 Water System Manager 17
5.4 Water System Facility Editor 18
5.5 Energy Source Manager 21

Chapter 6. Model Outputs 25

Chapter 7. Conclusions...27

References...28

Figures

2.1 Flow diagram of water and wastewater systems. 4
2.2 Example of a simple simulation. 7

4.1 Changing the trust center settings. 12
4.2 Changing the macro settings. 13
4.3 Security warning panel in Excel 2007. 14
4.4 Enabling macros in Excel 2007. 14

5.1 Model start page with navigation panel circled. 16
5.2 Scenario manager page. 17
5.3 Water system editor page. 18
5.4 Water system facility editor page. 19
5.5 WESim default wizard. 20
5.6 Energy source manager page. 21

6.1 Model output page. 26

Tables

2.1 Sample Desalination Facility 5
2.2 Sample Recycled Water Facility 5

5.1 Greenhouse Gas Emissions Factors for Various Fuels and for Electricity 22

Acronyms

AWWARF	American Water Works Association Research Foundation (now the Water Research Foundation)
$CO_{2\text{-eq}}$	carbon dioxide equivalents
eGRID	Emissions and Generation Resource Integrated Database
EPA	U.S. Environmental Protection Agency
PAC	Project Advisory Committee
RAC	Research Advisory Committee
VBA	Visual Basic for Applications
WESim	Water–Energy Simulator

Foreword

The WateReuse Research Foundation, a nonprofit corporation, sponsors research that advances the science of water reclamation, recycling, reuse, and desalination. The Foundation funds projects that meet the water reuse and desalination research needs of water and wastewater agencies and the public. The goal of the Foundation's research is to ensure that water reuse and desalination projects provide high-quality water, protect public health, and improve the environment.

An Operating Plan guides the Foundation's research program. Under the plan, a research agenda of high-priority topics is maintained. The agenda is developed in cooperation with the water reuse and desalination communities including water professionals, academics, and Foundation subscribers. The Foundation's research focuses on a broad range of water reuse research topics including

- Definition of and addressing emerging contaminants
- Public perceptions of the benefits and risks of water reuse
- Management practices related to indirect potable reuse
- Groundwater recharge and aquifer storage and recovery
- Evaluation and methods for managing salinity and desalination
- Economics and marketing of water reuse

The Operating Plan outlines the role of the Foundation's Research Advisory Committee (RAC), Project Advisory Committees (PACs), and Foundation staff. The RAC sets priorities, recommends projects for funding, and provides advice and recommendations on the Foundation's research agenda and other related efforts. PACs are convened for each project and provide technical review and oversight. The Foundation's RAC and PACs consist of experts in their fields and provide the Foundation with an independent review, which ensures the credibility of the Foundation's research results. The Foundation's Project Managers facilitate the efforts of the RAC and PACs and provide overall management of projects.

Water management decisions can have significant energy impacts. Water use entails energy in all phases, from collection to treatment to distribution to use to wastewater treatment. Multiple factors will influence the energy intensity of the water sector in the near future: climate change will affect water supply, quality, and demand, potentially creating a need for new water supply options; population growth, water use patterns, technology, and price all affect water demand; and emerging contaminants may require more energy-intensive treatment technologies. The Water–Energy Simulator (WESim) is an easy-to-use analytical tool that can be applied by water agencies, municipalities, and decision makers to evaluate the energy and greenhouse gas implications of water management decisions.

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The research team would like to thank the project sponsors for funding this applied research project, as well as the following organizations for their in-kind contributions: the Metropolitan Water District of Southern California (CA), the Santa Clara Valley Water District (CA), the City of Santa Fe (NM), the Inland Empire Utilities Agency (CA), the Sonoma County Water Agency (CA), Toronto Water (Canada), and the West Basin Municipal Water District (CA).

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Chapter 1

Introduction

Water provision and use require energy in all phases, from source extraction to the discharge of wastewater. First, water is taken from a source and delivered to a community. In some cases, the force of gravity is sufficient; but in many cases, water must be pumped from groundwater wells or over long distances and steep terrain. Water must then be treated to drinking water standards through a variety of processes that require energy, including filtration, sedimentation, and disinfection. Treated water is then delivered to the tap, either by gravity or by additional pumping. Even more energy is used in homes, businesses, and institutions to heat, cool, purify, and pump water. Water that is used indoors must then be returned, and in some cases pumped, to a wastewater treatment facility, where it undergoes further processing that requires energy. Treated wastewater then either is returned to the environment by gravity or pumping or undergoes additional processing and is reused.

Multiple factors will influence the energy intensity of the water sector in the near future: climate change will affect water supply, quality, and demand, potentially creating a need for new energy-intensive supply and treatment options; population growth, water use patterns, technology, and price all will affect water demand; and emerging contaminants may require more energy-intensive treatment technologies. These trends highlight the need for a clear and consistent methodology for evaluating the energy and greenhouse gas implications of water management decisions.

The Pacific Institute and Dr. Bob Wilkinson, with support from the WateReuse Research Foundation, the California Energy Commission, the Canada Mortgage and Housing Corporation, and the Bureau of Reclamation, have developed the Water–Energy Simulator (WESim) as an easy-to-use analytical tool that can be applied by water and energy managers, municipalities, and decision makers. The model allows the user to evaluate the energy and greenhouse gas implications of population growth, the impact of climate change, the development of alternative water and energy sources, and needed water treatment improvements resulting from emerging contaminants and stricter water-quality guidelines. The tool is suitable for individual water utilities, groups of water utilities, and policymakers and decision makers.

WESim does not provide “the answer.” Rather, it is a tool that creates a common framework in which you can explore alternative scenarios. For example, you can compare the energy and greenhouse gas implications of using recycled water and of seawater desalination. Alternatively, you can explore the implications of installing ozone disinfection at a water treatment facility or biogas recovery at a wastewater treatment facility. You can also evaluate ways to offset the energy use and greenhouse gas emissions associated with energy-intensive water sources through the installation of renewable energy technologies or investments in conservation and efficiency.

The model is designed to allow you to input actual operating data on water and energy use, as this will allow an analysis that better reflects operating conditions. However, we recognize that not all users will have this information. To facilitate use of the model, we provide defaults for the energy requirements of various components of the water and wastewater system. Detailed information about the structure and design of WESim can be found in the accompanying main report.

Chapter 2
Terminology

2.1 Water System Components

The model uses a basic analytical approach developed by Dr. Robert Wilkinson (2000) of the University of California at Santa Barbara (and refined and improved upon by a number of experts), which divides the water cycle into the stages shown in Figure 2.1. We suggest grouping facilities into the following system components:

- *Source extraction* refers to the extraction of water from a source to the surface of the Earth. Energy requirements for water supply depend on the location of the water relative to the surface and the method of extraction. Using this definition, the energy intensity of water extraction for water that is already at the surface, for example, seawater, recycled water, or river water, is zero.
- *Water conveyance* refers to the transport of untreated water through aqueducts, canals, and pipelines from its source to a water treatment facility or directly to an end user. Energy requirements for conveyance depend primarily on the distance and net elevation through which it is pumped, as well as the efficiency of the pumps used.
- *Water treatment* refers to processes and technologies that treat water to potable water standards prior to its distribution to homes and businesses. The energy requirements for treatment depend on the quality of the source water and the technology employed to treat that water. For recycled water, the energy requirements include the incremental treatment required to bring treated wastewater to recycled water standards. The energy intensity of recycled water treatment depends on the level of treatment required prior to discharge and the additional treatment required to bring it to the appropriate standard for the intended customer.
- *Water distribution* refers to the transport of treated water (both potable and nonpotable water) to customers. As with conveyance, the energy intensity of distribution depends largely on the distance and elevation through which water is pumped, as well as the energy efficiency of the pumps.
- *Customer end use* of water refers to the multitude of ways in which we use water in residential, commercial, industrial, institutional, and agricultural settings, which include personal hygiene, dish and clothes washing, landscape and crop irrigation, process water, and equipment cooling. Energy use associated with customer water end use is typically associated with heating, cooling, water treatment (e.g., filtering and softening), circulation, and supplemental pressurization in high-rises.
- *Wastewater collection* refers to the movement of untreated wastewater from the end user to a wastewater treatment facility. The energy requirements for wastewater collection depend on local geography and pump efficiency.
- *Wastewater treatment* refers to the application of biological, physical, and/or chemical processes to bring wastewater to discharge standards. The energy requirements for wastewater treatment depend on the level of treatment and, because wastewater must be pumped throughout the treatment facility, on pump efficiency.

- *Wastewater discharge* refers to the movement of treated wastewater from a wastewater treatment facility to the receiving waters. Energy requirements for wastewater discharge depend on local geography and pump efficiency.

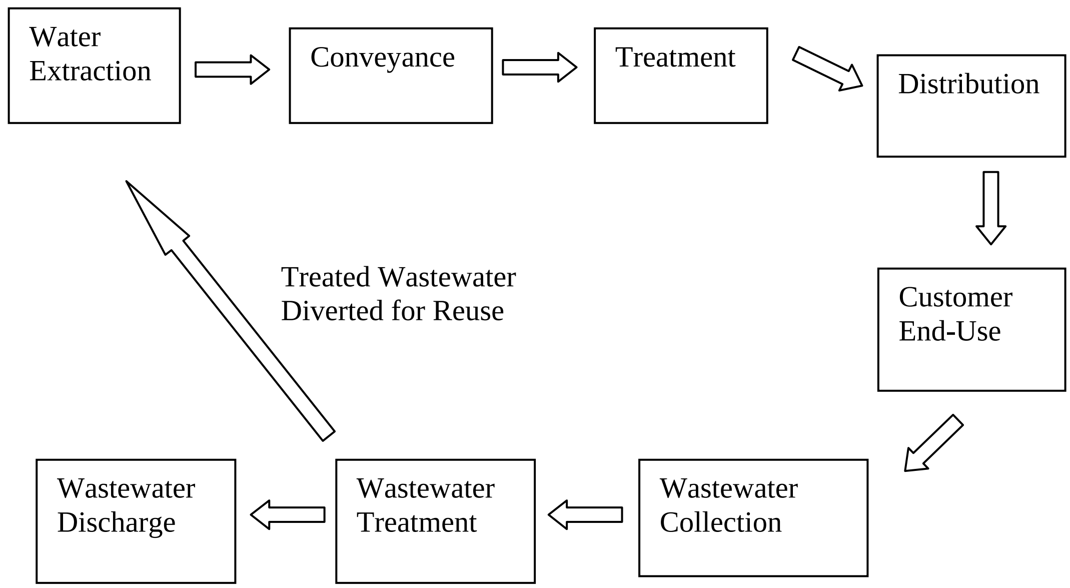

Figure 2.1. Flow diagram of water and wastewater systems.

Source: This schematic and method are based on Wilkinson (2000) with refinements by California Energy Commission staff and others.

Although these definitions set forth clear boundaries between the system components, in reality, these boundaries can be fuzzy. For example, an agency might pump high-quality groundwater from a well and add a small amount of chlorine at the well for disinfection prior to distribution to customers. In this case, the energy requirements for groundwater pumping and chlorine injection are likely captured by a single electricity meter. Thus, there is no way to distinguish between source water extraction and treatment. Using the WESim analytical framework, the user will have to classify the energy requirements as *either* source extraction or treatment. Either classification is acceptable; however, the user must be sure not to include the energy requirements as *both* source extraction and treatment, to avoid double counting.

The following example might assist you in thinking about your system using this framework. Say that a water agency operates a seawater desalination facility (Table 2.1). In this case, the energy intensity of water extraction is zero, because the water is already at the surface. Seawater is pumped from the ocean to the desalination facility, which requires an energy intensity of 50 kilowatt-hours (kWh) per million gallons (0.013 kWh per cubic meter). The seawater is then treated using reverse osmosis, which requires 15,000 kWh per million gallons (4.0 kWh per cubic meter). The treated water is distributed to customers, requiring 850 kWh per million gallons (0.22 kWh per cubic meter).

Table 2.1. Sample Desalination Facility

	Energy Intensity	
	kWh/m^3	**kWh/MG**
Source extraction	0	0
Conveyance	0.013	50
Treatment	4.0	15,000
Distribution	0.22	850

Notes: All numbers rounded to two significant figures. MG = million gallons; m^3 = cubic meters.

As a second example, consider recycled water. Say that we have a system where wastewater receives secondary treatment at the Smith Facility before it is discharged into the ocean using gravity. Some of the wastewater receives additional treatment at the Smith Facility to bring it to recycled water standards (Table 2.2). In this example, the recycled water is already at the surface and is not transported to another facility for the additional treatment it receives. Thus the energy intensity of water extraction and conveyance is effectively zero. The energy intensity of treatment is the additional energy required to bring the secondary-treated wastewater to recycled water standards, or 1100 kWh per million gallons (0.29 kWh per cubic meter). The recycled water must then be distributed to the end users, which is estimated to require 900 kWh per million gallons (0.24 kWh per cubic meter).

Table 2.2. Sample Recycled Water Facility

	Energy Intensity	
	kWh/m^3	**kWh/MG**
Source extraction	0	0
Conveyance	0	0
Treatment	0.29	1,100
Distribution	0.24	900

Note: All numbers rounded to two significant figures. MG = million gallons; m^3 = cubic meters.

2.2 Scenarios, Water Systems, and Water System Facilities

WESim uses scenario-based planning to model how changes to water systems will affect energy use and greenhouse gas emissions. WESim uses the concepts of water *systems,* water system *facilities,* and *scenarios* to model these changes. A water system facility is a facility, such as a well or treatment plant, or a group of facilities that are related, such as a well field. The water system is made up of any number of these facilities. Each scenario is a description of the water system under a certain set of conditions. Most users will begin by creating a scenario that represents current conditions, or the “baseline.”

For example, a small water agency extracts water from a local reservoir, provides treatment at a nearby facility, and distributes treated water to its customers. This agency also collects, treats, and discharges wastewater. The agency is considering recycling some of the wastewater to offset withdrawals from the local reservoir.

To begin with, you should first develop the Baseline Scenario, containing all of the existing water system facilities, including the pumps to convey raw water and wastewater to the treatment facilities, the water and wastewater treatment facilities, and the booster pumps to distribute treated water to the customers. Add as much detail as is available or appropriate. It requires time and effort to accurately and completely represent your water system. Once the Baseline Scenario has been completed, however, WESim is a powerful tool for envisioning possible water and energy futures.

After you have developed a Baseline Scenario, create a new scenario by duplicating the Baseline Scenario and renaming it “Baseline with Water Recycling.” Then make the following adjustments to the water system that features recycling:

- reduce the volume of wastewater that is discharged;
- add a new source extraction facility called “recycled water”;
- reduce the volume of surface water that is conveyed, treated, and distributed;
- add a new treatment facility, which captures the additional treatment required to bring the treated wastewater to recycled water standards; and
- add new facilities needed to distribute recycled water.

Once these changes to the new scenario have been made, you can view the model output and compare the overall energy consumption and greenhouse gas emissions between the “Baseline” and “Baseline with Water Recycling” scenarios. This example is illustrated in Figure 2.2.

Scenarios:	**Baseline**	**Baseline with Water Recycling**
System	Source Extraction Local surface water	Source Extraction **Local surface water** *Recycled water*
	Water Conveyance Raw water pumps	Water Conveyance **Raw water pumps**
	Water Treatment Treatment plant	Water Treatment **Treatment plant** *Recycled water treatment*
	Water Distribution Booster stations	Water Distribution **Booster stations** *Recycled water booster stations*
	End Use Commercial Industrial Residential	End Use Commercial Industrial Residential
	Wastewater Conveyance Sewer booster stations	Wastewater Conveyance Sewer booster stations
	Wastewater Treatment Wastewater Plant	Wastewater Treatment Wastewater plant
	Wastewater Discharge Gravity fed	Wastewater Discharge **Gravity fed**

Figure 2.2. Example of a simple simulation.

Note: The new components are shown in *italics*, and the modified components are shown in **bold**.

Chapter 3

Model Specifications

3.1 Minimum System Requirements

WESim is a Microsoft Excel workbook with a number of macros to facilitate data entry, calculation, and display of results. As you work, the information that you input will be stored in a Microsoft Access database file. The workbook is compatible with Excel 2000 and later versions on PC computers. WESim has not been tested on Macintosh computers. You must also have Microsoft Access installed on your computer.

3.2 About User Mode and Developer Mode

You may use the model in either user or developer mode.

User mode is suggested for most model users and is enabled by default. The user mode simplifies data entry, hides formulas, and displays one sheet at a time. You can return to user mode at any time by navigating to the Introduction page and clicking the “User Mode” button. It is also available at any time by typing Ctrl + Shift + U.

Developer mode allows you to “look under the hood.” The developer mode removes worksheet protection to make every cell selectable and shows all of the worksheets. It is available by clicking the “Developer Mode” button on the Introduction page or by typing Ctrl + Shift + R.

Even with the Excel workbook in developer mode, much of the program’s logic and calculations are done in Visual Basic for Applications (VBA) code. You can view the program using Visual Basic Editor. Please refer to the help manual within Excel for instructions on performing this operation.

Chapter 4

Getting Started

4.1 Model Overview

Here, we provide a general overview of the steps required to use the model. For additional information on each step, please refer to the section indicated.

1. Open WESim in Excel and enable macros (see Section 4.2 for instructions).
2. Establish a working file on the *Start Page* (see Section 5.1 for instructions).
3. Create a new scenario on the *Scenario Manager* page (see Section 5.2 for instructions). Click on the button that shows the name of the scenario you would like to edit to go to the *Water System Manager* page.
4. On the *Water System Manager* page, begin adding water and wastewater system facilities to the scenario (see Section 5.3 for instructions).
5. On the *Water System Facility Editor* page, add details about each facility, including its name, classification, flow, and energy use (see Section 5.4 for instructions).
6. On the *Energy Source Manager* page, edit your energy sources; include all of the energy sources that power your system (see Section 5.5 for instructions).
7. Add additional scenarios by repeating steps 3–6.
8. Once you have entered all of the scenarios, review the model output (see Section 6.1 for instructions).

4.2 Enabling Macros

This workbook contains custom VBA macros. Most Excel programs, however, have security settings that will not allow macros. To use WESim, you must change the Excel security settings. Detailed instructions for changing the security settings can be found in Section 4.2.1. *Please note that you will only need to change the security settings once.* Once you have changed the security settings, you can enable the macros by following the procedure outlined in Section 4.2.2.

4.2.1 Changing the Security Settings

This workbook contains custom VBA macros that must be enabled when opened. To enable macros, you must first change the security settings on Excel. You will only need to do this once. To change the security settings, follow the outlined procedure for the version of Excel that you are using. Note that you should not have the WESim Excel file open while changing the security settings.

Excel 2000–2003 (including Office XP)

(1) In Excel, choose Tools > Macro > Security.
(2) In the Security window, choose "*Medium*" and click "*OK*." *You have now changed the security settings of Excel. You will only need to perform these steps once.*

Excel 2007

(1) Click the File tab or round Office Button () at the upper left of the screen, and then click "*Excel Options*," which is located at the bottom of the window.
(2) Within the Excel Options window, select the Trust Center tab on the left. Click the button "*Trust Center Settings*" (Figure 4.1).
(3) Under the Macro Settings tab, select "*Disable all macros with notification*," and click "*OK*" (Figure 4.2). Click "*OK*" again to save your Excel options. *You have now changed the security settings of Excel. You will only need to perform these steps once.*

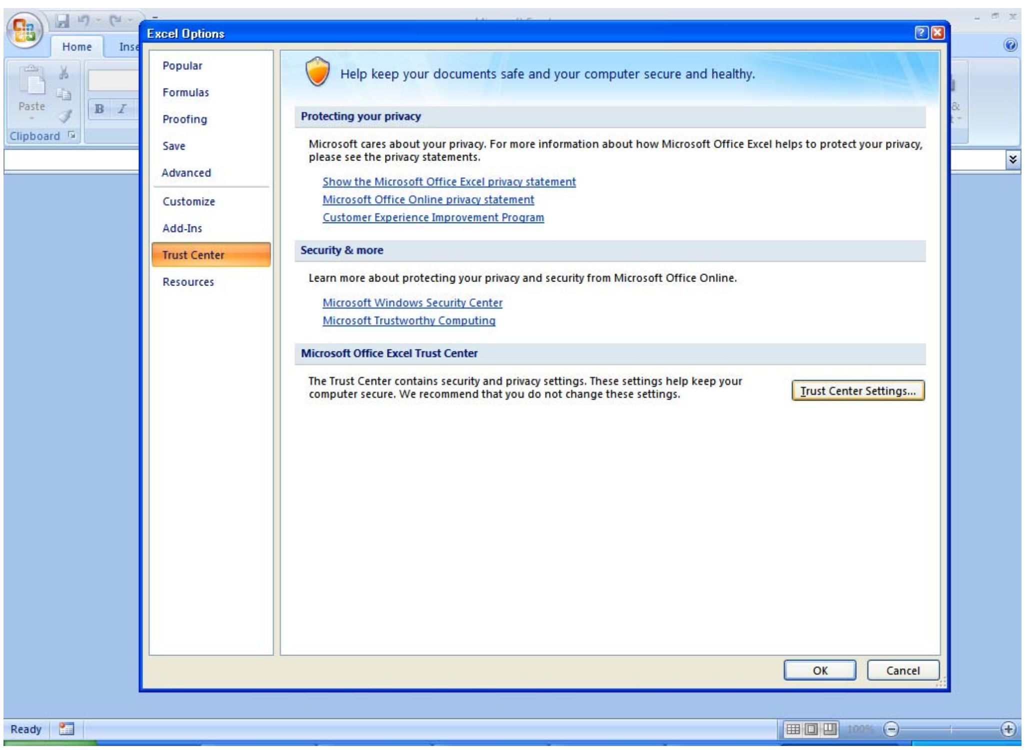

Figure 4.1. Changing the trust center settings.

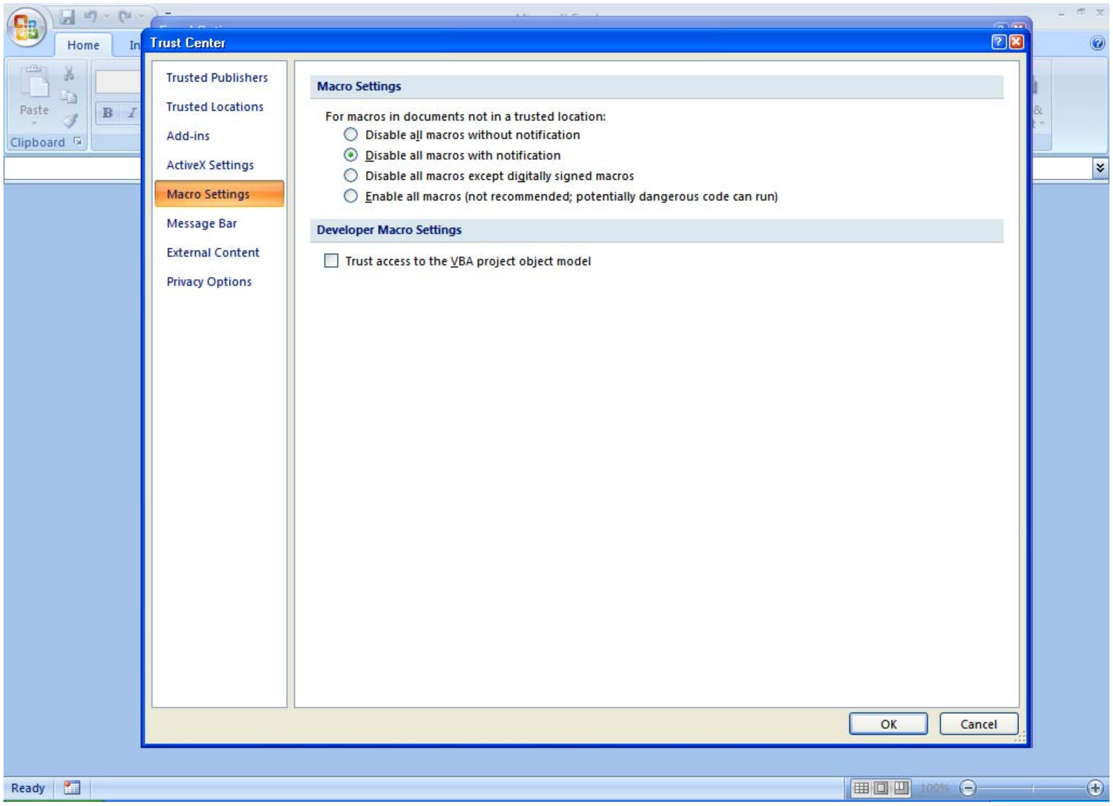

Figure 4.2. Changing the macro settings.

4.2.2 Enabling Macros

Enabling macros requires slightly different procedure depending on the version of Excel that you are using. Directions are provided below for Microsoft Excel 2000–2003 and Excel 2007. For other versions of Excel, please refer to the help file within Excel for direction on enabling macros.

Excel 2000–2003 (including Office XP)

(1) Download WESim to your computer. Open the WESim Excel file.
(2) A pop-up dialog box will appear.
(3) Click the button to Enable Macros. You will need to repeat this step every time you open WESim.

Microsoft Excel 2007

(1) Download WESim to your computer. Open the WESim Excel file.
(2) A message bar will appear near the top of the Excel window, titled “Security Warning.” Click the “*Options . . .*” button (indicated by the arrow in Figure 4.3).
(3) In the Microsoft Office Security Options window, choose “Enable this content” and click “*OK*” (Figure 4.4). You will need to do this step every time you open WESim.

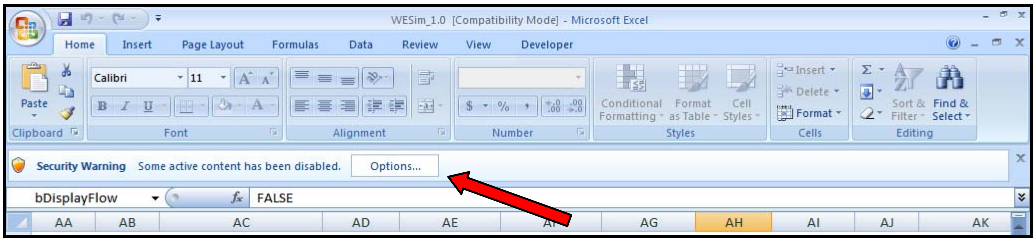

Figure 4.3. Security warning panel in Excel 2007.

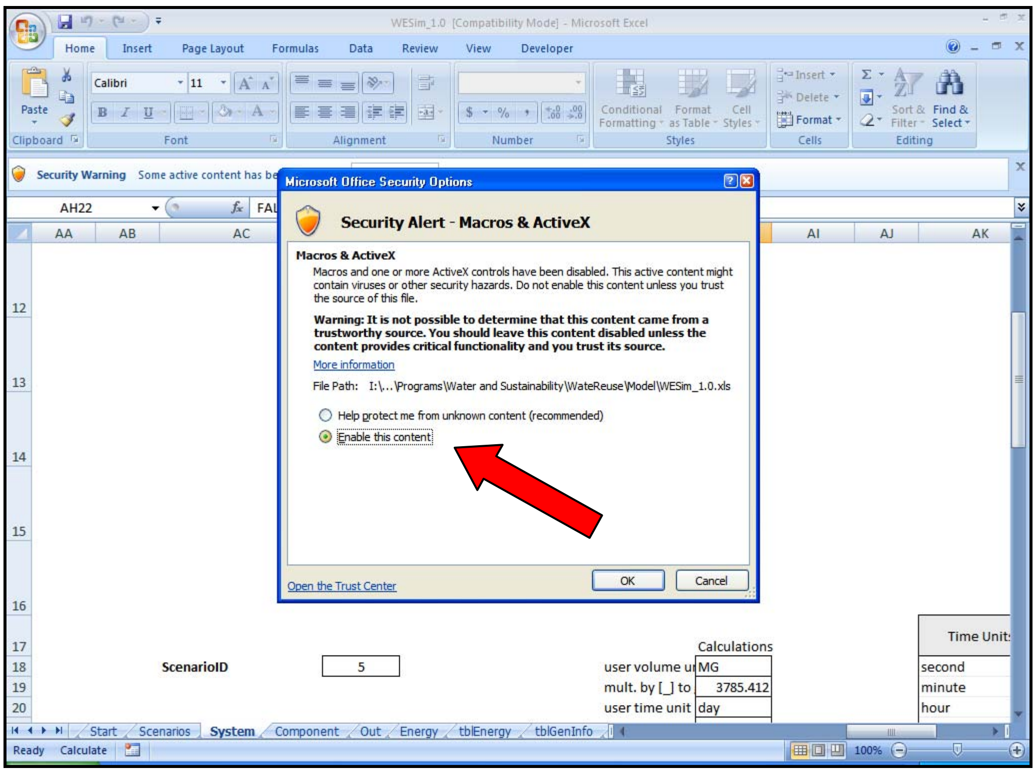

Figure 4.4. Enabling macros in Excel 2007.

Chapter 5

Model Inputs

Once you have enabled the macros, you can begin using WESim. You will enter information on five worksheets: (1) the *Start Page, (2)* the *Scenario Manager*, (3) the *Energy Source Manager*, (4) the *Water System Manager*, and (5) the *Water System Facility Editor*. Inputs for each worksheet are described in the following sections.

5.1 Start Page

The Start Page contains the basic data file management tasks (Figure 5.1). You must first set up a working database, where responses will be stored as worksheets are completed. To create a new database, click "**Create a New File**." Select the country where the facilities are located; your selection here will determine the units used throughout the model, as well as default values for the greenhouse gas emissions associated with various fuels in Canada and the United States and the electricity grid loss factors (see Section 5.5 and Cooley et al., 2012 for additional information). Once you have selected the appropriate country, specify a file name and location and click "**Save**." You are free to save this file anywhere on your computer or local network. WESim will set up this new file as the current working database. Do not move or delete the working database file while using the model. To continue working with a previously created scenario, click "**Open an Existing File**" and navigate to the appropriate Access database (.mdb) file. As you navigate from one sheet to another, responses are automatically saved in the database file.

After you have established a working file, you may begin creating your baseline scenario by proceeding to the Scenario Manager page. Go to the Scenario Manager page by selecting the "**Scenario Manager**" hyperlink at the top of the screen or on the navigation panel (Figure 5.1). Instructions for adding scenarios can be found in Section 5.2.

A number of data file management tasks can be accessed from the Start Page. In addition to creating a new or opening an existing file, you can do the following:

- From time to time, you may wish to make a backup of your current data file to return to a particular set of inputs at a later time. "**Duplicate the Current File**" will make a copy of the active database file with a name you specify.
- If you work with a single database file for a while, the file size will steadily increase. From time to time, you may wish to click "**Compact Database File**." This step is not mandatory, but may result in slightly faster performance.
- Click "**Check Database Connection**" to verify that the file shown is a valid WESim database. You will likely never need to use this button.
- Click "**View Folder**" to open Windows Explorer and identify the directory where your database file is stored. This may be useful for managing or moving your data files.
- Click "**Clear This Sheet**" to remove all of your entries from the page.

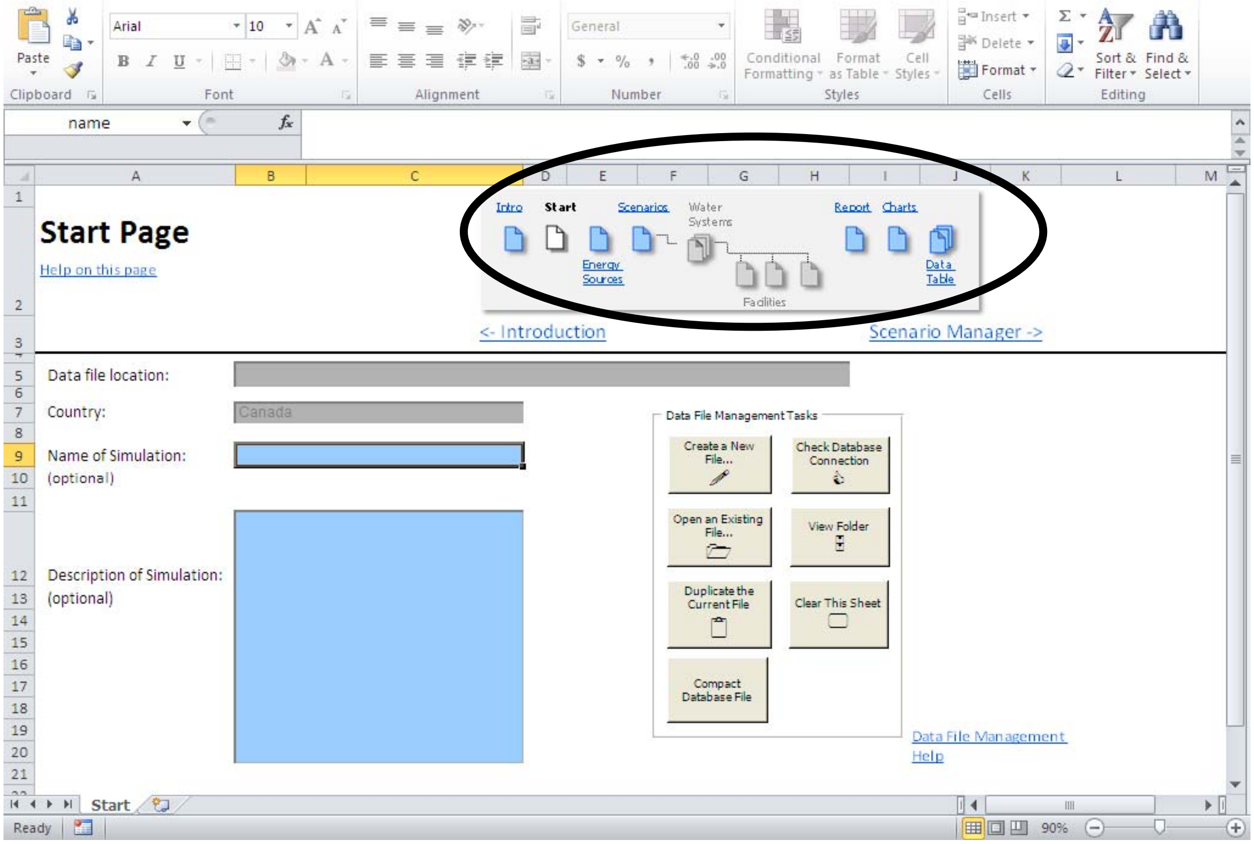

Figure 5.1. Model start page with navigation panel circled.

5.2 Scenario Manager

On the Scenario Manager page, you can create up to 10 different scenarios (Figure 5.2). To get started on the Scenario Manager page, click the "**Add a Scenario**" button in the Scenario Management section. Type a name for the scenario when prompted—for example, "Baseline." This scenario will appear as a button. Once you have created your first scenario, click on the scenario button to go to the Water System Manager page, where you can begin entering information about the various facilities within your water/wastewater system.

Depending on the level of detail you wish to enter, modeling the system and adding all of the necessary information can be time-consuming. Once you have filled in the water system to your satisfaction, you can create a carbon copy of it that you can easily modify. To do this, click the "**Duplicate Scenario**" button and choose the scenario to copy. Enter a new scenario name and click "**OK**." A button will appear on the Scenario Manager page with the new scenario name. Click on the scenario button to go to the Water System Manager page, where you make changes to existing facilities or add new facilities.

You can also delete or rename scenarios, and move them up and down in the list by clicking "**Change Order**." *Please note that deleting a scenario is permanent and there is no way to undo this.*

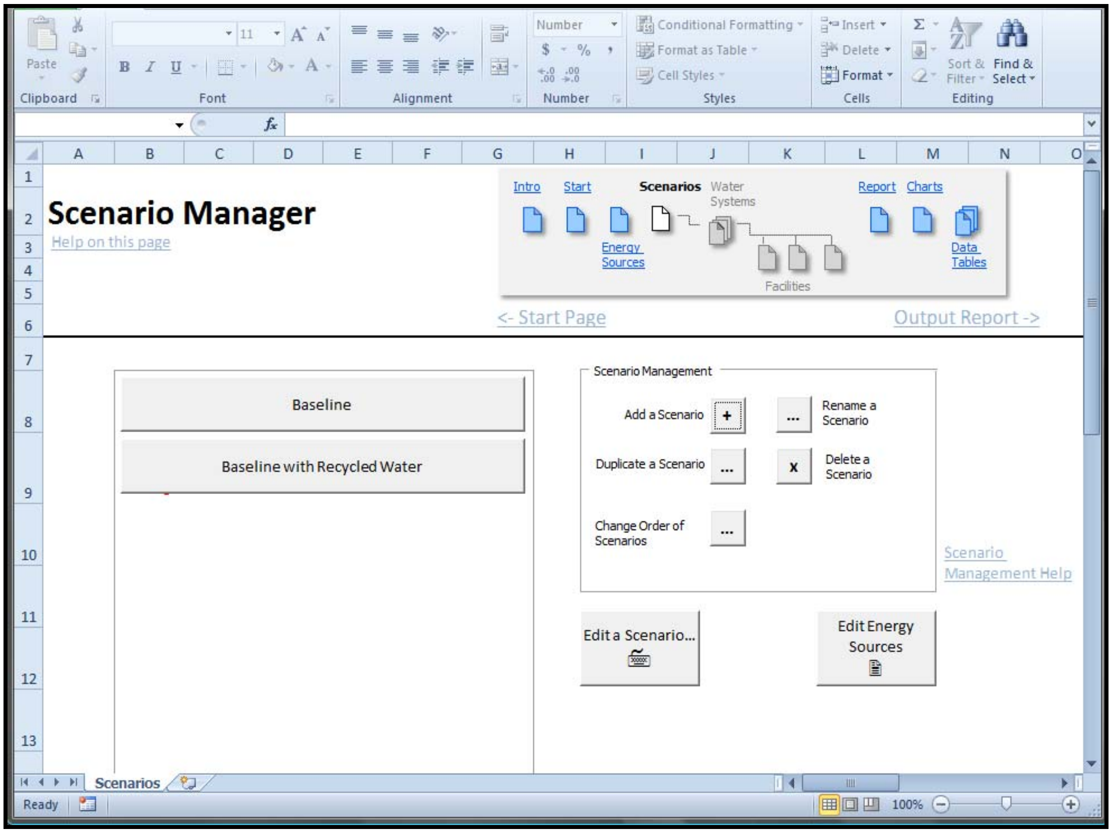

Figure 5.2. Scenario manager page.

5.3 Water System Manager

The Water System Manager is where you can build a water system by adding, deleting, or duplicating system facilities such as groundwater wells, conveyance systems, or water treatment facilities (Figure 5.3). WESim allows you to add as much detail as you wish, or as is appropriate for your agency. For example, you can enter data for each groundwater well by making each well a separate facility, or for all wells combined. Likewise, you can enter information on each section of the water distribution system or for all sections of the water distribution system combined.

To begin, click the "**Add a Facility**" button in the Facility Management section. You will then be taken to the Water System Facility Editor page, where you can begin filling in information on the water system facility and its water and energy use (see Section 5.4 for instructions). Once you have created a facility, it will appear as a button on the Water System Manager page. You can edit information about this facility by clicking on this button.

On the Water System Manager page, you have the option to display the water volume and energy use for system facilities by clicking the checkboxes near the top of the sheet. You can also choose from a wide range of units. WESim will automatically convert the results and display them on the sheet in the units you select. The numbers in blue correspond to water flow, while the numbers in red correspond to energy usage.

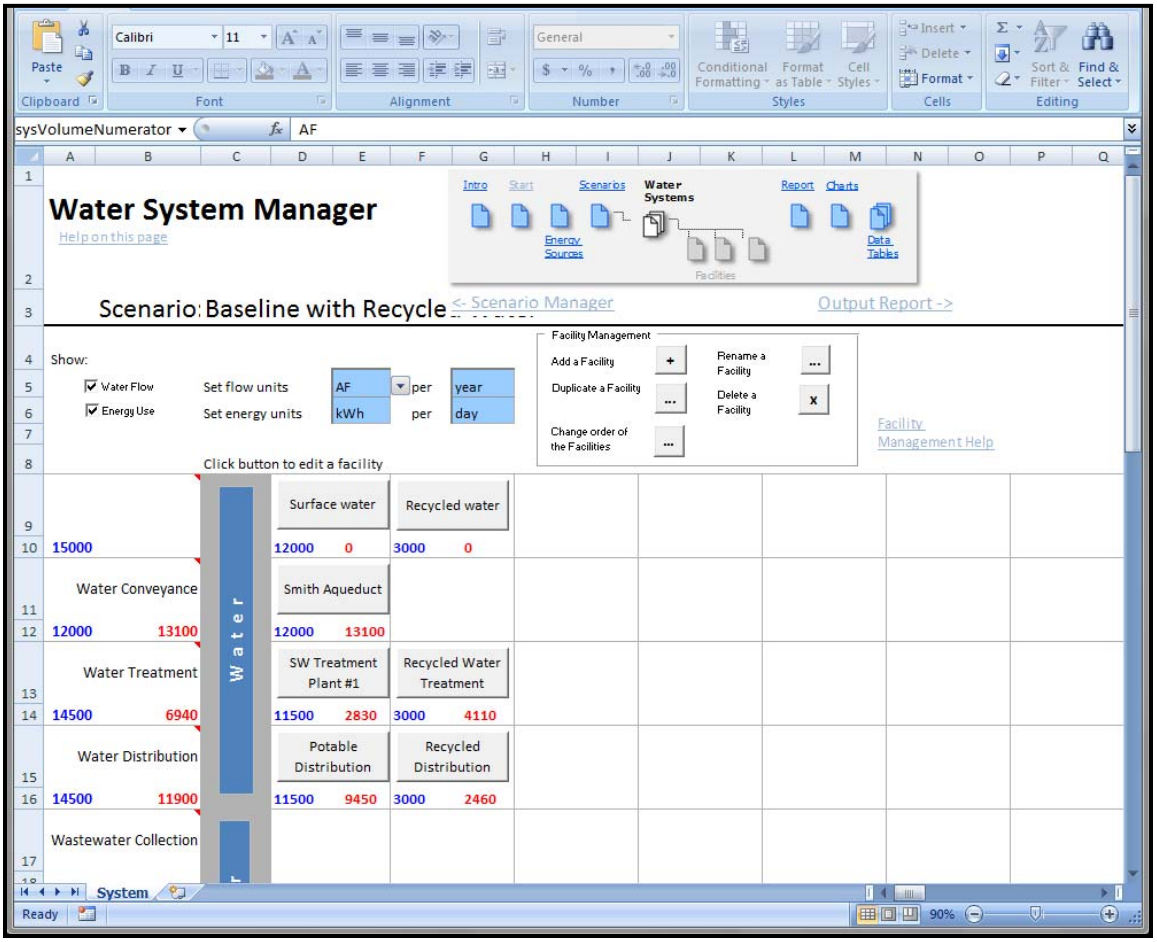

Figure 5.3. Water system editor page.

If the numbers displayed under a component button look like this, #####, then the number is too large to be displayed in the cell. Try changing the units of time in the denominator, for example, from “per month” to “per day” or “per year.” Large numbers will be displayed in scientific notation (1.34E+09), and smaller numbers will take less room to display.

5.4 Water System Facility Editor

The Water System Facility Editor page is where you specify the water flow and energy use for a particular facility (Figure 5.4). Before entering water system facilities, be sure you have entered all of the energy sources that power your water and wastewater system into the Energy Source Manager. If you have not already done this, select “**Edit Energy Sources**” to go to the Energy Source Manager page (for additional instructions on this page, see Section 5.5). After you have finished entering the energy sources, select “**Save**” to return to the Water System Facility Editor page.

Once you have entered all of the energy sources, begin by naming the facility and selecting whether it represents extraction, conveyance, treatment, distribution, end use, wastewater collection, wastewater treatment, or wastewater discharge. You should then indicate the volume of water that is conveyed through or treated at the facility. You can enter the actual energy consumption of the facility or some estimate of its energy intensity. Because a single facility may be powered by multiple energy sources, e.g., electricity plus a natural gas–powered backup generator, WESim allows you to enter up to five different energy sources for a single facility. Note that you will *not* be able to save the facility if data are missing or filled out incorrectly.

Actual energy use may be found on electric and gas bills or meter records. Bills for electricity are usually expressed in kWh or megawatt-hours (MWh), and natural gas is often billed in units of therms. WESim offers you a number of choices of units for entering data. You should use some caution when using a bill from a single month, or meter readings for a day or week, especially if water demand varies seasonally. We suggest collecting a year's worth of bills and entering an annual total.

Some users may not have access to this information. To assist these users, WESim provides default values for a number of water system facilities. To develop default values, we conducted an extensive literature review of energy intensity values for each stage of the water use cycle, e.g., water extraction, water conveyance, water distribution, customer end use, wastewater collection, wastewater treatment, and wastewater discharge. A preliminary analysis of the data revealed significant variability among water and wastewater systems. In many cases, additional information was not available to determine the cause of this variability, e.g., the size of the facility or the various treatment processes employed. Detailed surveys of water and wastewater utilities are needed to develop more robust energy intensity estimates. Such an effort, however, was beyond the scope of this project.

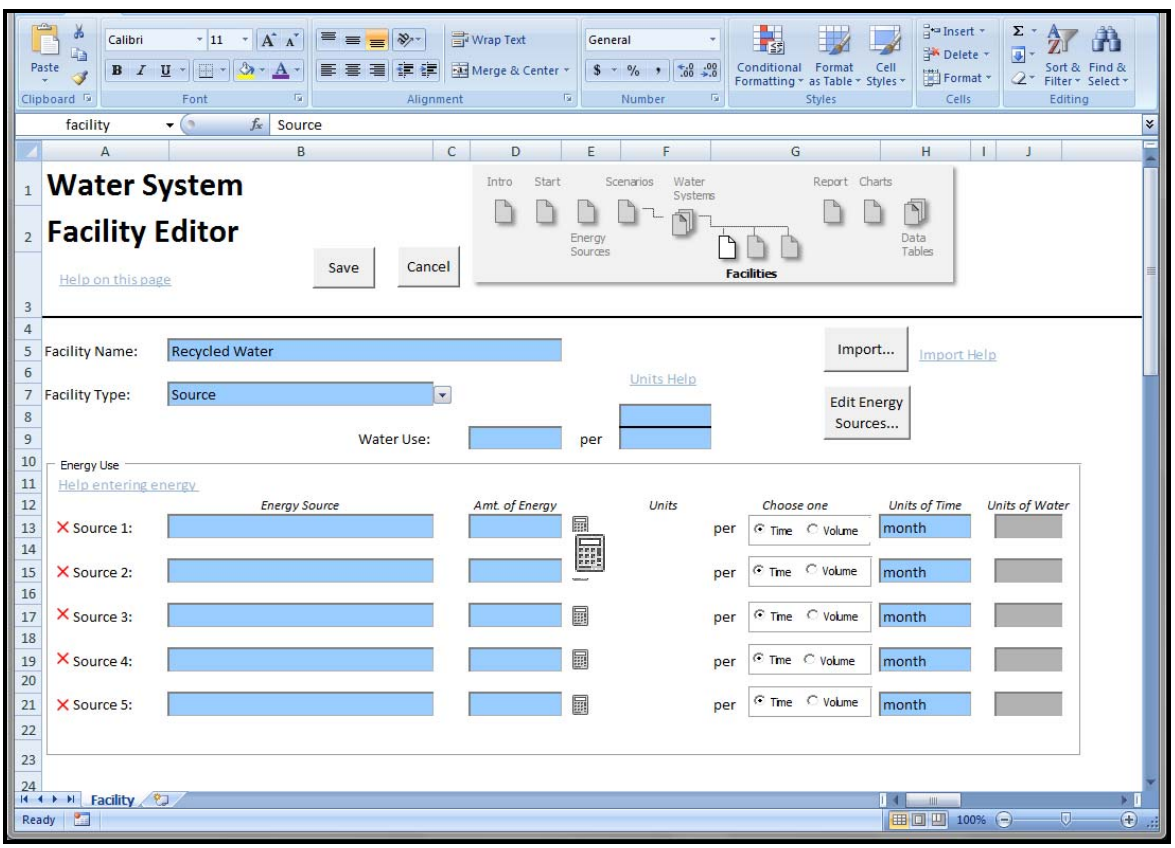

Figure 5.4. Water system facility editor page.

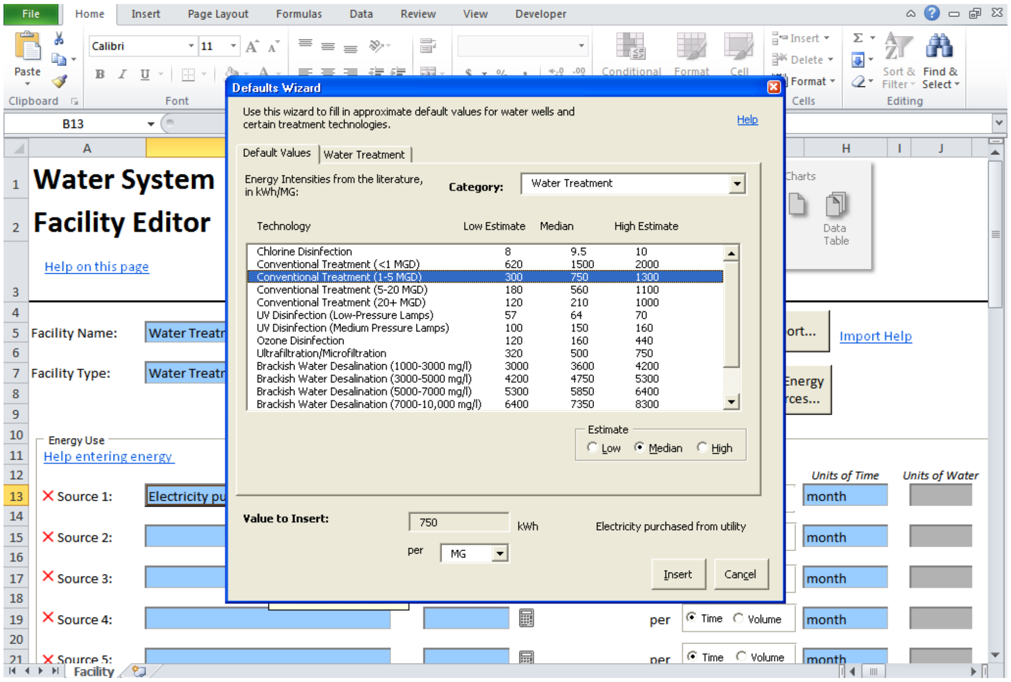

Figure 5.5. WESim default wizard.

During the course of the literature review, we identified a comprehensive study funded by the AWWA Research Foundation (AWWARF), the California Energy Commission, and the New York State Energy Research and Development Authority that was designed to develop an energy index for benchmarking water and wastewater utilities (AWWARF, 2007). Data were gathered from 266 wastewater treatment plants and 125 water utilities, and regression analyses were performed to test the correlation of various system parameters and energy use. These regression equations have been adopted by the U.S. Environmental Protection Agency (EPA) in its benchmarking tool for water and wastewater utilities and have been integrated into WESim.

To provide additional flexibility, WESim allows you to use a default value from the literature or one estimated by entering information into the regression equation to produce a more customized estimate. To look up a default value, click the small calculator button () next to the energy input. A default wizard will appear (Figure 5.5). To access the default values from the literature, choose the Default Values tab. Defaults are organized by the component of the water and wastewater system (e.g., source, treatment, distribution, wastewater collection). Choose a category and then select the appropriate default value. Indicate whether you would like to use the low, median, or high value and click "**Insert**." Great care should be exercised here, as average values from the literature often vary widely. The conscientious modeler should run the simulation several times, using combinations of high and low estimates and observing the impact on the results.

To use the regression equation, select the water system category and click on the tab with the category name. Fill in the required information based on your water/wastewater system. Once you have entered the information, click "**Insert**." The model defaults for each of the water and wastewater system components are described in greater detail in Cooley et al. (2012).

5.5 Energy Source Manager

The Energy Source Manager is where you can enter information on the energy sources that power your system and the associated greenhouse gas emissions factors. Water and wastewater systems may be powered using a variety of energy sources, including electricity purchased from a third party, self-generated electricity, natural gas, and diesel fuel. Even a single facility may be powered by a multitude of sources. For example, a wastewater treatment plant may use biogas recovery to offset some of its electricity use, purchase electricity from a third party, and operate a diesel-powered backup generator.

WESim allows you to enter all of the energy sources that power the water and wastewater system and evaluate how changes in the energy mix affect greenhouse gas emissions. On the Energy Source Manager page, enter every energy source that powers your water and wastewater system (Figure 5.6). This information should include electricity purchased from third parties and fuels used on site to produce electricity, heat, or motive power. For each energy source, identify whether it is natural gas, off-site electricity, on-site electricity, diesel, propane, residual fuel oil, or gasoline.

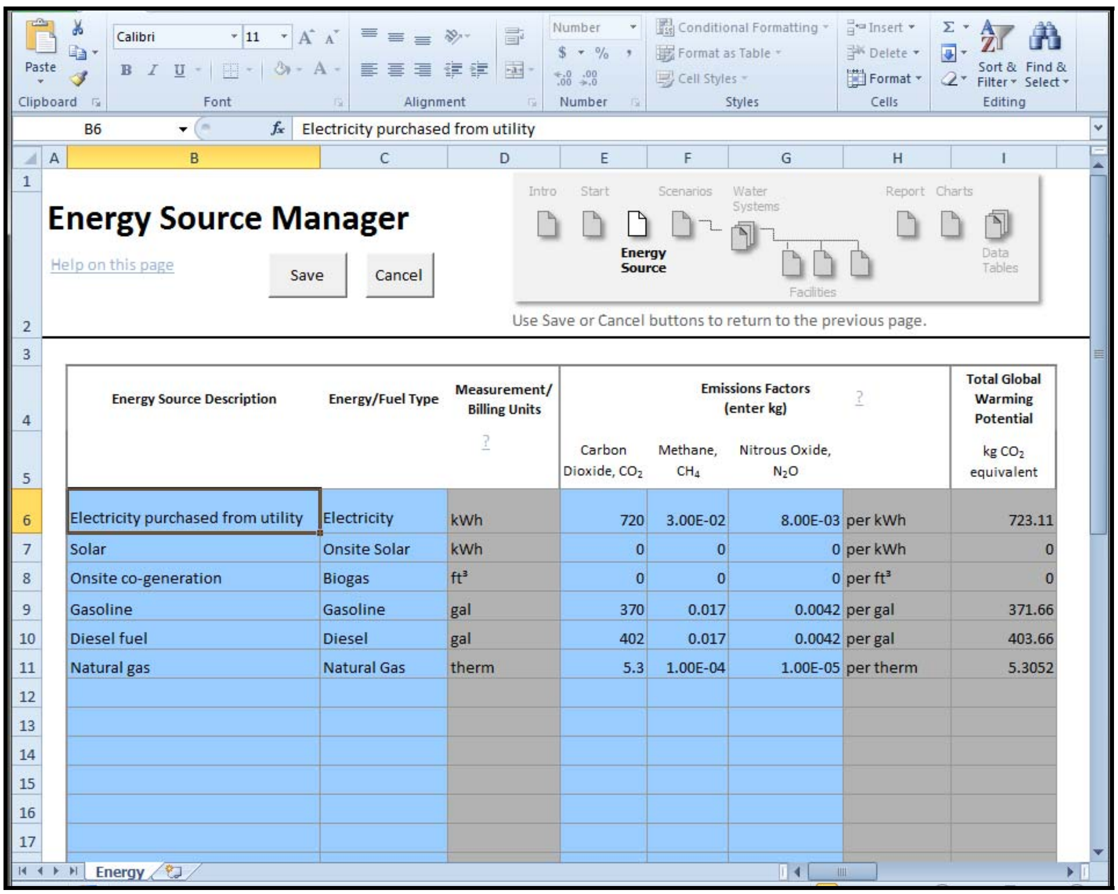

Figure 5.6. Energy source manager page.

Table 5.1. Greenhouse Gas Emissions Factors for Various Fuels and for Electricity

		Emissions Factors (kg/energy unit)		
Fuel Type	**Energy Unit**	**Carbon Dioxide (CO_2)**	**Methane (CH_4)**	**Nitrous Oxide (N_2O)**
Electricity (avg. U.S. grid)	kWh	0.588	1.14×10^{-5}	8.93×10^{-6}
Electricity (avg. Canadian grid)	kWh	0.206	9.00×10^{-6}	4.00×10^{-6}
Solar	kWh	0	0	0
Onsite cogeneration	ft^3 or m^3	0	0	0
Gasoline	gal	8.780	1.40×10^{-3}	1.00×10^{-4}
Gasoline (Canadian metric)	L	2.289	1.2×10^{-4}	1.6×10^{-4}
Diesel fuel	gal	10.21	1.50×10^{-3}	1.00×10^{-4}
Diesel fuel (Canadian metric)	L	2.663	1.33×10^{-4}	4.00×10^{-4}
Natural gas (United States)	therms	5.302	1.00×10^{-4}	1.00×10^{-5}
Natural gas (Canadian metric)	m^3	1.881	3.70×10^{-5}	3.5×10^{-5}

Source: Tables G1, G11, and G19 in CARB (2010); Table A1 in EPA (2008); and Environment Canada (2010a,b).

Notes: Natural gas emissions for Canada were based on average of Canadian provinces (except Northwest Territories) in Environment Canada (2010b). Electricity emission factors are based on average grid in the United States and Canada in 2007 from Table A1 in EPA (2008) and Environment Canada (2010a).

For each energy source, you must also enter its greenhouse gas emission factor**,** which represents the amount of greenhouse gas emissions per unit of fuel or energy consumption. Default greenhouse gas emission factors are provided for some energy sources, including solar, cogeneration, ethanol, natural gas, and diesel fuel (Table 5.1). In some cases, as with electricity and natural gas, there is regional and/or temporal variation in these factors. WESim allows you to enter custom emission factors to account for alternative energy sources and any changes in the emissions factors over time. Enter additional energy sources as appropriate for your system by entering the information as a new line in the table on the Energy Source Manager page.

The default emission factors for electricity are based on the average U.S. grid in 2007 and the average Canadian grid. These values should be used with great caution. The greenhouse gas emissions associated with electricity use are driven by the types of fuels that are used to generate the electricity, which varies regionally and temporally. In addition, as energy utilities alter their fuel mixes to meet renewable portfolio standards and goals, the greenhouse gas emissions factors will change. Therefore, emission factors that are specific to your area, and that correspond for the year for which you are reporting data, should be used whenever possible.

Electricity emissions data can be accessed from a variety of sources. These data are typically either regional or utility-specific values. When possible, utility-specific values should be used since the regional data do not capture local variability in emission factors. Users can contact their local electricity providers to obtain appropriate emission factors. Third-party verified emission factors for electricity providers that are members of the California Climate Action Registry can be found in Table G.6 in California Air Resources Board (2010), at http://www.theclimateregistry.org/downloads/2010/05/2010-05-06-LGO-1.1.pdf.

It is not yet standard for utilities to calculate and verify their emission factors. In the absence of these data, regional electricity emission factors may be needed. These regional estimates can be found at the following:

1. The EPA produces the Emissions and Generation Resource Integrated Database (eGRID), a comprehensive data source for electricity emission factors for 26 subregions across the United States. These data are updated periodically to better reflect changes in emissions from the U.S. electricity grid. The newest version, released in February 2011, provides data for the year 2007. The eGrid data can be found in EPA (2011), at http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2010V1_1_year07_SummaryTables.pdf.

2. For Canada, province-level data are available in Environment Canada (2010a), at http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=EAF0E96A-1#section1.

3. For all other countries, emission factors for electricity production can be found in IEA (2010), at http://www.iea.org/co2highlights/CO2highlights.pdf.

Greenhouse gas emission factors for primary fuels are much less variable than those for electricity. However, in some cases, as with natural gas, there is some regional variation. Additional factors for primary fuels can be found in a variety of locations, including Environment Canada (2010b) and California Air Resources Board (2010).

Chapter 6

Model Outputs

Model outputs include energy use and greenhouse gas emissions for each alternative scenario (Figure 6.1). You can select among a range of units for viewing the outputs. Outputs are provided in tabular and graphical form and can be exported for use in other programs, such as Microsoft® Word, Excel, and PowerPoint, and webpages for use in reports and presentations.

Energy use outputs include both source and site energy. Site energy is the sum of the various energy sources used to power a water or wastewater system. Site energy units typically include kWh of electricity, therms of natural gas, and gallons of liquid fuels. Because these energy uses are reported in different units, it is difficult to compare across scenarios. How, for example, does 5 therms of natural gas compare to 125 kWh of electricity? Furthermore, there are different conversion efficiencies associated with each of the energy sources. Although site energy may not be useful for comparing total energy requirements for alternative scenarios, site energy values can be useful for other analyses. For example, a scenario may result in the use of 125,000 kWh of electricity, 550 therms of natural gas, and 5200 gallons of diesel fuel. These data are provided in tabular form, allowing the user to combine the output with other information, such as current and projected energy prices, to evaluate energy cost trends and sensitivity to changes in energy price over time.

Source energy provides a means to compare scenarios that contain facilities powered by a variety of energy sources. Source energy is the total amount of raw fuel that is consumed to operate the facility (including fuel used to produce electricity off site). Water and wastewater facilities commonly use a combination of energy sources; some of these energy sources (natural gas, diesel, and biogas) are primary energy sources, meaning that the raw fuel is consumed onsite to produce heat or electricity. Electricity, on the other hand, is a secondary energy source because it is the product of a raw fuel burned elsewhere. Because different energy sources are measured in different units and have different efficiency losses associated with them, calculating total system energy use requires converting the diverse energy sources into comparable units. WESim reports source energy in units of British Thermal Units (Btu) and kilojoules (kJ). Because most energy managers are familiar with units of electricity, WESim converts all of the source energy into site energy and reports in units of kilowatt-hour equivalents (kWh_{-eq}) and megawatt-hour equivalents (MWh_{-eq}).

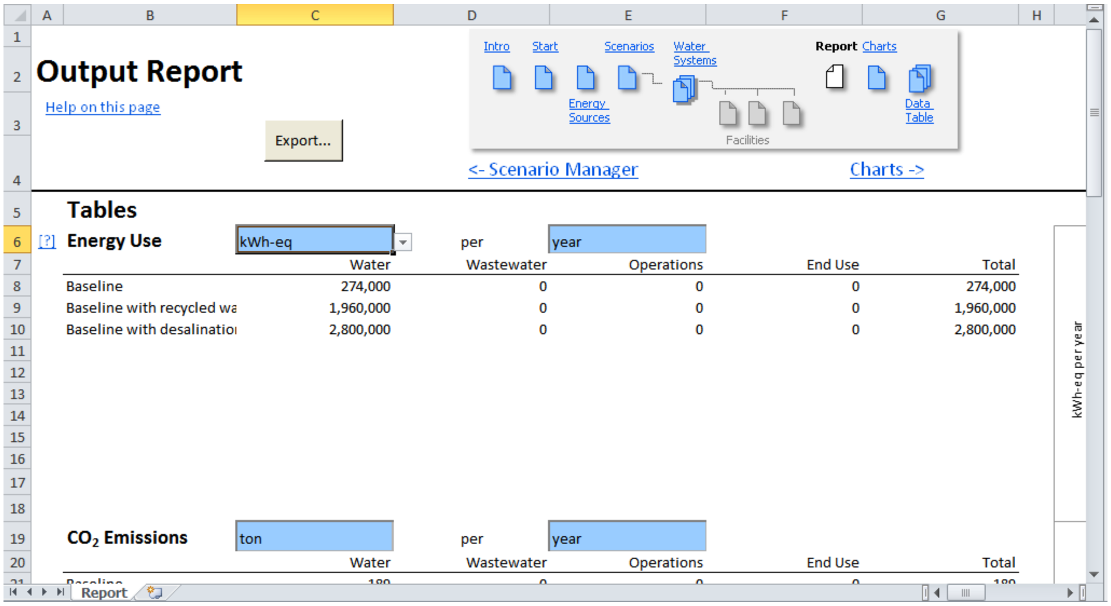

Figure 6.1. Model output page.

For each scenario, WESim reports greenhouse gas emissions for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Each of these greenhouse gases has a different warming potential. To facilitate comparison among scenarios, greenhouse gas emissions are reported in carbon dioxide equivalents ($CO_{2\text{-eq}}$).

Chapter 7

Conclusions

Water managers face increasing challenges and increasing constraints on providing reliable, high-quality water supplies. Rapid population growth, emerging contaminants, rising costs, and climate changes are only some of the challenges. New tools are needed that provide water managers and decision makers with useful information and can facilitate quantification of alternative scenarios for decision support.

The Water–Energy Simulator (WESim) is an easy-to-use analytical tool that allows the user to evaluate the energy and greenhouse gas implications of water management decisions. The tool is suitable for individual water utilities, groups of water utilities, and policymakers and decision makers. The model has been designed to allow the user to input actual operating data for water and energy use, as this will allow an analysis that better reflects operating conditions. Defaults for the energy requirements of various components of the water and wastewater system have also been provided.

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