Threat Ensemble Vulnerability Assessment – Sensor Placement Optimization Tool (TEVA-SPOT) Graphical User Interface User's Manual

Version 2.3.1
September, 2012

U.S. EPA National Homeland Security Research Center (NHSRC)

EPA/600/R-08/147

Disclaimer

This manual contains specific examples for demonstration purposes in order to easily familiarize a user with the TEVA-SPOT Graphical User Interface version of the software.

If the user is not familiar with the various components that comprise a water distribution system and how these are represented in a model, please review the EPANET User's Manual. If the user needs more information about the sensor placement optimization tool (SPOT), please refer to the TEVA-SPOT Toolkit Users Manual, which is included with the TEVA-SPOT software.

The U.S. Environmental Protection Agency through the Office of Research and Development funded, managed, and participated in the research described here under an interagency agreement. The views expressed in this TEVA-SPOT Tutorial are those of the authors and do not necessarily reflect the views or policies of the U.S. EPA. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Work at Argonne National Laboratory was sponsored by the U.S. EPA under an interagency agreement through U.S. Department of Energy Contract DE-AC02-06CH11357.

Portions of TEVA-SPOT software resulted from work under Contract No. DE-AC02-06CH11357 between the U.S. Department of Energy (DOE) and the University of Chicago, Argonne, LLC for the operation of Argonne National Laboratory.

The TEVA-SPOT graphical user interface software must not be redistributed or sold.

Questions or Problems

Questions concerning this document or the TEVA-SPOT software should be addressed to:

Robert Janke
U.S. EPA/NHSRC
Mail Stop NG-16
26 W. Martin Luther King Drive
Cincinnati, OH 45268
(513) 569-7160
janke.robert@epa.gov

Problems with the TEVA-SPOT software can be handled by emailing Robert Janke at the above email address

Added or Changed Features…

- Incorporation of complete EPANET-MSX capabilities…refer to the EPANET-MSX Users Manual for details. This resulted in a number of changes that are not readily visible to the user, such as the significant change to the underlying data storage structure for the EPANET-MSX contaminant concentration data. To run MSX capabilities within TEVA-SPOT, perform the following steps (in this order):
  - Create a new ensemble
  - Load the INP file
  - Load the EPANET-MSX file
  - Specify the contaminant(s) under Injection Definition, specify SINGLE or MULTIPLE contaminants.
  - For SINGLE contaminant, choose particular species from drop down box and then enter data as before, i.e., NAME, SPECIES, START and STOP times.
  - For MULTIPLE contaminants, Add MASS INJECTION RATE, CONCENTRATION ZERO THRESHOLD and WATER QUALITY TOLERANCE values for each available contaminant under the "SPECIES" drop down box.
  - Available "SPECIES" are determined by what is designated under [SPECIES] in the .MSX file.
  - Proceed as before….
- Node set definitions, ability to specify ensemble of contamination scenarios using a random number generator process.
- Output file(s) (C:\TEVA-SPOT-Database\COLLECTION NAME\ENSEMBLE NAME\Health Impacts Analysis) that details number of nodes with population that received a dose at or above the specified dose levels.
- Infrastructure Impacts Analysis (IIA) module. Output file(s) in (C:\TEVA-SPOT-Database\COLLECTION NAME\ENSEMBLE NAME\Infrastructure Impacts Analysis). Tab delineated text file provides total number of pipe feet contaminated (based on witnessing contamination) at or above each specified concentration (e.g., mg/L) indicated.
- Ability to run Health Impacts Analysis without dose response functionality.
- User defined model for the timing of tap water ingestion. 0 (12:00 AM) to hour 24.
- Addition of the specification of the "Number of worst case dosage scenarios able to be saved". Present in the Health Impacts Analysis module, allows the user the ability to analyze detailed concentration data for a small number of scenarios based on dose levels.

THINGS TO BE CAREFUL ABOUT OR AWARE OF….

Flow Units

All flow units within an EPANET *inp* file are converted to gallons per minute. For example, cubic meters per hour flow rate units are converted in TEVA-SPOT to gallons per minute. If the VC impact measure is in units of gallons, there are 264 gallons per cubic meter, so results will appear quite high if believed to be cubic meters.

Running simulations with very small dose levels…

With small and very small injection amounts, there are many nodes with very small concentrations which turn into very small doses, which then get accounted for in the small dose thresholds which can result large errors. This can be overcome or reduced by specifying a value in "Concentration Zero Threshold mg/L" box of "Injection Definition" that is 1E-6 or greater.

Using the "Zero Concentration Threshold" in Injection Definition…

The "Concentration Zero Threshold" is applied at each water quality time step, not at the reporting interval. The difference being that if your water quality time step is less than the reporting interval, the time-weighted average concentration could be smaller than the zero threshold value! For example, if only one of the water quality (WQ) steps had a concentration equal to the zero threshold and all other WQ steps in the hour were either 0 or below the threshold.

VISUAL C for MSX Analyses

MSX-based analyses run much slower than standard (tracer or first order decay) simulations in EPANET. Using a Visual C compiler can help reduce runtimes. "VC" is specified in the .MSX file for COMPILER.

For 32 bit computers, the visual studio express can be downloaded from the web for free, but for 64 bit computers the only option is to buy the visual C program, i.e., M.S. visual studio.net. When installing TEVA-SPOT GUI on a computer that is 64 bit, the only option is to have the full version of visual studio otherwise the software will assume that no VC compiler is available and the resulting simulations will run much, much slower.

Removing ensembles that were deleted from showing up in the TEVA-SPOT "Load Ensemble" Window

In order to remove the ensembles that you deleted from showing up in TEVA-SPOT, for instance when you try to load an ensemble, please follow these steps:

Open TEVA-SPOT and choose "Ensemble Management". You may need to browse to the appropriate collection.

1. Identify all the ensembles that were deleted or will no longer load. Write down their names.
2. Close TEVA-SPOT
3. Open Windows Explorer or a MY COMPUTER window and browse to the TEVA-SPOT collection within the TEVA-SPOT-Database where the ensembles were located.
4. Create a blank folder in the directory or the TEVA-SPOT collection where the ensemble was located for each of these ensembles that you want removed. Be sure to name each folder exactly as it appears under "Ensemble Management". We are re-creating a folder in order to give TEVA-SPOT something to delete.
5. Open TEVA-SPOT, choose "Ensemble Management" again and select or highlight those ensembles that you had previously deleted through Windows Explorer. Once selected, choose DELETE.
6. The ensembles should now be removed.

Forward

Since its inception in 1970, EPA's mission has been to pursue a cleaner, healthier environment for the American people. The Agency was assigned the daunting task of repairing the damage already done to the natural environment and establishing new criteria to guide Americans in making a cleaner environment a reality. Since 1970, the EPA has worked with federal, state, tribal, and local partners to advance its mission to protect human health and the environment. In order to carry out its mission, EPA employs and collaborates with some of the nation's best scientific minds. EPA prides itself in applying sound science and state-of-the-art techniques and methods to develop and test innovations that will protect both human health and the environment.

Under existing laws and recent Homeland Security Presidential Directives, EPA has been called upon to play a vital role in helping to secure the nation against foreign and domestic enemies. The National Homeland Security Research Center (NHSRC) was formed in 2002 to conduct research in support of EPA's role in homeland security. NHSRC research efforts focus on five areas: water infrastructure protection, threat and consequence assessment, decontamination and consequence management, response capability enhancement, and homeland security technology testing and evaluation. EPA is the lead federal agency for drinking water and wastewater systems and the NHSRC is working to reduce system vulnerabilities, prevent and prepare for terrorist attacks, minimize public health impacts and infrastructure damage, and enhance recovery. This Users Manual for the TEVA-SPOT GUI software is published and made available by EPA's Office of Research and Development to assist the water utility community.

Jonathan Herrmann, Director
National Homeland Security Research Center
Office of Research and Development
U. S. Environmental Protection Agency

License Notice

The U.S. Government is granted for itself and others acting on its behalf a paid-up, non-exclusive, irrevocable worldwide license in the binary software libraries associated with TEVA-SPOT to reproduce, prepare derivative works, and perform publicly and display publicly, including the right to distribute to other Government contractors.

The binary software libraries may be distributed, provided that they are only distributed as part, and remain a part of the TEVA-SPOT software. Argonne has agreed that all users of TEVA-SPOT and derivative systems have a perpetual, royalty-free license to use and distribute for free JeoViewer, DIAS, and MSV Java Utility Library binary software as part of TEVA-SPOT. However, the source code is not provided as part of this licensing agreement. The existing executables for JeoViewer, DIAS, and MSV Java Utility Library, as well as any improvements and modifications to these systems, are and will be freely available to the EPA and the users of TEVA-SPOT as part of this effort.

Portions of TEVA-SPOT are being distributed under the Lesser GNU Public License (LGPL). The LGPL is described in the LICENSE.lgpl file included with the software. TEVA-SPOT includes a variety of other software packages with different licenses. The use of this software should be for research purposes, there are restrictions on commercial usages in some cases:

- EPANET: Lesser GNU Public License
- tevaUtils: Lesser GNU Public License
- grasp: AT&T commercial license
- randomsample, sideconstraints - ATT Software for noncommercial use.
- ufl - Common Public License

Acknowledgements

The National Homeland Security Research Center would like to acknowledge the following organizations and individuals for their support in the development of the TEVA-SPOT User's Manual and in the development and testing of the TEVA-SPOT Software.

Office of Research and Development - National Homeland Security Research Center
Robert Janke
Regan Murray
Terra Baranowski-Haxton

Argonne National Laboratory
Thomas Taxon

Science Applications International Corporation
Rakesh Bahadur
William Samuels

Sandia National Laboratories
Jonathan Berry
Erik Boman
William Hart
Lee Ann Riesen
Cynthia Phillips
Jean-Paul Watson

University of Cincinnati
James Uber

American Water Works Association Utility Users Group
Kevin Morley (AWWA)

Table of Contents

List of Figures

List of Tables

1. Introduction

Threat Ensemble Vulnerability Assessment – Sensor Placement Optimization Tool (TEVA-SPOT) allows users to define a water network contamination "scenario," simulate the spread of the contaminant or contaminants throughout the water network, analyze the consequences, and display the results in a variety of graphical and tabular forms. The ultimate aim of a simulation and its subsequent analysis is to determine the vulnerability of the distribution system to contaminant releases and determine the optimal locations to place a set of water quality sensors in the network to mitigate the impacts of contamination. This Users Manual helps to familiarize users with the TEVA-SPOT Graphical User Interface (GUI) functionality. TEVA-SPOT assumes ones familiarity and use with EPANET. Users should first be sure their network model runs in EPANET prior to running the model in TEVA-SPOT.

1.1. Data Structure Concepts

The TEVA-SPOT user typically creates an ensemble of contaminant release locations in a water network, simulates contaminant release(s), performs various ensemble analyses on the results, and then displays the results. The goal of these steps is to determine and characterize certain effects of the contaminant release, given its inherent uncertainties. For example, without knowing precisely which nodes represent potential contaminant release locations, one can determine average and worst case exposures, doses, infections, and estimated fatalities on a collection of all possible release locations. This section defines and discusses the principal data structures. These objects are hierarchically organized as shown in Figure 1.

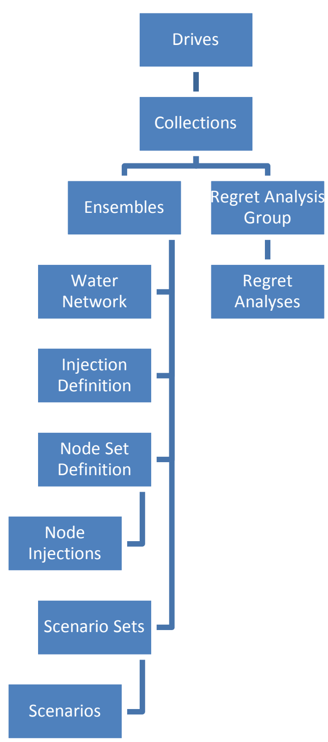


Figure 1. Data Flow Chart of TEVA-SPOT

The user must assign a name to each ensemble, injection definition, node set definition, collection, regret analysis group, and regret analysis when it is created, and may assign a name to each scenario set. Node injections and scenarios do not have user-assigned names but can be considered to have a two-part name consisting of those of the injection definition and node set definition on which they are based.

Two modes of operation exist for TEVA-SPOT: (1) ensemble analysis mode and (2) regret analysis mode. Ensemble analysis mode is found on starting TEVA-SPOT. Ensemble analysis mode is where contaminant vulnerability analyses and sensor network designs are performed. Regret analysis mode is where sensor network designs can be further evaluated.

Regret analysis is a trade-off analysis that determines how well a particular sensor design meets an objective(s) other than the one they were intended to achieve. Regret analysis uses the impact files and sensor designs generated by TEVA-SPOT and designated by the user in order to create or edit regret analysis parameters.

1.2. Installation

The distribution executable (.exe file) contains the TEVA-SPOT program and Users Manual. The prerequisite software can be obtained from the FTP site below or from the internet by searching for the required items below. Prerequisite software includes the Java Development Kit (JDK) Version 1.6 update 20 and the Python Scripting Language, version 2.6 or later. The JDK and Python products need to be installed first prior to the installation of TEVA-SPOT. The JDK and Python versions installed need to be consistent with the computer's capabilities. In other words, use the 64 bit versions of JAVA and Python if hardware and software on the host computer is 64 bit compatible. TEVA-SPOT has been tested on Windows XP and Windows 7, not Windows Vista. Below are the JDK and Python installers needed depending on the computer hardware and operating system that TEVA-SPOT will be installed on:

- jdk-6u20-windows-586.exe (32 bit version)
- jdk-6u20-windows-x64.exe (64 bit version)
- python-2.6.5.msi (32 bit version)
- python-2.6.5amd64.msi (64 bit version)

After the prerequisites of JAVA and Python are installed, the TEVA-SPOT system is installed and configured to the c:\Program Files\TEVA-SPOT folder. Output files generated by TEVA-SPOT are stored in c:\TEVA-SPOT-Database. During installation the drive location can be changed if desired, e.g., D:\Program Files\TEVA-SPOT.

Updates to TEVA-SPOT can be installed by downloading the update from the EPA TEVA Research Program website (http://www.epa.gov/nhsrc/water/teva.html). TEVA-SPOT can also be obtained from the following File Transfer Protocol (ftp) website: ftp://scienceftp.epa.gov/ and entering the appropriate login and password information which can be obtained via email from janke.robert@epa.gov. All users who request TEVA-SPOT will be automatically placed on an email list for notification of updates!

Each TEVA-SPOT installation (.exe) file is tagged with a date of release, e.g., TEVA-SPOTInstaller-2.3.1-MSX Beta 201100926.exe, signifying a release date of September 26, 2012 (last number in the file name). The initial two numbers in the file name describe the version number, i.e., 2.3.1, refers to the major release number (2) and the minor release number (3) and are consistent with the version numbering for the TEVA-SPOT toolkit. The final number in the file name that describes the version number, i.e., 1, designates a sub-minor release which is specific to TEVA-SPOT graphical user interface.

Older versions of TEVA-SPOT should be removed first using the following procedure before installing the updated version:

- Choose STOP TEVA-SPOT Services from START Programs/TEVA-SPOT
- Move the “contaminants.xml file” from the “client” folder under Program Files/TEVA-SPOT/client to suitable location. During installation of a TEVA-SPOT update the contaminants.xml file is replaced with a blank version. After installation replace the blank contaminants.xml file with the saved contaminants.xml file.
- Choose Uninstall TEVA-SPOT from START Programs/TEVA-SPOT
- Navigate to Programs/TEVA-SPOT and Remove the TEVA-SPOT folder and its contents.
- Install the TEVA-SPOT update by double-clicking on the TEVA-SPOT executable icon.

Updates are installed without lost of older ensemble data residing in the TEVA-SPOT-Database folder.

2. Getting Started with TEVA-SPOT

This section provides a quick overview of TEVA-SPOT, including input parameters, management of ensembles and collections, and starting and executing TEVA-SPOT. It is important to understand that running TEVA-SPOT initiates TEVA-SPOT services that work independently of the graphical user interface (GUI) client. In other words, closing TEVA-SPOT after an ensemble or regret analysis has started will not stop the simulations or analyses. Choosing “Terminate” will stop the TEVA-SPOT services but it may take some time to complete depending on the EPANET model and the option running at the time “Terminate” is selected. Choosing “Stop TEVA-SPOT Services” or “Restart TEVA-SPOT Services” will stop TEVA-SPOT simulations and analyses immediately.

Therefore, if it is desired to stop TEVA-SPOT quickly in order, for example, to change input parameters, select “Restart TEVA-SPOT Services,” from the START Menu, then close the TEVA-SPOT client, and then reopen TEVA-SPOT and load the appropriate ensemble and continue as needed.

If you are experiencing problems it usually helps to initiate the Restart TEVA-SPOT Services, close down TEVA-SPOT, and then restart TEVA-SPOT after the Restart TEVA-SPOT Services has completed.

2.1. Tutorial Example

Table 1. Example Input Parameters for TEVA-SPOT Ensemble Mode

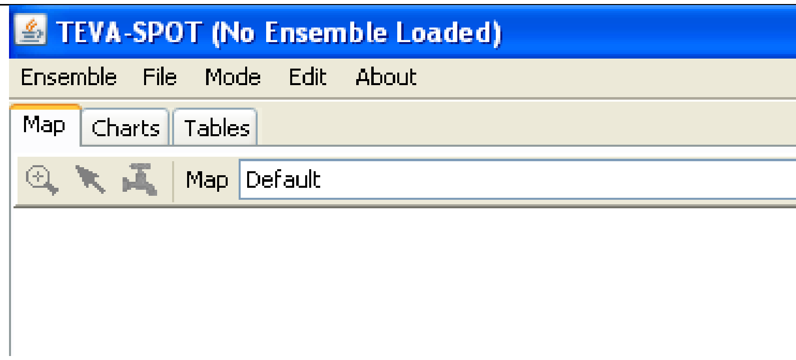
	Input Parameter	**Parameter Value**
EPANET Simulations	Simulation Time	24 hour
	Scenarios (Set of release nodes)	All non-zero demand nodes
	Time of Release (Duration)	1 hr
	Population Estimate	Demand Based
	Mass Injection Rate (mg/min)	1.74E+04 mg/min (The Mass Injection Rate is always in mg/min)
Health Impact Analysis	Contaminant	Enter contaminant data
TSO to Impacts Analysis	User designates: Response Time Delay, Detection Limit Base filename and then selects which impact metrics are desired.	Response time delay: minutes Detection limit: mg/L of chemical or toxin or organisms, cells, or user specified "units" per liter.
Infrastructure Impacts Analysis	Contaminant name Concentration thresholds	Concentration units: mg/L of chemical or toxin or organisms, cells, or user specified "units" per liter.
Sensor Placement	Exposure Model (Water ingestion)	Demand Based
	Sensor Set Sizes	1, 5, 10, 15, 20, 25
	Response Delay Times	0, 360, 720 minutes
	Detection Limits	0, 0.01, 1 milligrams per liter
	Sensor Placement Algorithm	Heuristic
	Sensor Placement Objective/Statistic	Population Exposed, Mean, or another metric

Table 1 shows input parameters to run TEVA-SPOT in Ensemble Mode. Remember TEVA-SPOT is based on running an extended period simulation based on the introduction of a contaminant. <u>Therefore, QUALITY must be set to CHEMICAL in the EPANET input (*.inp) file.</u>

2.2. *Starting TEVA-SPOT*

The TEVA-SPOT simulation can start by going to the Start Menu and clicking “All Programs,” and navigating to TEVA-SPOT

This will open the TEVA-SPOT frame as shown.

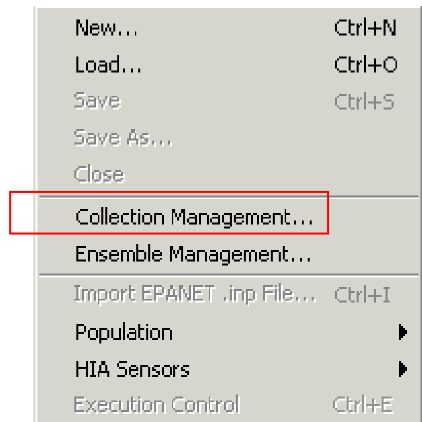


2.3. *Collection*

The first step is to define the **Collection Management**.

Navigate to **Collection Management** under the **Ensemble Menu**. This will open a **Collection Management** window.

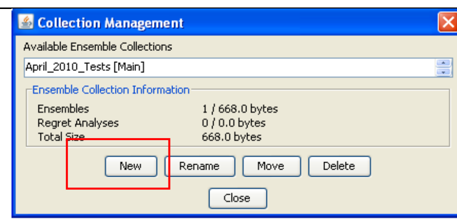
At this stage there are no names in the window.



Create a new Collection by choosing the **New** button.

This will open **New Ensemble Collection** window. The **OK** button is initially disabled (grayed out), whereas the **Cancel** button is always enabled.

(On some computers, the window “New Ensemble Collection” may not completely open because of screen resolution. In this case, drag the window until the OK button is visible). The window can be resized in both the horizontal and vertical directions.



Click the **Ensemble Name** text box and type the name DEMO for the new ensemble.

Caution: Avoid entering a name that contains embedded blanks, e.g., “SmallTown” is okay, but “Small Town” is not.

The **OK** button becomes enabled. Click the **OK** button.

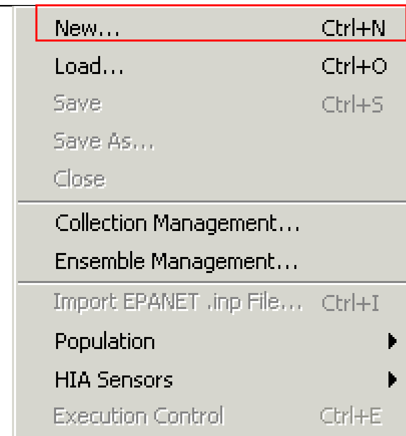
Close the Collection Management window. The screen will still read “No Ensemble Loaded.”

2.4. Ensemble

The next step is to create a New Ensemble.

In the **Ensemble** Menu, click **New**.

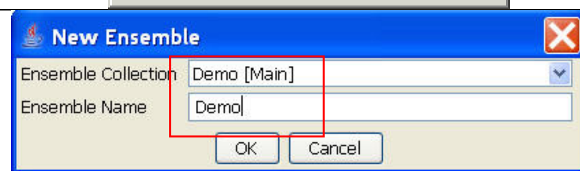
The **New Ensemble** dialogue box opens.



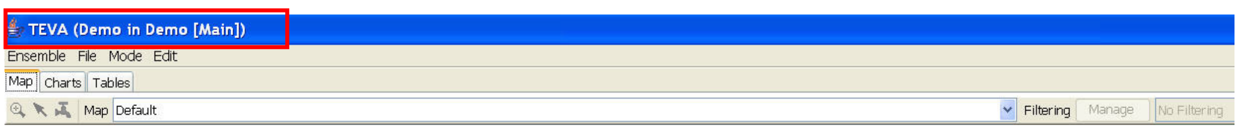
From the **Ensemble Collection** pull-down menu, select Demo [Main].

Click the **Ensemble Name** text box and type the name Demo. This is the name of the Ensemble.

Click the **OK** button. The dialogue box closes.



At the top of the screen, it will show TEVA-SPOT (Demo in Demo [Main]).



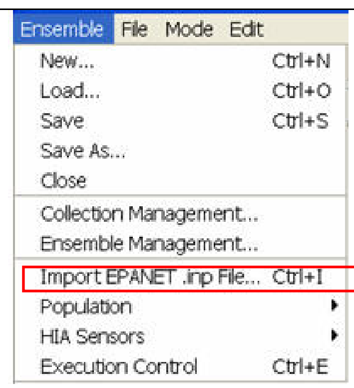
2.5. Import EPANET Input File

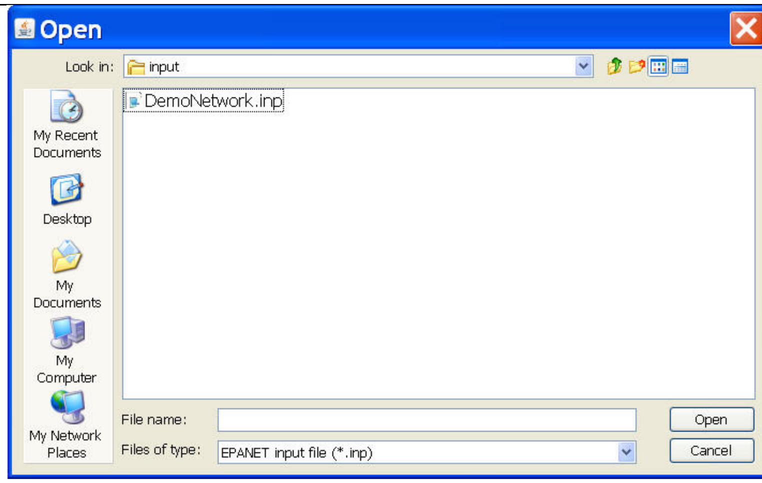
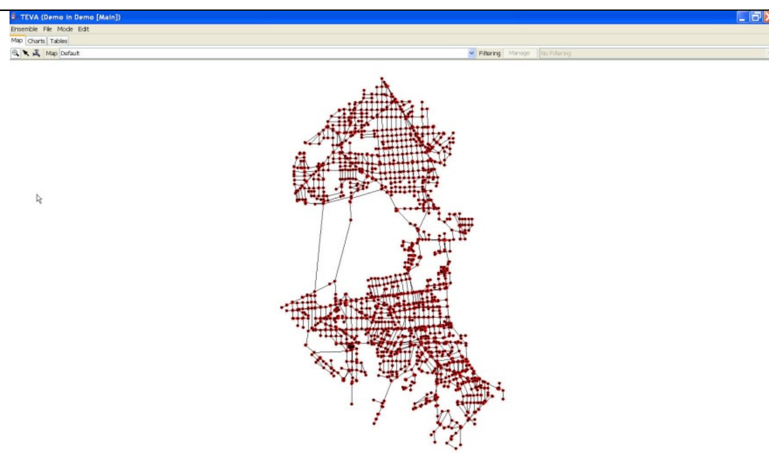
In the **Ensemble Menu**, click **Import EPANET.inp File**.

Note: **Import EPANET.inp File** is only available as an option when an ensemble is loaded. EPANET *.net* files are not supported by TEVA-SPOT.

An **Open** dialogue box opens to select the EPANET input file.

The imported EPANET .inp file MUST have QUALTIY set to CHEMICAL and all SOURCES removed. If SOURCES are present TEVA-SPOT will remove them with a notification to the user.



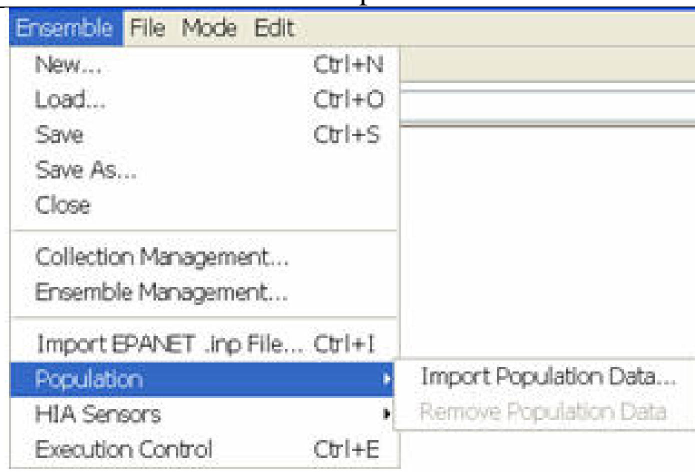
Browse to the directory where your network model is located (where the EPANET input file is located). Click the icon for your network, similar to the DemoNetwork.inp at right. Choosing the *.inp file places the name of the file into **File name:** text box. Click the **Open** button to import your network. For demonstration purposes the following, DemoNetwork.inp file is used.	
The dialog box closes, and the desired water network is imported as shown.	

2.6. Population

The Population command is always enabled (never grayed out), although when no ensemble is loaded into memory, all the subcommands of the Population submenu are disabled (grayed out).

Click **Population** in the **Ensemble** menu to display the **Population** submenu.

Click **Import Population Data…** in the **Population** sub menu. An **Open** dialogue box opens.



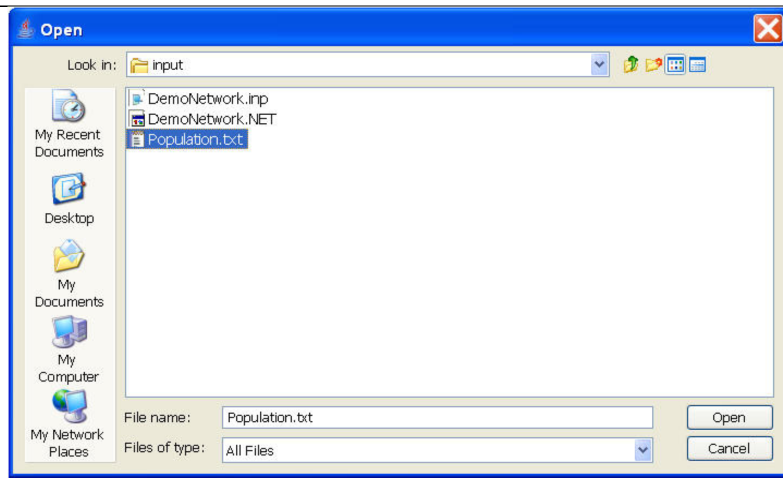
Navigate to the directory containing the population data file to be imported.

Select your population data file (e.g., Population.txt).

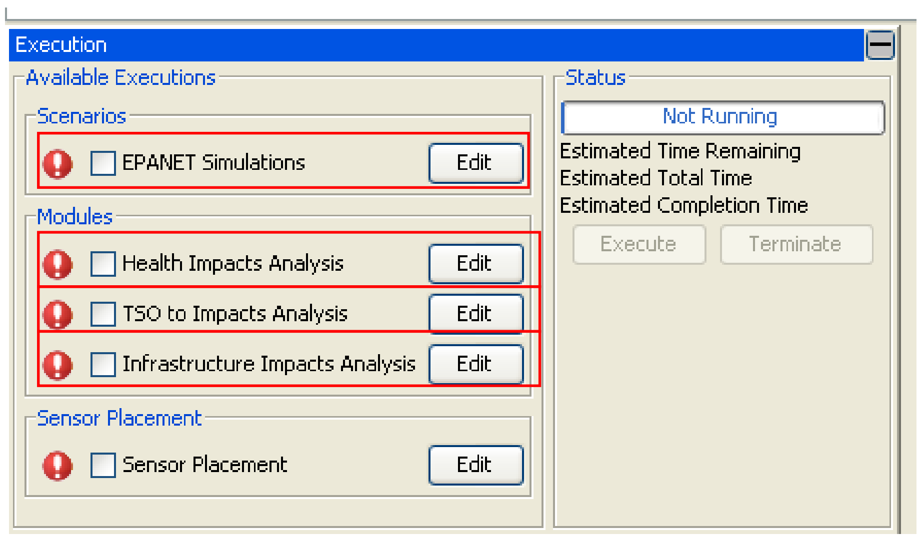
Choosing this file places the name of the file into **File name:** text box.

Click the **Open** button to import the selected population data.

Note: The procedure to create the Population.txt file is discussed in Appendix A. Also note that if using a demand-based population model no imported population file is needed.



TEVA-SPOT contains two types of population models: Demand and Census. Census refers to the user specifying the number people at each non-zero demand node and loading the associated data into TEVA-SPOT via a text file.

2.7. Execution Control Click **Execution Control** in the **Ensemble** menu.	
The **Execution** Panel is added. Note the TEVA-SPOT modules: EPANET simulations Health Impacts Analysis (HIA) TSO-to-Impacts Analysis Infrastructure Impacts Analysis Sensor Placement The TSO-to-Impacts Analysis is the stand-alone application. A separate TSO-to-Impacts Analysis occurs as the initial step in Sensor Placement.	

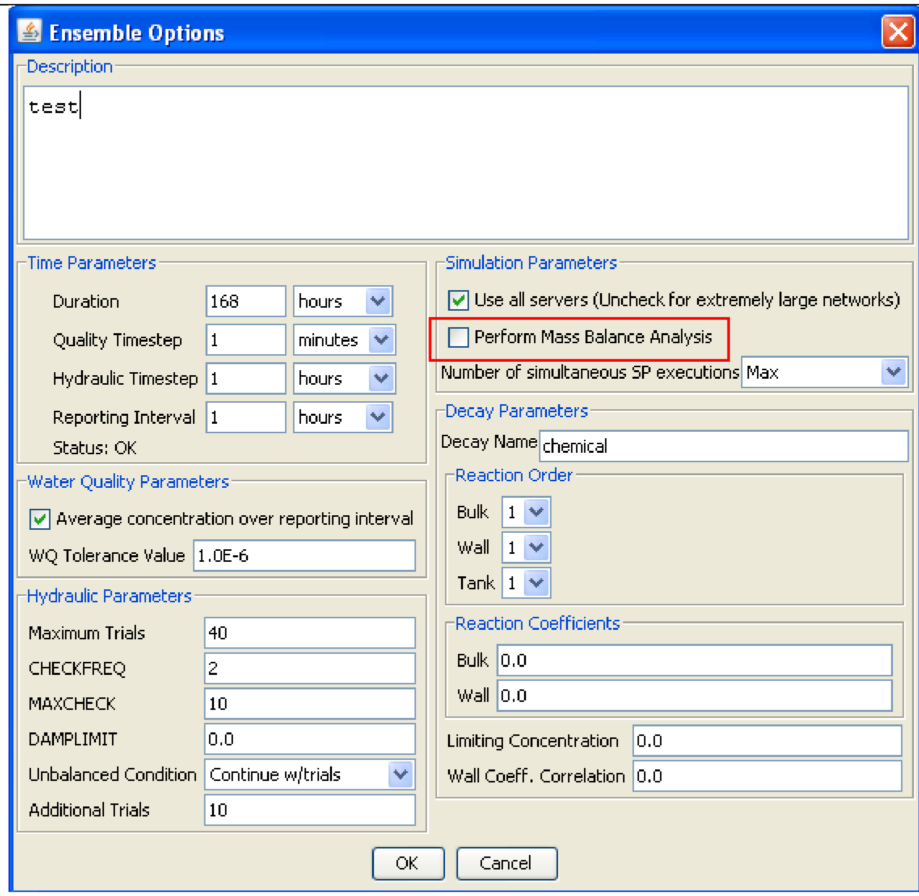
2.8. Ensemble Options

Click **Ensemble Options** in the **Edit** menu.

The **Ensemble Options** box allows users the ability to modify key EPANET parameters associated with: **Time**, **Water Quality**, **Hydraulic**, **Simulation**, and **Decay**.

The **Description** text box can be used to record pertinent information about the ensemble (e.g., reasons for the ensemble, network model information and dates, essentially anything that would explain or document the results for future use).

Under **Simulation Parameters**, the **Use all servers** is checked as a default. Uncheck this if a large network (>>13,000 nodes) is being used. This will result in only one processor being used for EPANET and HIA (if run together or only EPANET if run alone) and TSO-2-Impacts analyses if



NOTE: Choosing PERFORM MASS BALANCE ANALYSIS will increase run times!!

Mass tracking data for each simulation or scenario will appear in two text files (.txt) within the TEVA-SPOT-Database with the file names: (1) massData.txt and (2) massDataWithCalc.txt.*

***massData.txt** file provides for each scenario: mass injected, mass removed, mass in tanks, and mass in pipes for each time step of the simulation.*

***massDataWithCalc.txt** provides for each scenario the same data but with additional calculations as follows: Mass Injected (I), Mass Removed (R), Mass In Tanks (T), Mass In Pipes (P), Mass In Pipes (I-R-T), Mass In Network (I-R), and Mass In Network (T+P)*

Each of these text files will have the ensemble name as a prefix to the name of the text file.

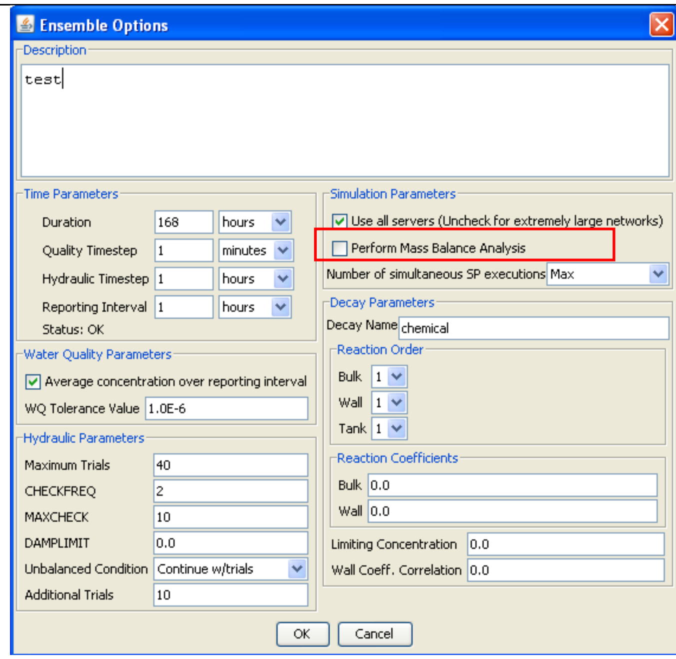
the stand-alone application is used.

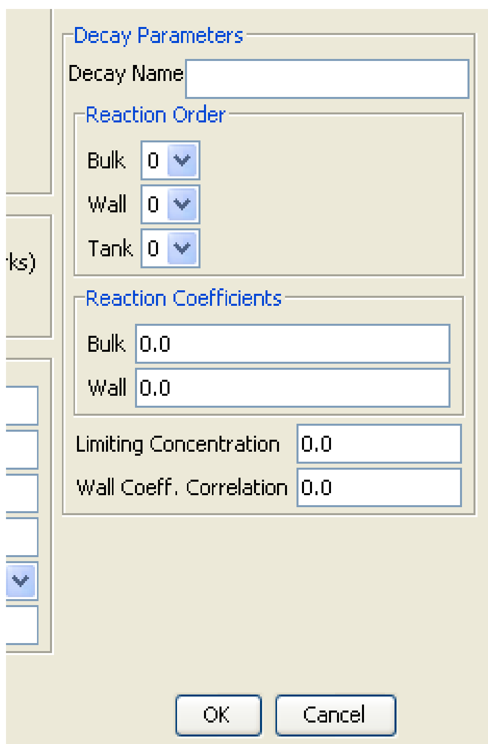
Perform Mass Balance should be unchecked and used only by the more experienced user. This function provides for each scenario contaminant mass tracking results in terms of mass injected, removed, mass in pipes and mass in tanks. The resulting text files appear within the TEVA-SPOT-Database/Ensemble Name/BaseEnsemble directory.

The **Time**, **Hydraulic**, and **Decay Parameters** are consistent with EPANET 2.00.12. For more information, please see the EPANET Users Manual.

Under **Decay Parameters**, the **Decay Name** specifies the name of the contaminant that is being studied.

Under **Water Quality Parameters**, **Water Quality (WQ) Tolerance** specifies the water quality tolerance used

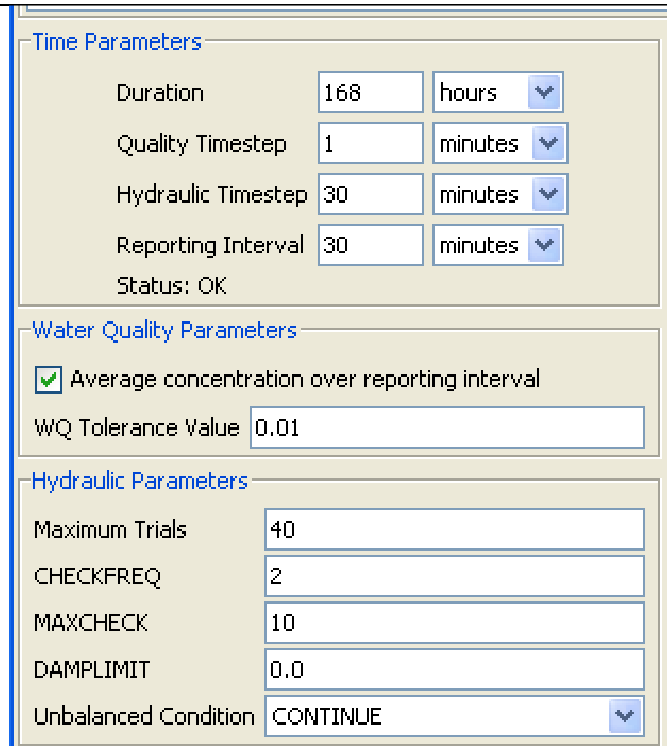




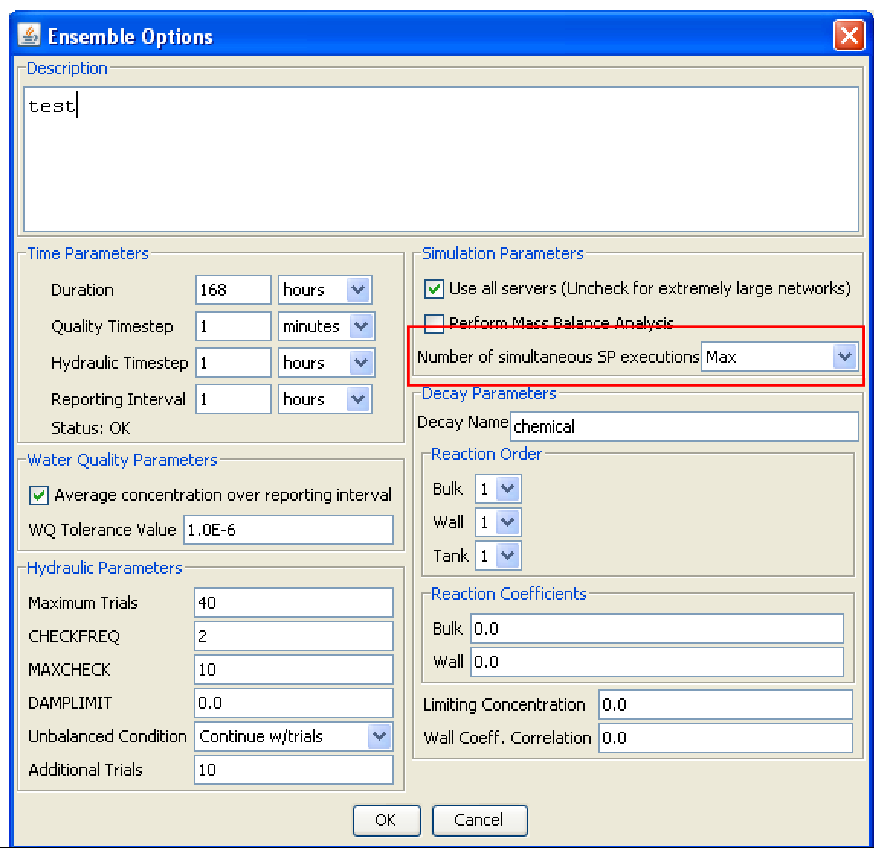
Note: If Reaction Order and Coefficients are used the results of contaminant decay will be seen in the Health Impact results, both baseline (no sensors case) and sensor design cases.

in the water quality simulation. This value will be overridden by any values specified under an **Ensemble Injection Definition**

Note the check box for **Number of simultaneous SP executions**. SP refers to sensor placement. Various options (Max, 1, 2, etc.) will be available in the drop down box depending on the computer hardware and memory resources available on the host computer. The options provide the ability to minimize the parallel processing of sensor network designs to conserve RAM memory. If the model is large (i.e., greater than 10,000 nodes) and the number of feasible sensor locations is also large (i.e., greater than 10,000), the user may need to set this to something other than "Max," in order for the sensor designs to be completed.



For more information on **Water Quality Tolerance** parameter please refer to the EPANET Users Manual.



3. Ensemble Analysis Mode

This section describes how to use the execution controls in the ensemble analysis mode. Figure 2 shows the hierarchy of the EPANET Simulations.

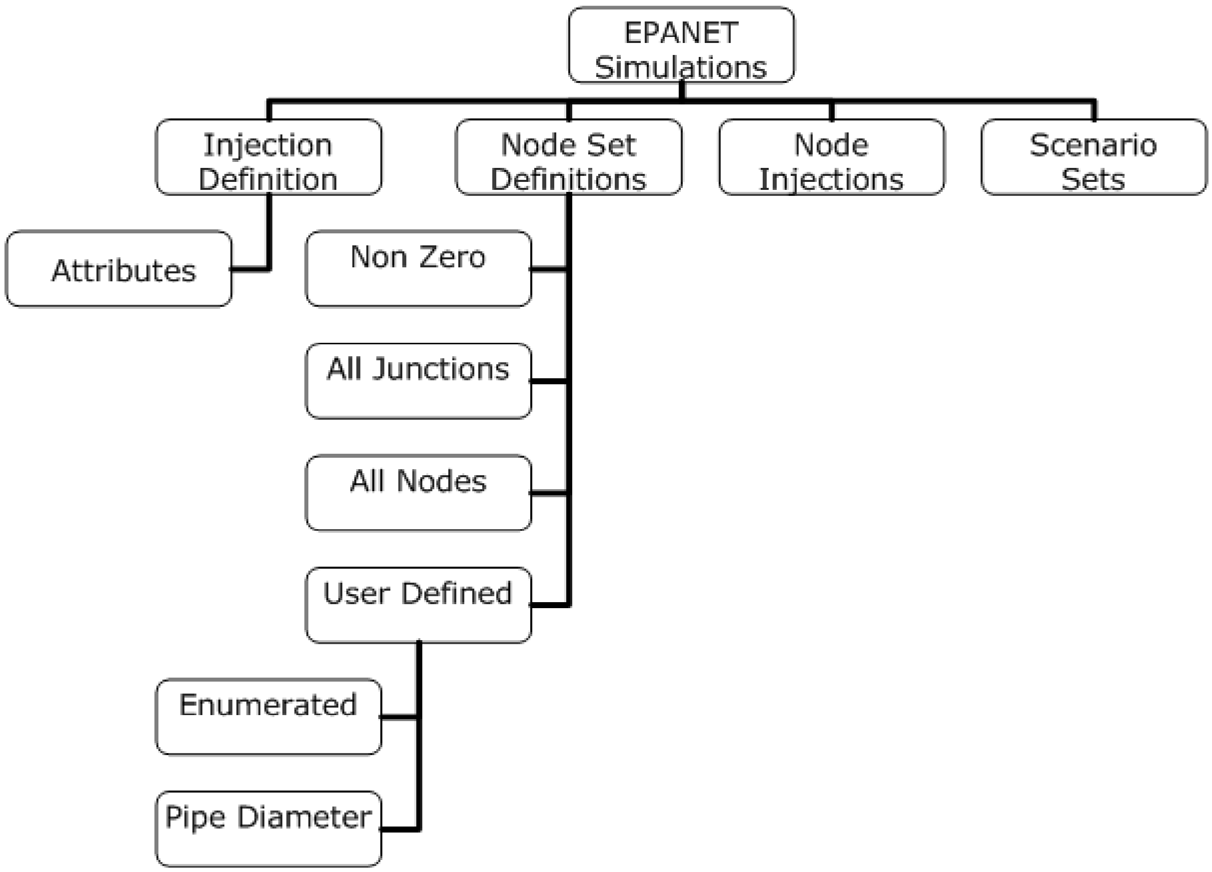
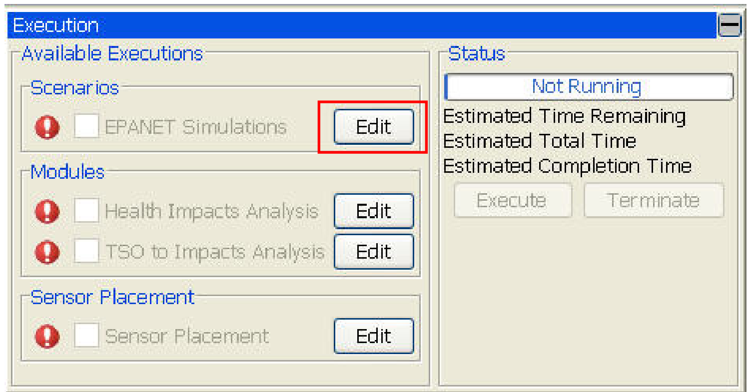


Figure 2. Flow Chart for EPANET Simulations

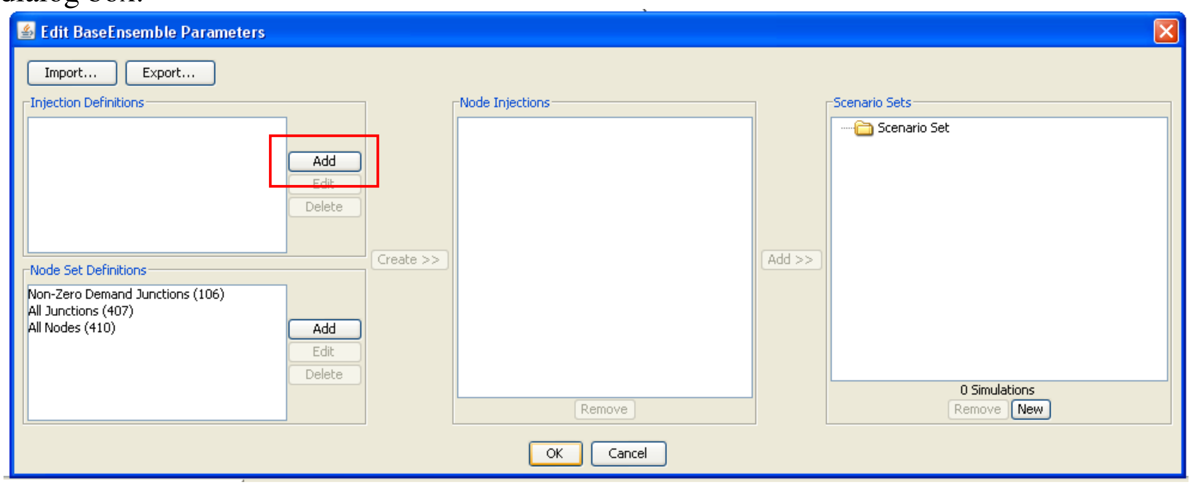
3.1. Injection Definitions

In the **Execution** panel, click the **Edit** button to the right of the **EPANET Simulations** check box.

This will open the **EPANET Simulations Parameters** dialog box. **EPANET Simulations** will be grayed out until information has been added.



Click the **Add** button in the **Injection Definitions** panel of the **Edit BaseEnsemble Parameters** dialog box.

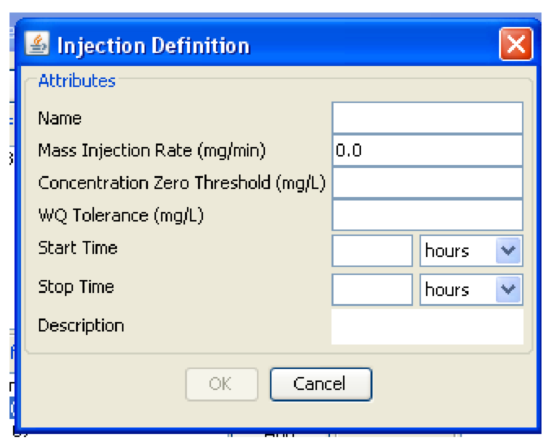


The **Injection Definition** dialog box opens.

Type in the required information specified in the **Injection Definition** window.

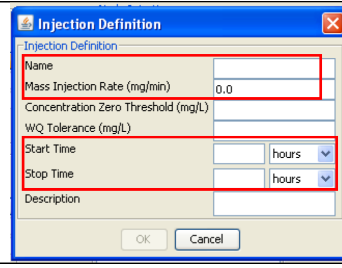
Inserting a **WQ Tolerance (mg/L)** value will override the WQ Tolerance specified in the EDIT/ Ensemble Options box; however no value need be specified.

Inserting a value (e.g., 0.000001) into the **Concentration Zero Threshold (mg/L)** box will result in zero values for all contaminant concentrations below the indicated value. No value need be specified.

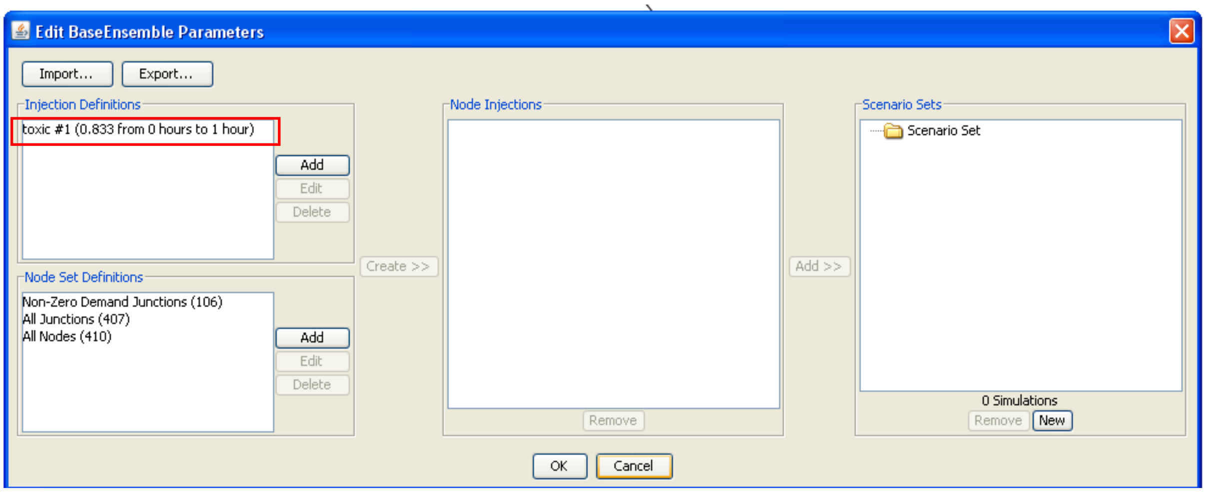


Click the **OK** button to accept the injection definition.

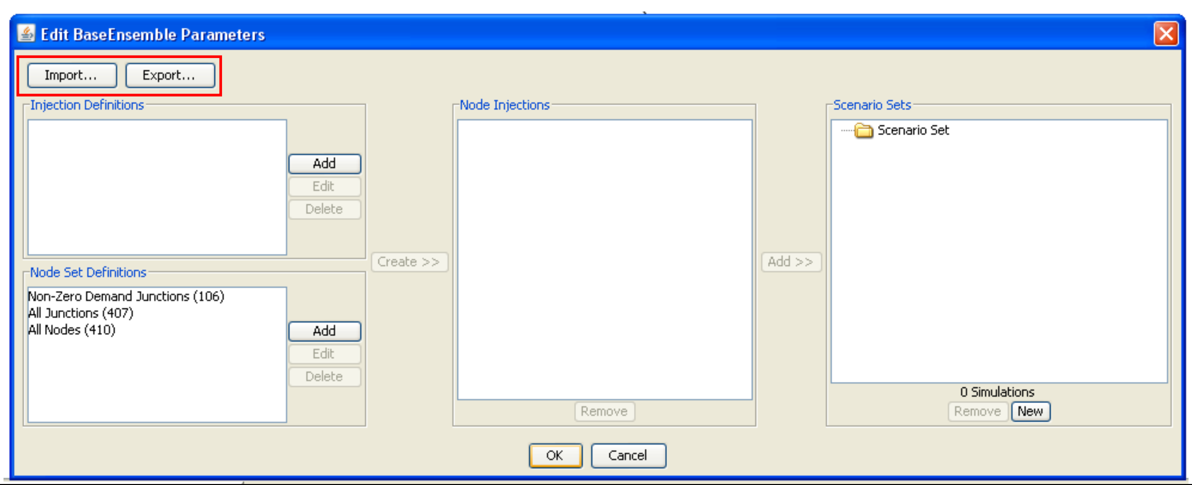
Only required data entries are: Name, Mass Injection Rate, and Start and Stop Times.



The **Injection Definition** dialog box closes, and the injection definition is added to the ensemble and displayed in the **Injection Definitions** pane of the **Edit BaseEnsemble Parameters** dialog box. (Note: 0.833 mg/min was entered as the Mass Injection Rate, the Start Time was 0 hour, and the Stop Time was 1 hour).



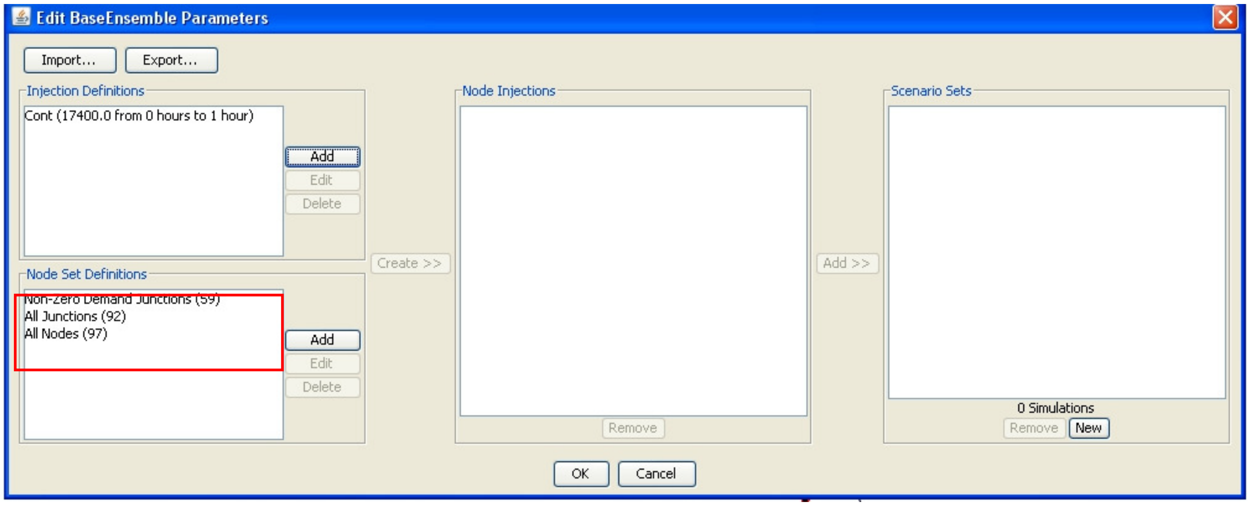
Import and **Export** allows the easy incorporation or export of Injection Definitions and Node Set Definitions into TEVA-SPOT.



3.2. Node Set Definitions

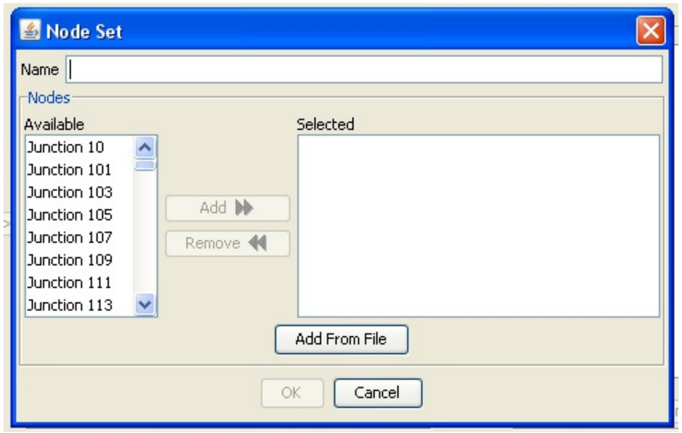
Four options are available for Node Set Definitions. Node set defines the set of nodes that are treated as potential contamination injection sites. The three pre-loaded options are:

- Non-Zero Demand Junctions
- All Junctions
- All Nodes (includes junctions, tanks, and reservoirs)

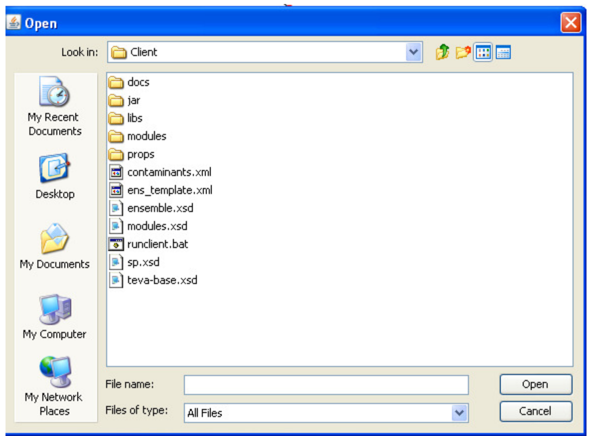


The fourth option is a user defined node set, which is a smaller sub-set of nodes. Click **Add** to create a user defined node set. Two choices are listed **Enumerated** and **PipeDiameter**. To edit a user defined node set, Click **Edit** to view the associated **Node Set** dialog window. Only the user defined node sets can be edited.

Select **Enumerated** and a **Node Set** dialog window opens. This option is used to select specific nodes as the contamination injection sites. Highlight nodes in the **Available** area and then Click **Add** to add them to the **Selected** area. Click the **Add from File** button to use a pre-defined list of nodes. In this **Node Set** window, the **Name** of the node is required along with at least one node listed in the **Selected** area.

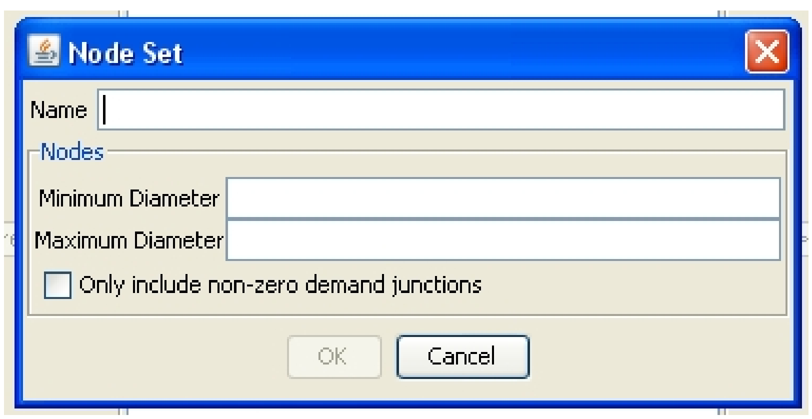


Clicking “Add From File” will open a dialogue box:



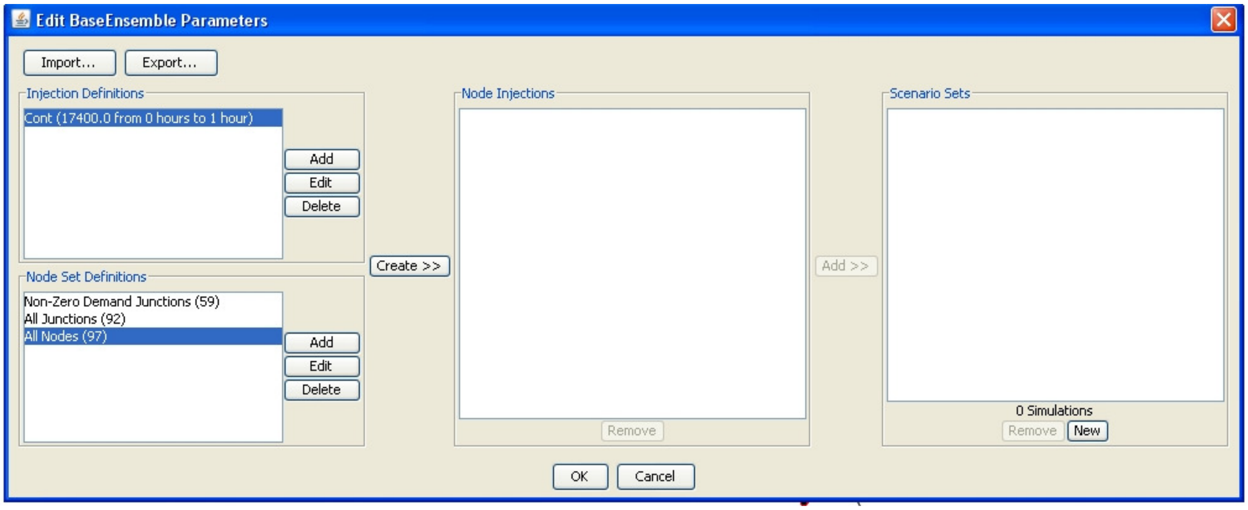
Select **PipeDiameter** and another **Node Set** dialog window opens. This option is used to select nodes that are connected to pipes of specified diameters. In this **Node Set** window, the **Name** of the node set is required along with either a value in the **Minimum** or **Maximum Diameter** text box.

Checking the box “**Only include non-zero demand junctions**” will result in only the non-zero demand nodes associated with the pipe diameter specifications to be identified.

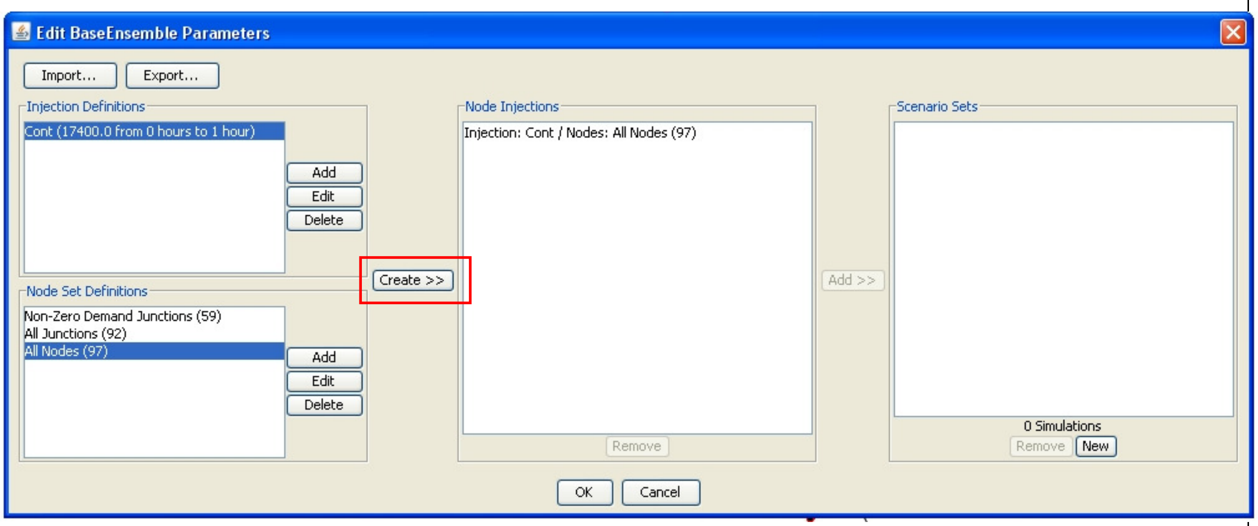


3.3. *Node Injections*

Select one **Injection Definitions** and one **Node Set Definitions**.



Click **Create >>** button.



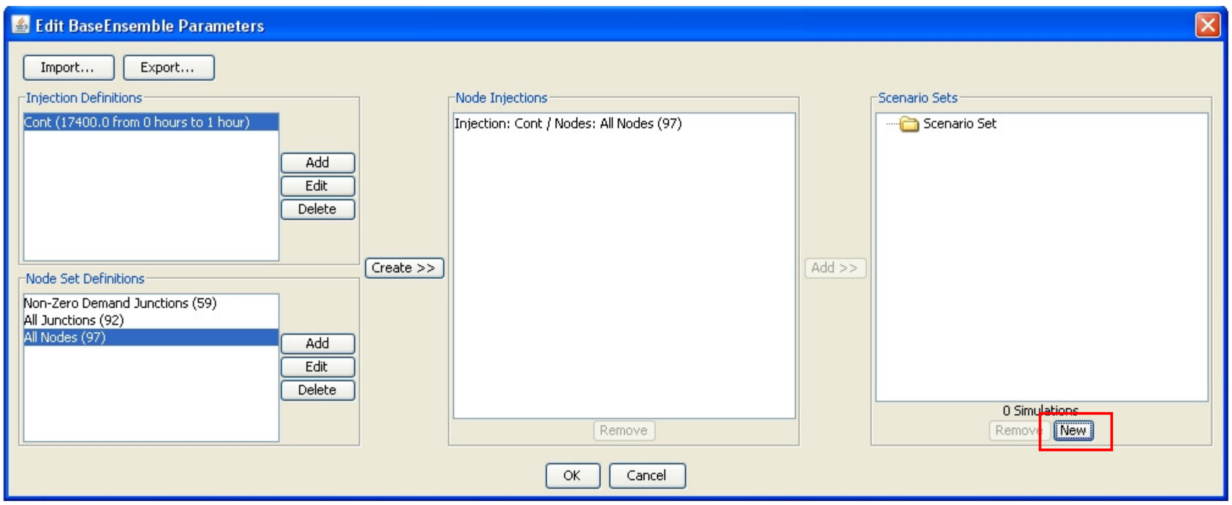
The node injection formed by combining the selected injection definition with the selected node set definition is created and displayed in the **Node Injections** pane of the **Edit BaseEnsemble Parameters** dialog box.

3.4. Scenario Sets

Click the **New** button of the **Scenario Sets** pane in the **Edit BaseEnsemble Parameters** dialog box. A scenario set is a folder that defines a set of injection nodes or scenarios.

A new scenario set, named **Scenario Set**, is created and displayed in the **Scenario Sets** pane.

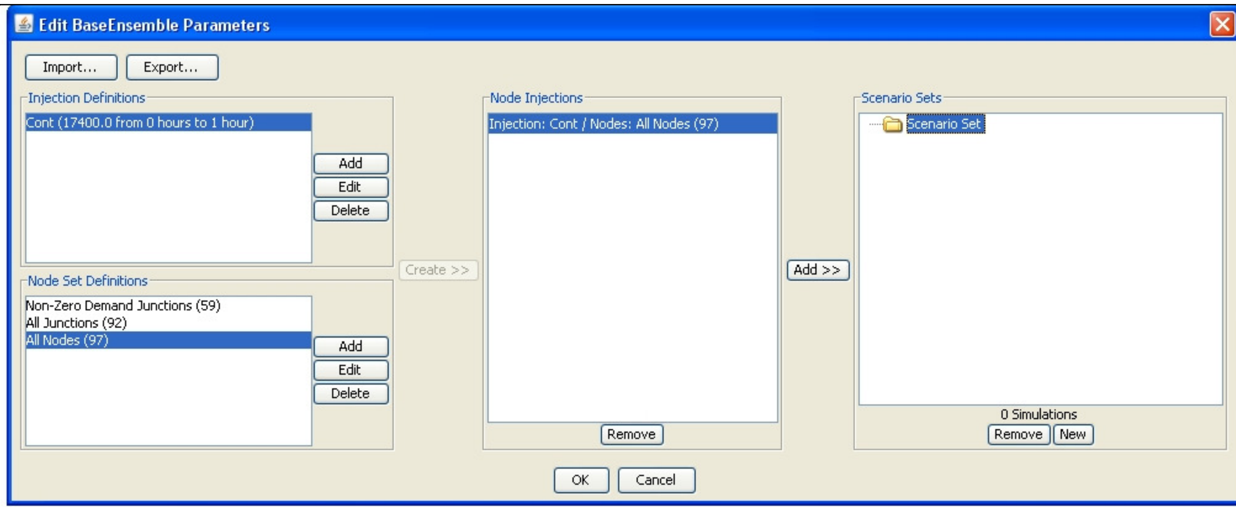
Because the newly created scenario set is empty, its folder icon is closed and is not preceded by a box plus or minus sign.



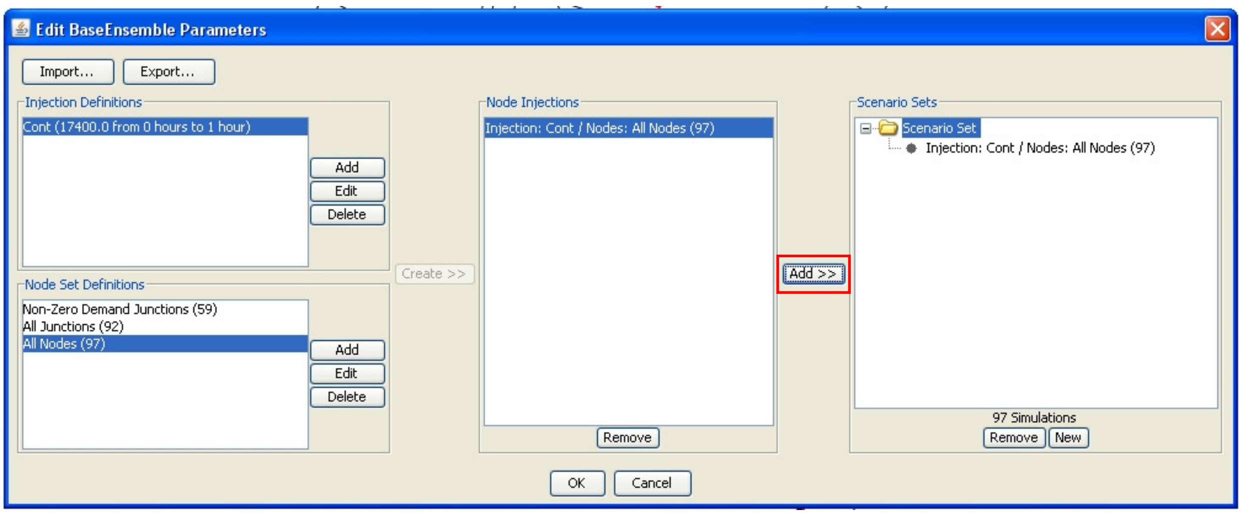
Select the currently loaded ensemble's node injections by clicking on the **Node Injections** pane of the **Edit BaseEnsemble Parameters** dialog box. The selected node injection becomes highlighted.

Select the currently loaded ensemble's scenario sets by clicking on the **Scenario Sets** pane of the **Edit BaseEnsemble Parameters** dialog box. The selected scenario set becomes highlighted.

The **Add >>** button of the dialog box becomes enabled.



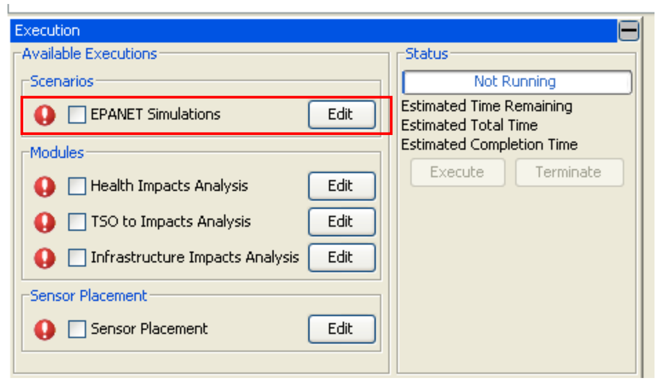
Click the **Add >>** button. The scenario formed from the selected node injection is added to the selected scenario set.



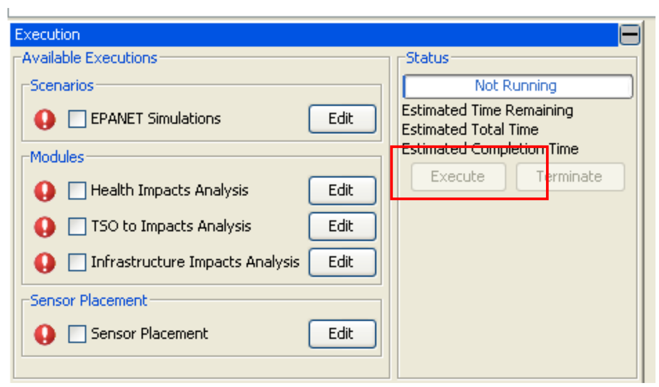
Click **OK** to close the **Edit BaseEnsemble Parameters** window.

3.5. Base Ensemble Execution

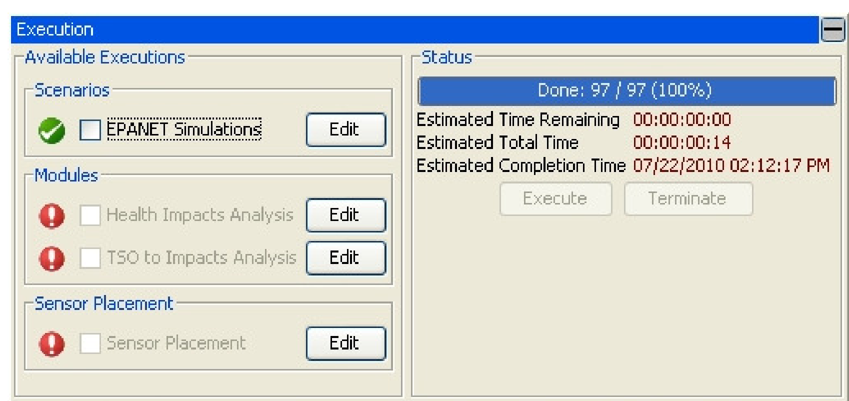
To schedule the simulation of the ensemble's attack scenario, click the **EPANET Simulations** check box.



Click the **Execute** button under **Status**. The **Execute** button will only be enabled when one of the **Available Executions** are checked.



At the completion of the execution, the **EPANET Simulations** will be highlighted with a green checkmark.



Note that if the progress bar and estimated completion time information are not viewable during execution, close the Execution Control Panel (above box) and Reopen.

4. Health Impacts Analysis

This section describes how to use the execution controls in ensemble analysis mode. Figure 3 shows the hierarchy of the Health Impacts Analysis module.

Parameter values shown as integers in the tables should be entered as integers; those shown with decimal places should be entered as decimal fixed-point (e.g., 1.307) or decimal floating-point (e.g., 2.87e13) values.

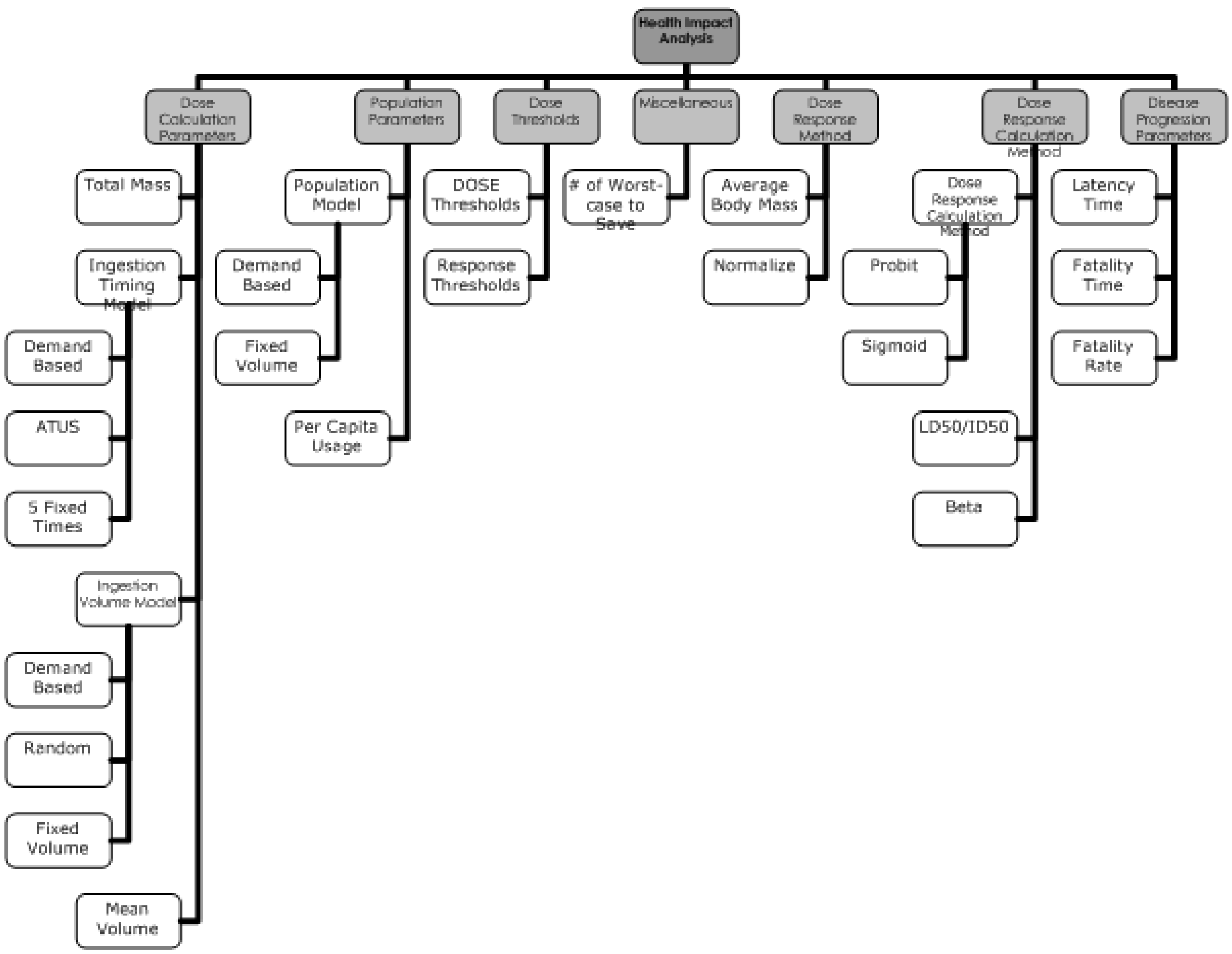
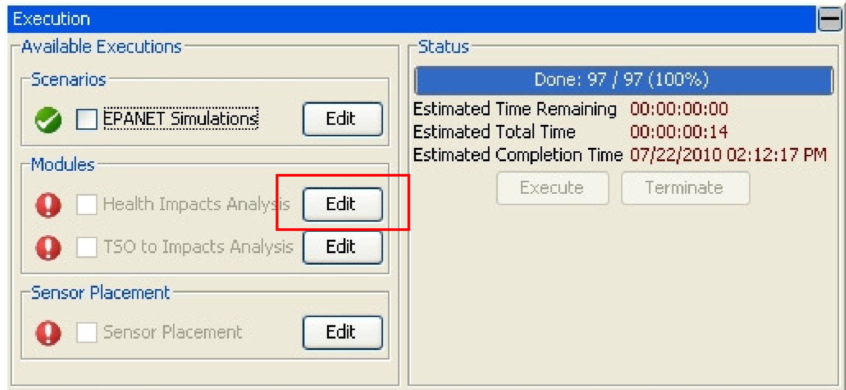
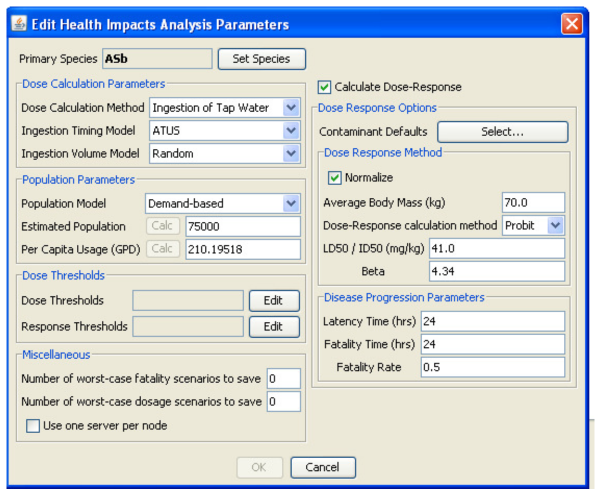


Figure 3. Health Impact Analysis Flow Chart

<table>
<tr>
<td>In the Execution panel, click the Edit button to the right of the Health Impacts Analysis checkbox.

Note: Health Impacts Analysis will be grayed out until information is added.</td>
<td>
</td>
</tr>
<tr>
<td>The Edit Health Impacts Analysis Parameters dialog box opens.

Notice the Primary Species and Set Species boxes. These appear when EPANET-MSX is initiated by loading an .MSX file</td>
<td>
</td>
</tr>
</table>

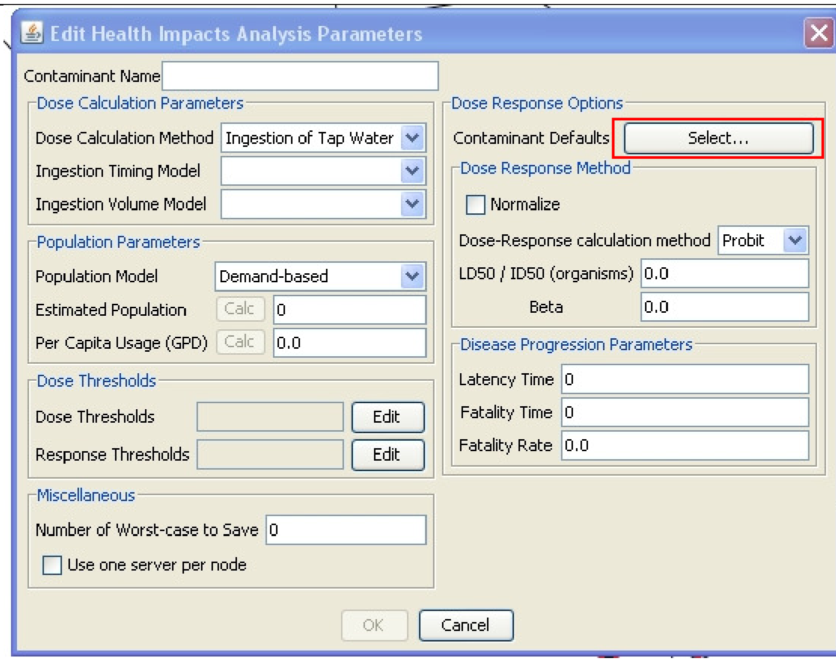
4.1. Contaminant Name

The cursor is initially positioned in the **Contaminant Name** text box. Type in the name of the contaminated that is going to be simulated.

The other option is to use a contaminant database, which is described below.

If a database of contaminants has been setup (XML file format), the user can click the **Select** button next to **Contaminant Defaults** under **Dose Response Options** to choose a particular contaminant.

The **Select Contaminant** dialog box opens, displaying an example contaminant.



NOTE: The format for the XML file is as follows:

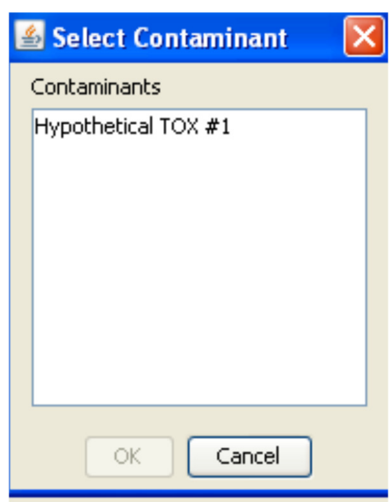
```
<Contaminants>
  <Contaminant name="EXAMPLE TOX #1" default_dr="Probit"
normalize="true">
    <DiseaseProgression latency_time="24" fatality_time="24"
fatality_rate="0.5"/>
    <Probit beta="4.34" ld50="0.001"/>
  </Contaminant>
</Contaminants>
```

Select a particular contaminant (e.g., **Hypothetical TOX # 1**) by clicking on its name.

The name becomes highlighted, and the **OK** button becomes enabled.

Click the **OK** button.

The dialog box closes and the name of the selected contaminant is entered into the **Contaminant Name** textbox.



The "contaminants.xml" must be located in the appropriate directory, e.g., C:\Program Files\TEVA-SPOT\Client directory in order to be recognized by TEVA-SPOT.

Under **Dose Response Options,** values associated with the contaminant can be entered.

For demonstration purposes, the example contaminant , EXAMPLE TOX #1, would have the following values entered under **Dose Response Method**:

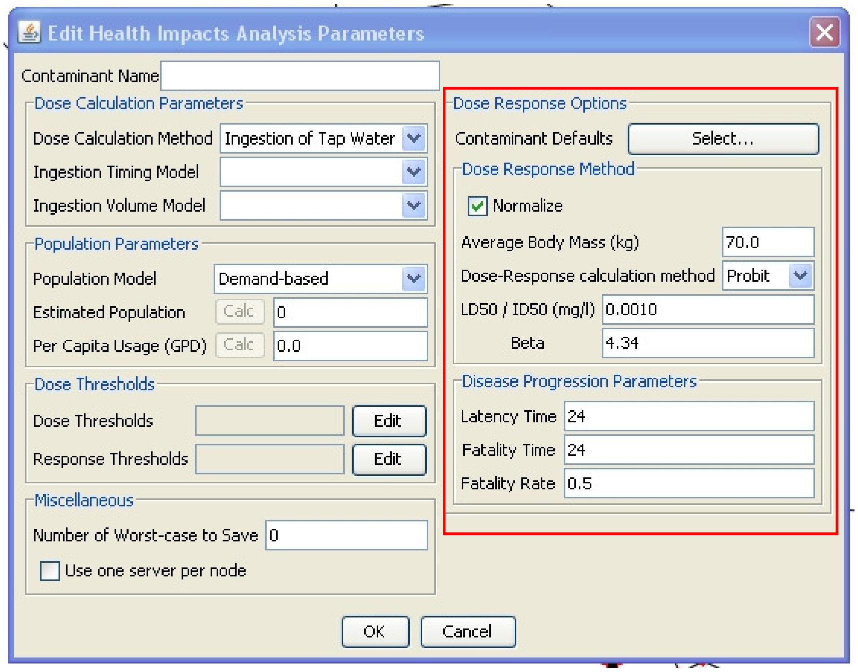
Dose-Response calculation method: Probit
LD50/ID50: 0.001
Beta: 4.34

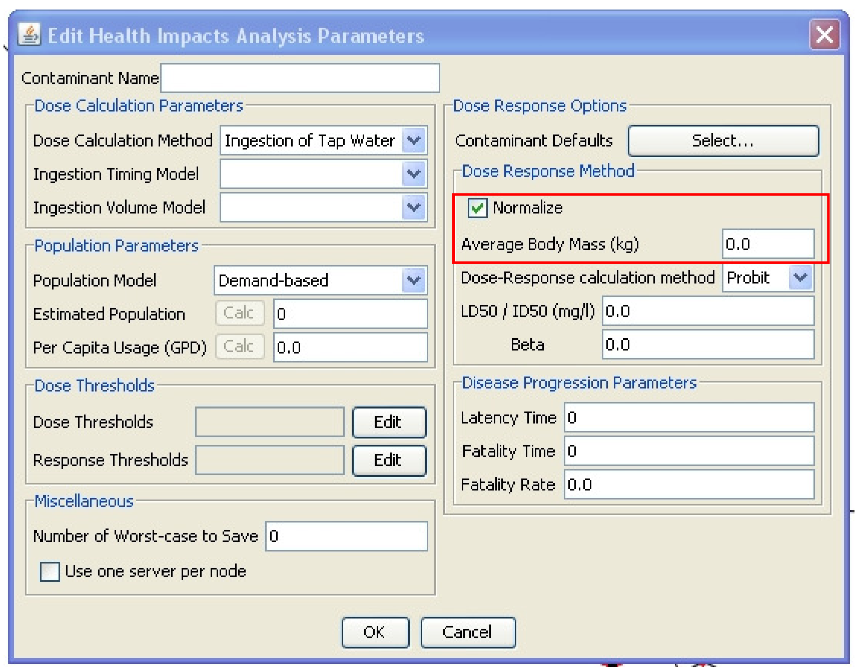
Under **Disease Progression Parameters,** the following values would be entered:
Latency Time: 24
Fatality Time: 24
Fatality Rate: 0.5

If the contaminant is considered a chemical or toxin with units of mg, then **Normalize** is selected.

If the contaminant is considered a biological with units of organisms or spores, then **Normalize** is <u>not</u> selected.

Average Body Weight (kg) is shown when the **Normalize** box is checked. Type **70.0** for **Average Body Mass.**





Normalize should only be used for contaminants, such as metals or toxins, which have an ID-50/LD-50 dose expressed in units per kilogram body weight.

4.2. Dose Calculation Parameters

Only **Ingestion of Tap Water** is available in the current version of TEVA-SPOT for Dose Calculation Method.

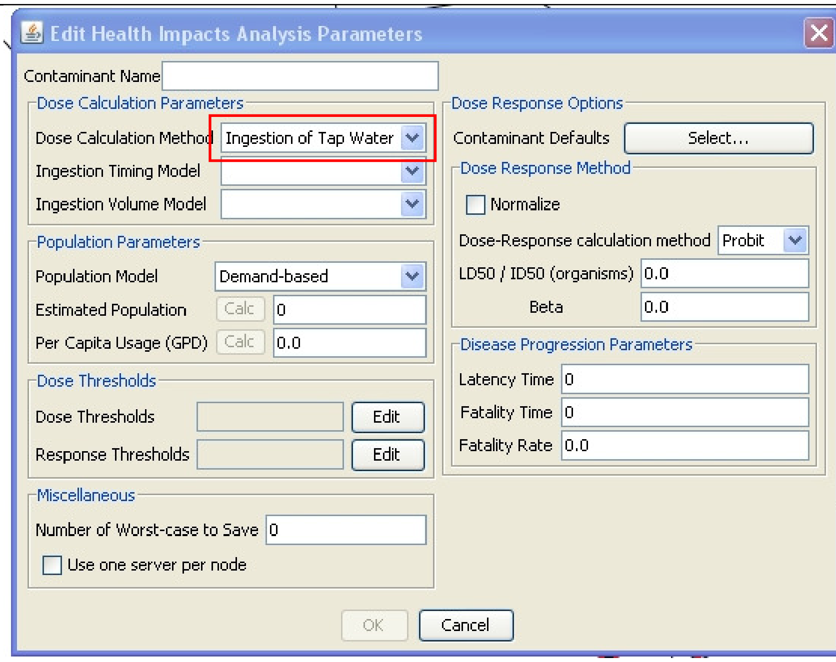
From the **Ingestion Timing Model** pull-down menu, three options are available: **Demand-based**, **ATUS**, and **5 Fixed Times**.

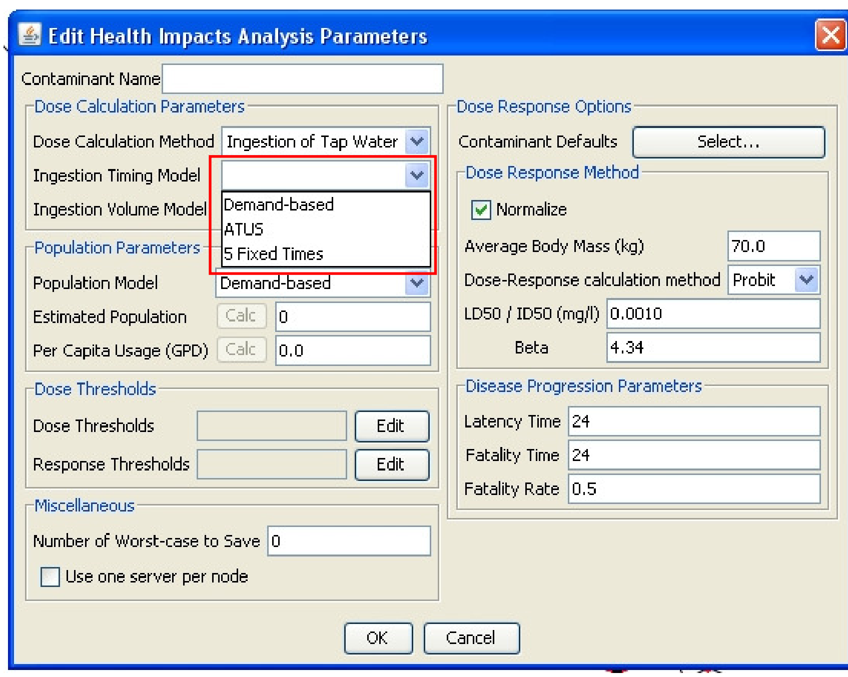
For demonstration purposes, **ATUS** is selected.

From the **Ingestion Volume Model** pull-down menu, two options are available: **Random** and **Fixed Volume**. If **Fixed Volume** is selected then, **Mean Volume (liters/person/day)** is shown.

For demonstration purposes, **Random** is selected.

Normally, it is recommended that users select **5 Fixed Times** and **Fixed Volume**, with a value of 1 liter per person per day. The random-based models (timing and volume) will result in varying results due to randomness.





ATUS = American Time Use Survey. Data collected by the Census to characterize when people eat and most likely drink water.

4.3. Population Parameters

Under **Population Model**, two pull-down options are available: **Demand-based** and **Census-based**.

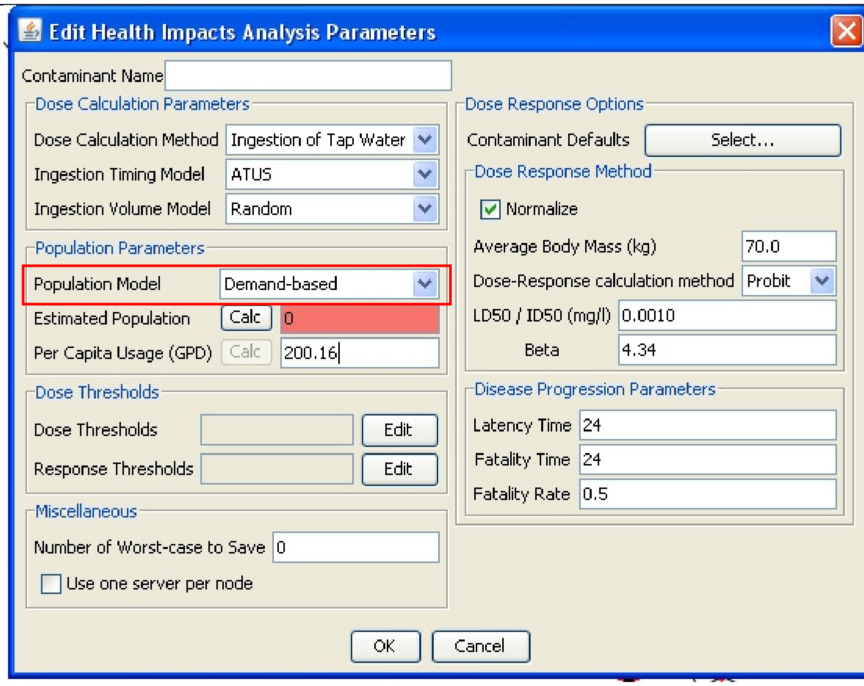
If **Demand-based** is selected, then **Estimated Population** and **Per Capita Usage (GPD)** are shown. If **Census-based** is selected, then a Population file must be loaded.

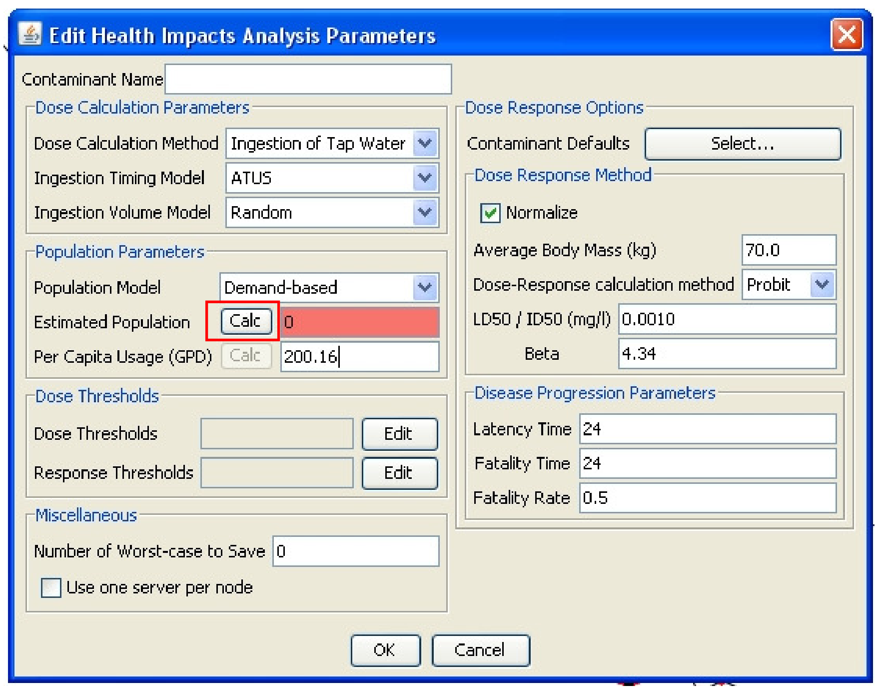
For demonstration purposes, select **Demand-based** from the pull-down menu.

Type in a value of **200.16** for **Per Capita Usage (GPD)** gallons per person per day.

The **Estimated Population** box gets highlighted. Click **Calc** to calculate the total population being served.

Using the **Demand-based** population model allows the user to input the population served by the distribution system being evaluated or by inputting an estimated per capita usage factor in units of GPD to determine the population for the distribution system.





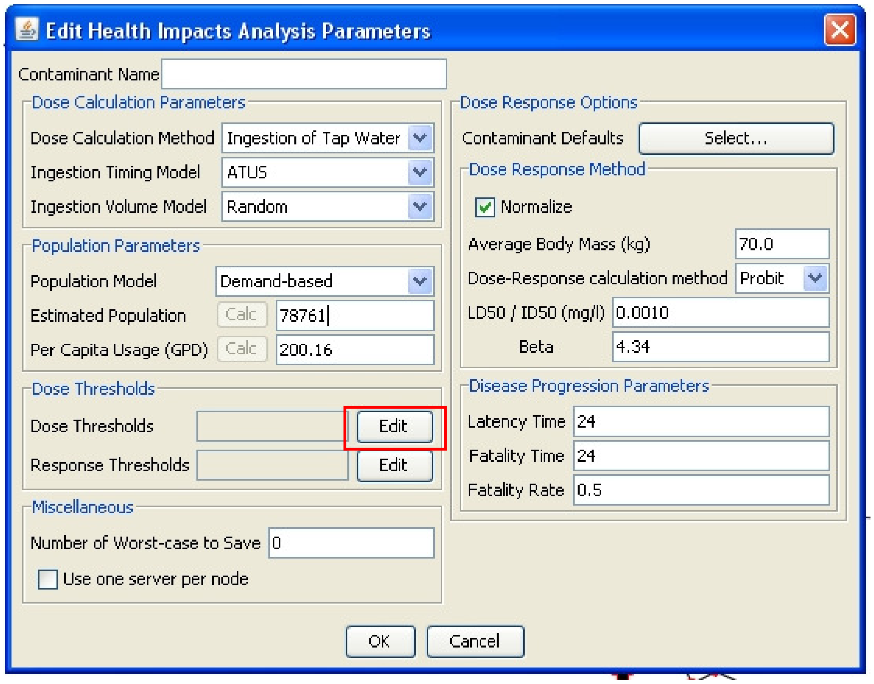
4.4. Dose Thresholds

These parameters (**Dose Thresholds** and **Response Thresholds**) are optional.

Click the **Edit** button to the right of the **Dose Thresholds** text box.

The **Edit Dose Thresholds** dialog box opens.

Dose thresholds can be used to evaluate contamination impacts without specifying a particular contaminant. In this case, the threshold could be an action or advisory level.

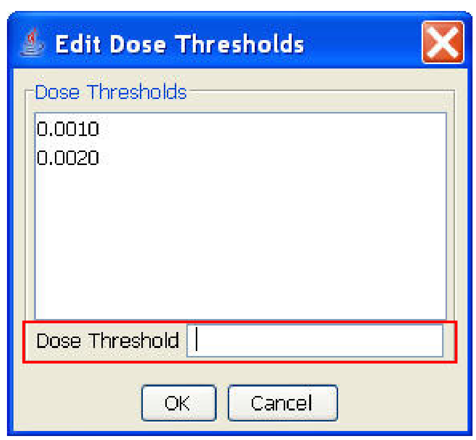


Click the **Dose Thresholds** text box.

Type in the values for each of the **Dose Thresholds** of interest. [The user can enter multiple values.]

For demonstration purposes, type **0.001** and press **Enter**. Again type **0.002** and press **Enter**.

Click the **OK** button to accept the **Dose Thresholds** values.



Note: Values can be entered as decimal or in scientific notation, e.g., 1.0E-3.

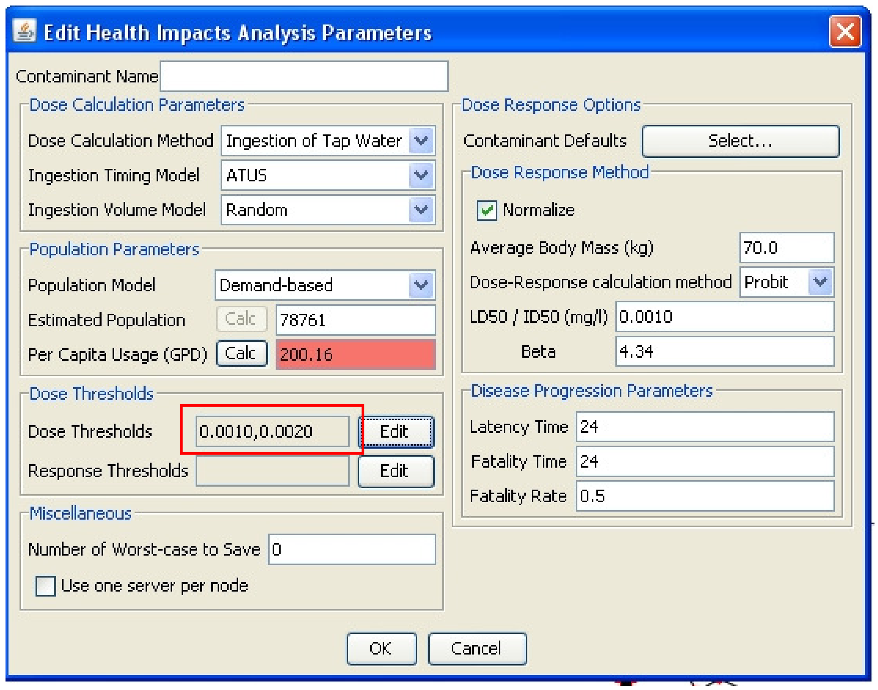
Dose thresholds are described in Davis, M. J., and Janke, R. (2010a). "Patterns in potential impacts associated with contamination events in water distribution systems." J. Water Resour. Planning Manage., (16 March 2010), 10.1061/(ASCE)WR.1943-5452.0000084.

<table>
<tr>
<td>

The **Edit Dose Thresholds** dialog box closes.

The defined **Dose Thresholds** are now displayed in the window.

</td>
<td>



</td>
</tr>
<tr>
<td>

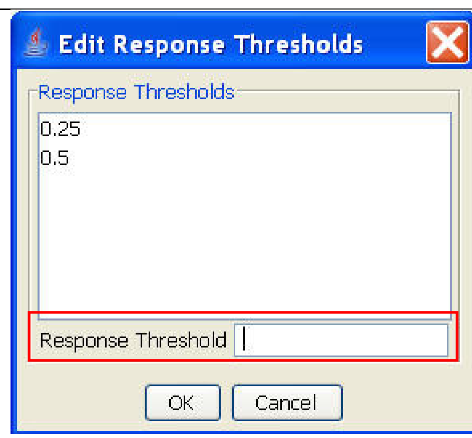
Click **the Response Threshold** text box.

Type in the values for each of the **Response Thresholds** of interest. [The user can enter multiple values.]

For demonstration purposes, type **0.25** and then press **Enter**. Again type **0.50** and then press **Enter**.

Click the **OK** button to accept the **Response Thresholds** values. The **Edit Response Thresholds** dialog box closes.

</td>
<td>



</td>
</tr>
</table>

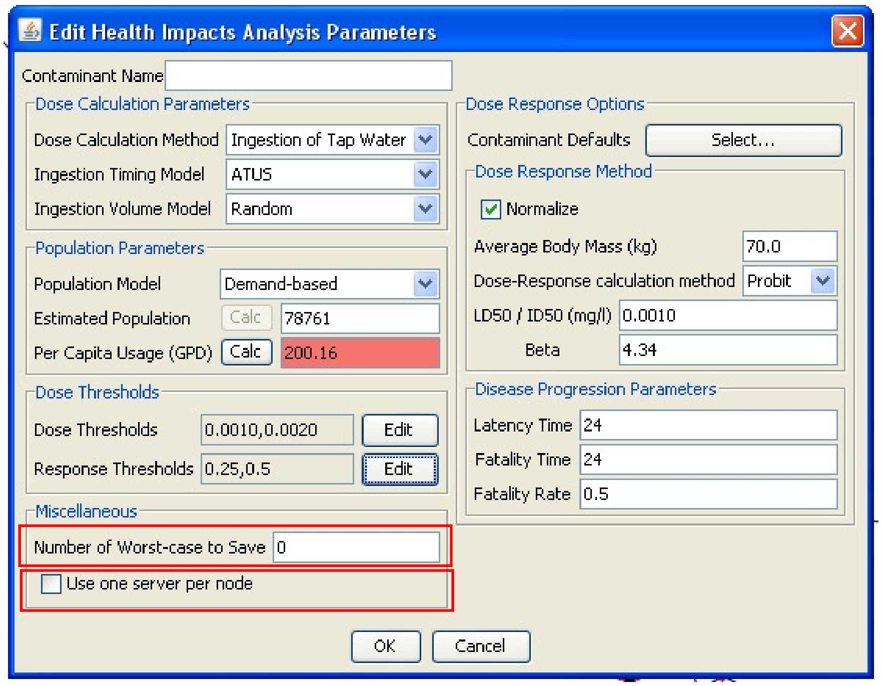
4.5. Miscellaneous

Inserting an integer number into the **Number of Worst-case to Save** box results in the corresponding number of scenarios being saved. Each scenario saved contains contaminant concentration data for the numbered scenario. A "1" will result in the highest ranked (in terms of health impacts) scenario being saved; whereas "5" will result in the top 5 highest ranked scenarios being saved.

For demonstration purposes, type in a value of **1** in the box for **Number of Worst-case to Save**.

Use one server per node is a feature that will reduce the computational burden of the HIA (and EPANET simulations if run with HIA) simulations on the host computer. Checking this box will result in only one HIA scenario being run at a time on the host computer regardless of how many processors are available.

The **Number of Worst-case to Save** refers to the number of scenarios for which complete contaminant concentration versus time data is saved for further analysis. This data is saved in the TEVA-SPOT-Database folder under the particular Ensemble Name and within the Health Impacts Analysis subdirectory (TEVA-SPOT-Database/Collection/Ensemble/Health Impacts Analysis folder).



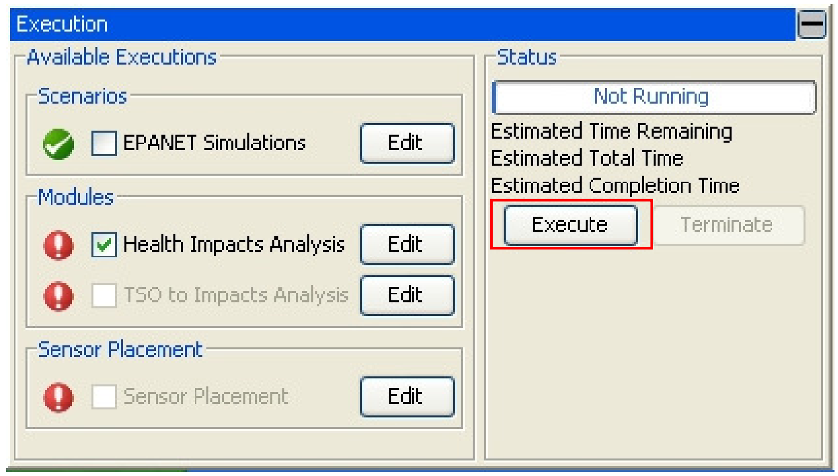
If "1" is used, then the worst case scenario in terms of dose response based impacts is chosen, "2" would result in the top 2 scenarios being saved.

NOTE: This value should not exceed 10 for any network greater than 3,000 nodes due to the large storage space required.

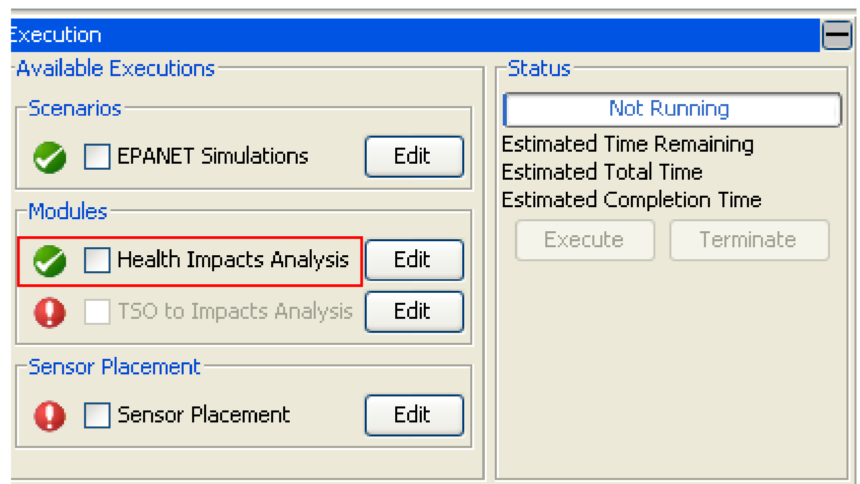
4.6. Health Impacts Analysis Execution

To determine the health impacts from the EPANET simulations that ran previously, click the **Health Impacts Analysis** check box.

Click the **Execute** button in Status.



At the completion of the execution, the Health Impacts Analysis will be highlighted with a green check.



5. Sensor Placement Algorithm

The Sensor Placement algorithm solves an optimization problem. The algorithm tries to find a solution to the problem of placing a given number of sensors in the water network to optimize a stated objective, usually subject to several constraints. Figure 4 below highlights the inputs for the sensor placement module within TEVA-SPOT. For more detailed description of these features, please refer to the TEVA-SPOT Toolkit Users Manual.

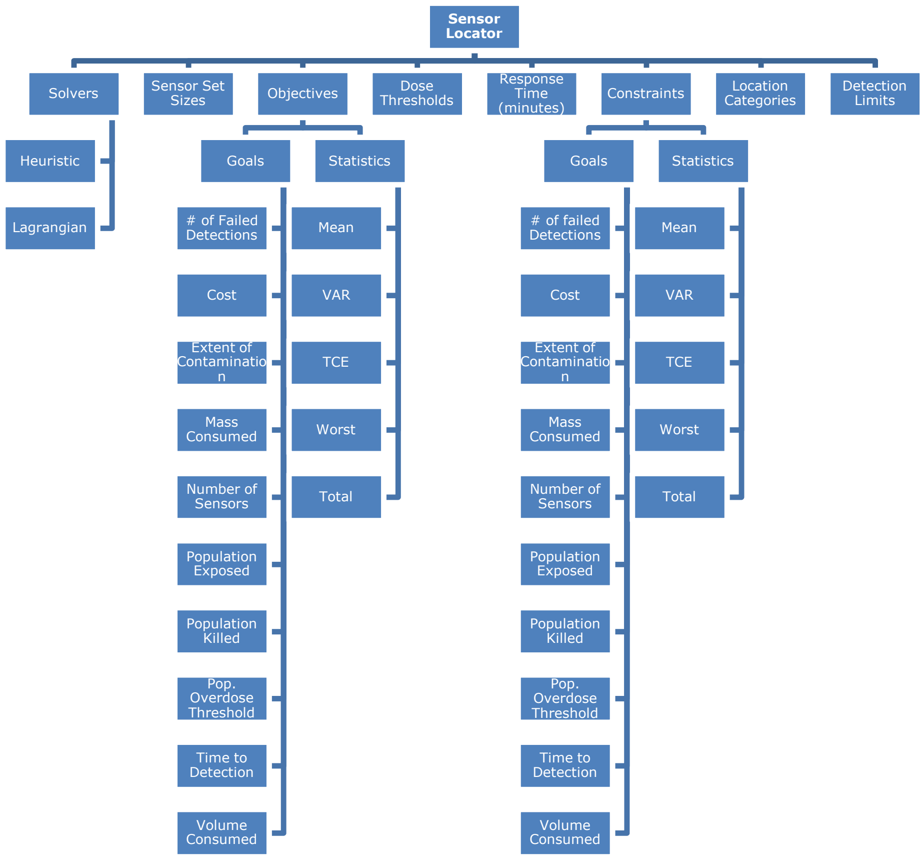
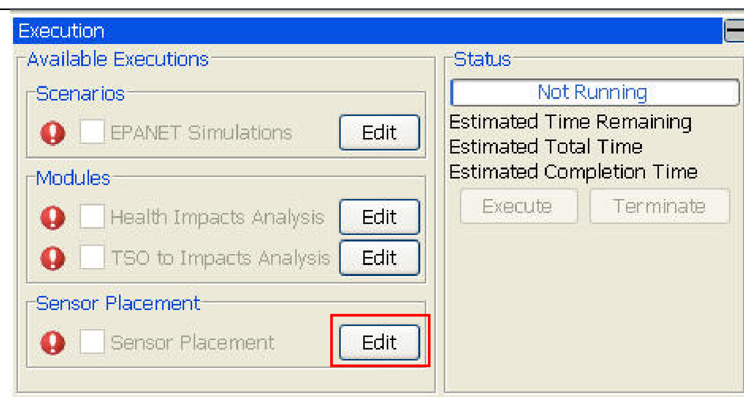
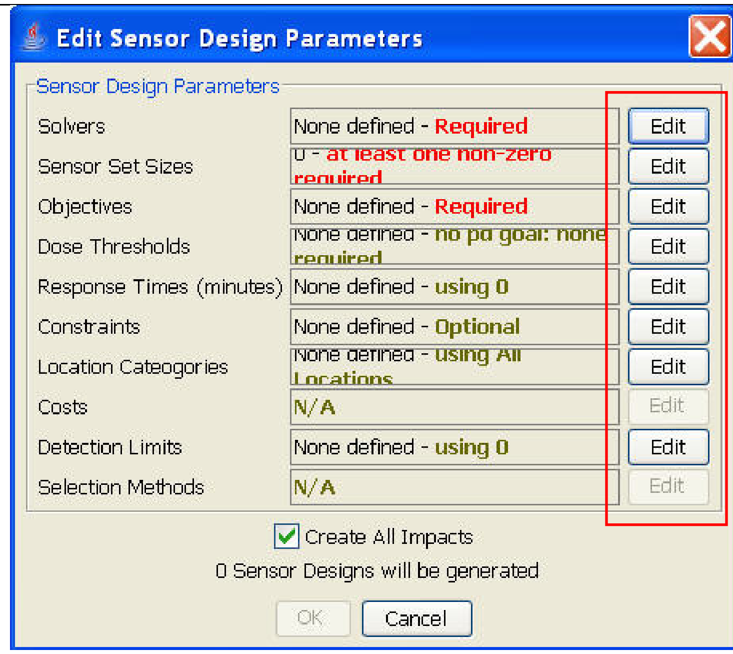


Figure 4. Sensor Placement Flow Chart

In the **Execution** panel, click the **Edit** button to the right of the **Sensor Placement** check box.	

The **Edit Sensor Design Parameters** dialog box opens.

All the parameters in the **Sensor Design Parameters** are entered by clicking the **Edit** buttons.

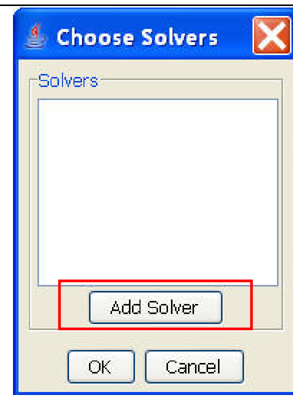


5.1. Specifying the Solvers

Click the **Edit** button to the right of the **Solvers** text box.

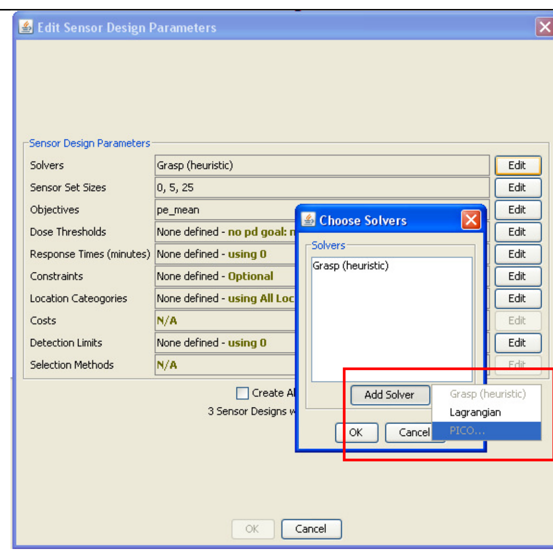
The **Choose Solvers** dialog box opens.

Click the **Add Solver** button.



Multiple solvers (**GRASP (Heuristic)** and **Lagrangian**) can be selected and added. Sensor designs specific to each solver will be created. However, run times will increase by a factor of two because sensor designs will be created for each algorithm selected.

Lagrangian algorithm is generally used for large or very large networks which will not run using the **GRASP** algorithm due to computer memory limitations.



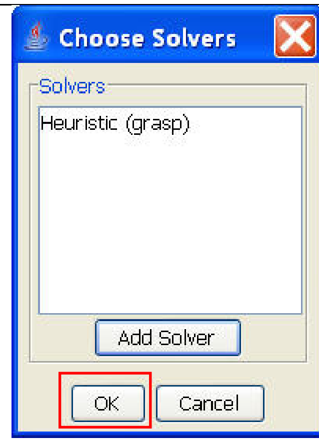
PICO is a true optimal solver, but only available in the toolkit version

For demonstration purposes, select **GRASP** solver by clicking on the enabled name in the list of solvers.

Click the **OK** button to accept the **Solvers** parameter, e.g., Heuristic.

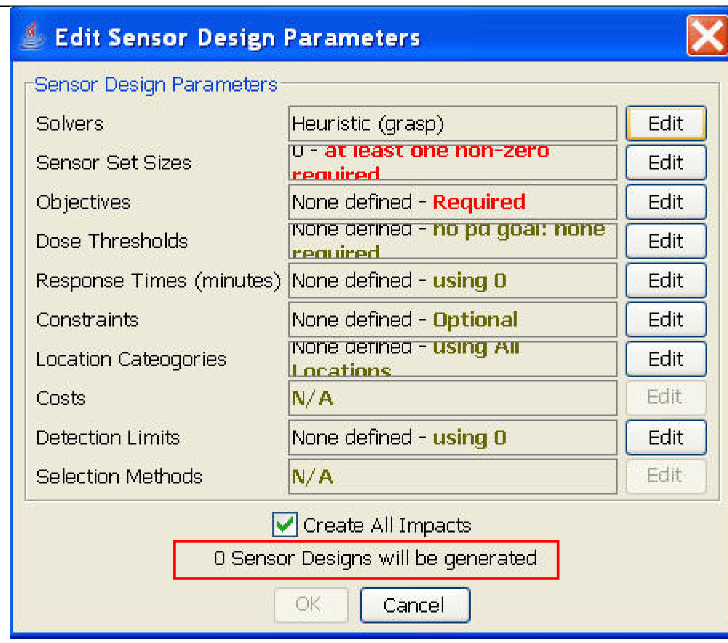
GRASP is the default solver. It will generally provide the better solution.

The **Choose Solvers** dialog box closes.



The figure shows that zero sensor designs will be generated: this is because a sufficiently complete set of Sensor Placement parameters has not yet been entered.

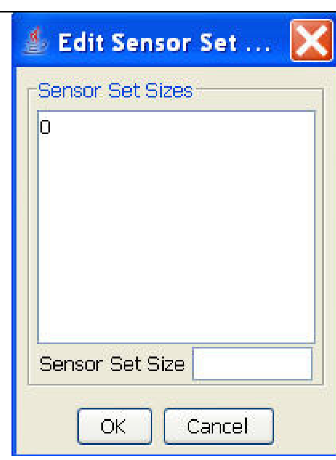
Note: **OK** button is disabled.



5.2. Specifying the Sensor Set Sizes

Click the **Edit** button on the right of the **Sensor Set Sizes** text box.

The **Edit Sensor Set Sizes** dialog box opens.

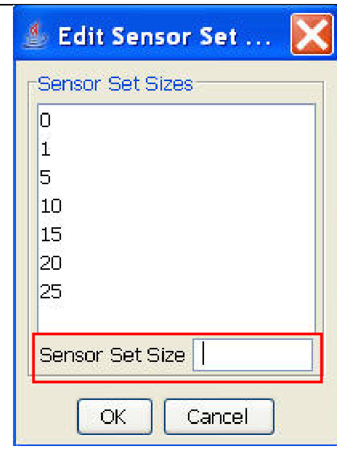


Click the **Sensor Set Size** text box.

For demonstration purposes, type **1** and press **Enter**. Repeat this process for **5**, **10**, **15**, **20**, and **25**, remembering to press **Enter** after each number.

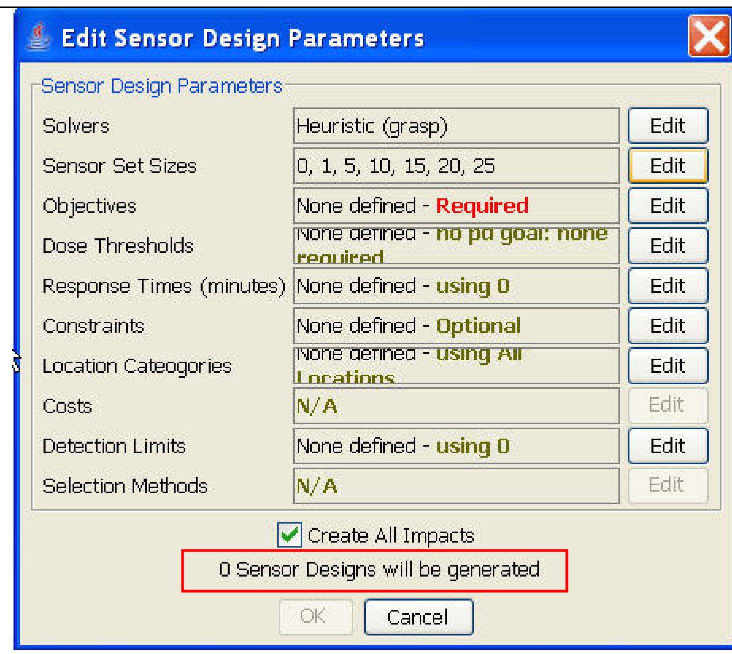
When done, click **OK**. The **Edit Sensor Set Sizes** dialog box closes.

NOTE: Values must be integers.



Again because a sufficiently complete set of Sensor Placement parameters has not yet been entered, the figure shows that zero sensor designs will be generated.

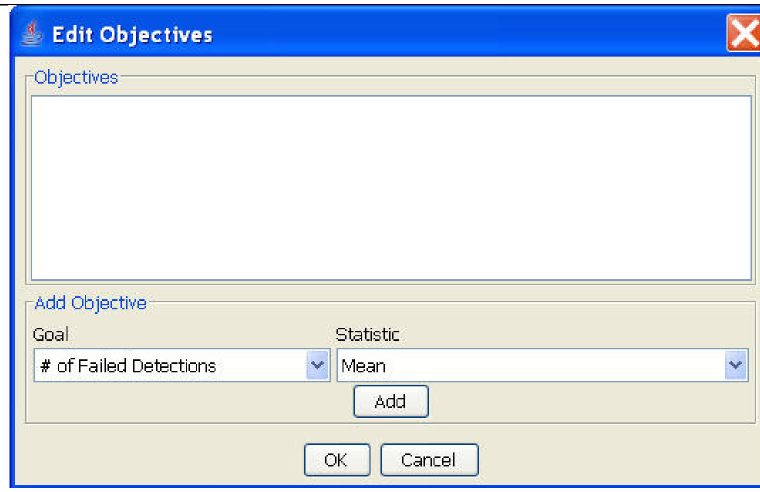
Note: **OK** button is still disabled.



5.3. Specifying the Objectives

Click the **Edit** button to the right of the **Objectives** text box.

The **Edit Objectives** dialog box opens.



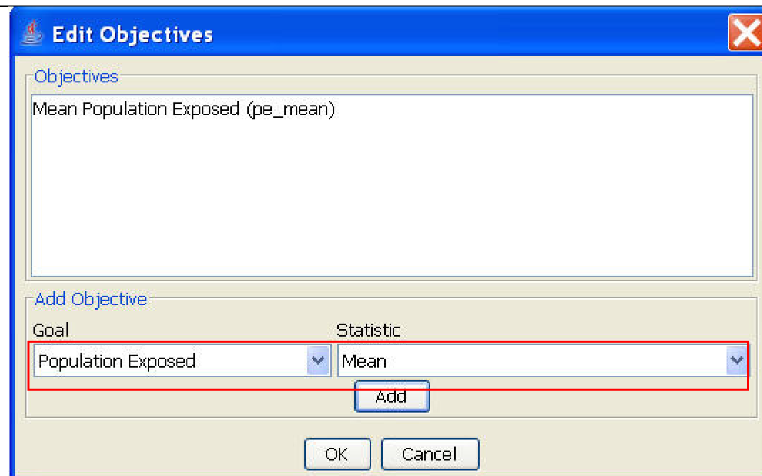
Click the **Goal** pull-down list box.

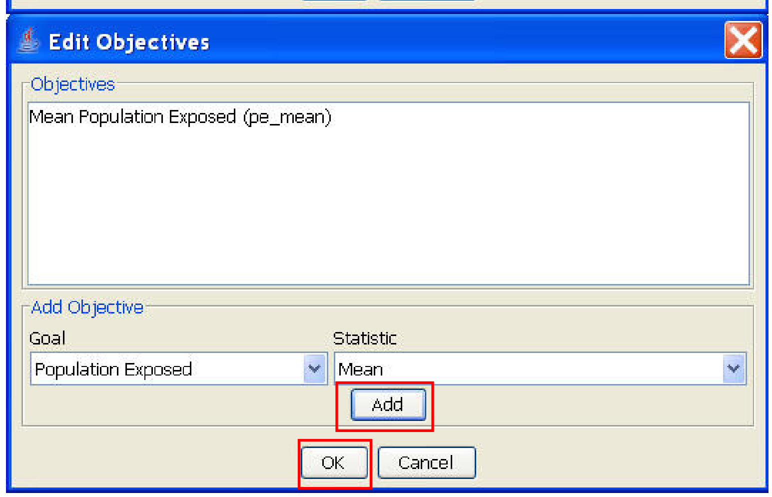
For demonstration purposes, select **Population Exposed** as the desired goal by clicking it. The list closes and the selected goal is displayed in the list box.

Select the **Mean** statistic as the desired statistic by clicking it. The list closes and the selected statistic is displayed in the list box. The **Worst case** statistic requires longer run times.

Click the **Add** button and then click **OK**.

Note: The other goals and statistics used to create additional objectives are described in the TEVA-SPOT Toolkit Users Manual which is located at ***C:\Program Files\TEVA-SPOT\Client\docs*** provided the default option was chosen for installing TEVA-SPOT.



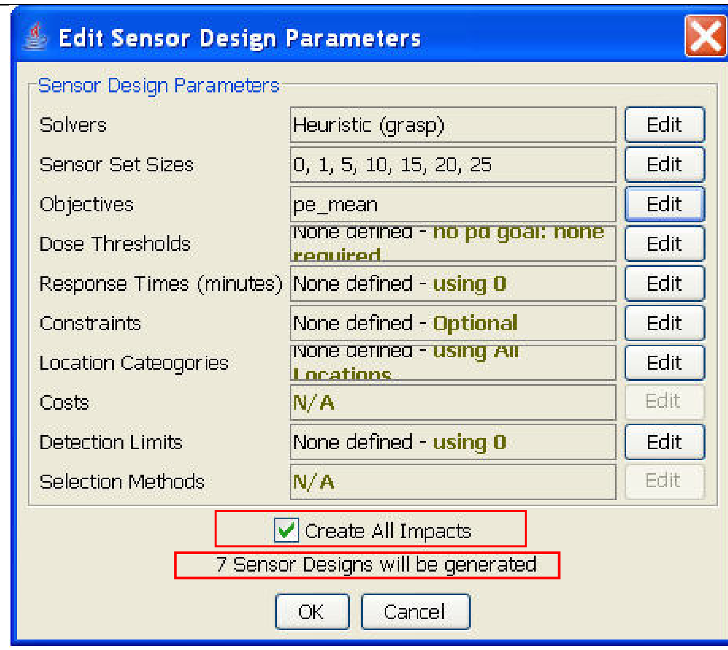


The **Edit Objectives** dialog box closes and the objectives are now listed in the **Objectives** text box.

The updated figure shows that seven (7) sensor designs will now be generated. These seven designs correspond to the seven different sensor set sizes that were selected.

Note: **OK** button is now enabled. This indicates that there is sufficient information provided to calculate the sensor locations. However, the user can specify additional data as described in the following sections.

Although the box "**Create All Impacts**" is checked – **for faster run times this box should not be checked**. Checking the box, "**Create All Impacts**" results in the generation of additional tso-2-impact files (located in the TEVA-SPOT-Database) for any objective not already selected, which can be used for Regret Analyses.



Using Regret Analysis, the user can evaluate sensor network design(s) developed for a particular objective against other objectives if "Create All Impacts" is selected.

5.4. Dose Threshold

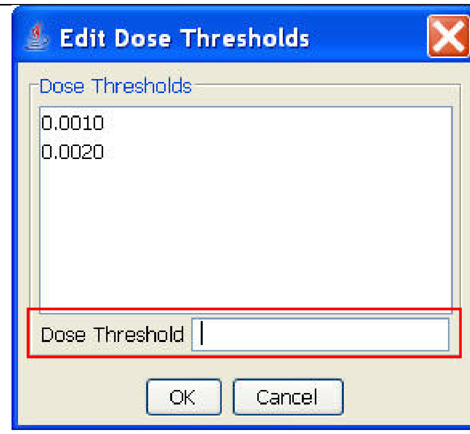
Click the **Edit** button to the right of the **Dose Thresholds** text box.

The **Edit Dose Thresholds** dialog box opens. If no **Dose Thresholds** are entered, no sensor designs for dose thresholds will be created. ***Population Dosed (PD) must be selected to produce sensor network designs based on dose thresholds.***

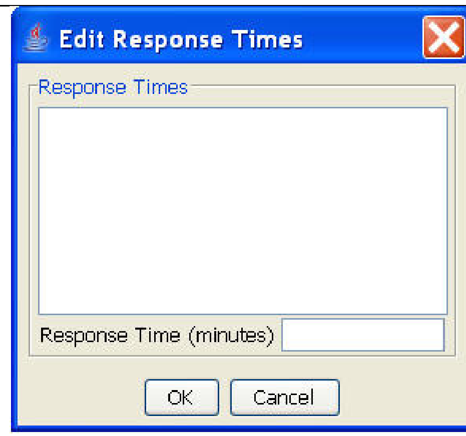
<table>
<tr>
<td>Click the Dose Threshold textbox.

Type a value of 0.001, and then press the Enter key.

Again type a value of 0.002 and press the Enter key.

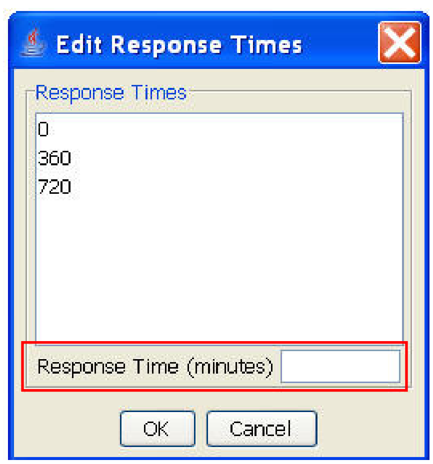
Click OK button to accept the changes to the Dose Thresholds parameter.</td>
<td>
</td>
</tr>
<tr>
<td>5.5. Specifying the Response Times

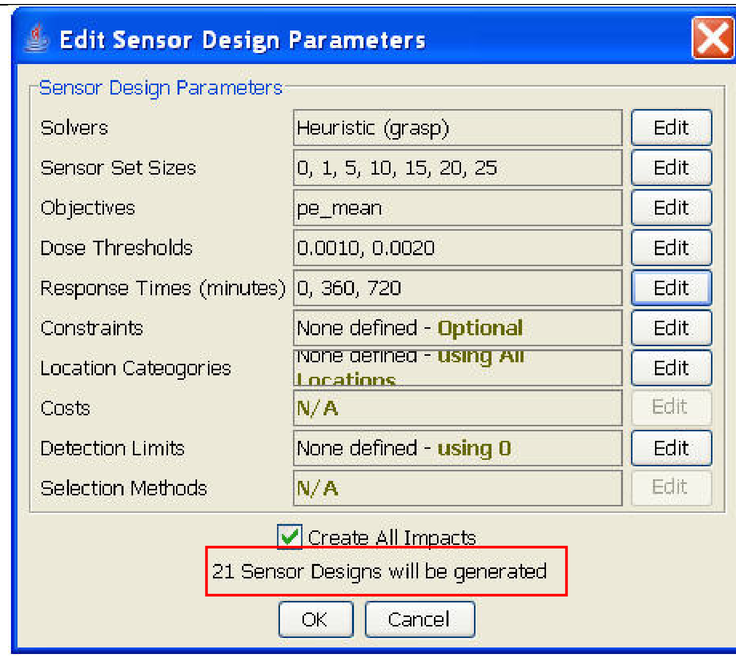
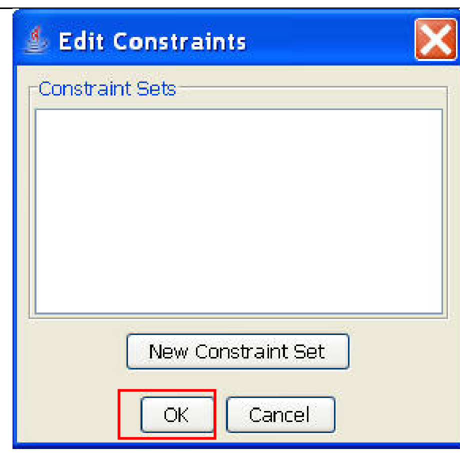
Click the Edit button to the right of the Response Times (minutes) text box.

The Edit Response Times dialog box opens. If no Response Times are entered, the default is zero.</td>
<td>
</td>
</tr>
<tr>
<td>Click the Response Time (minutes) text box.

Type the desired value 0 and press the Enter key.

Repeat this process for 360 and 720, remembering to press the Enter key after each entry.

Click OK button to accept the changes to the Response Times parameter.</td>
<td>
</td>
</tr>
</table>

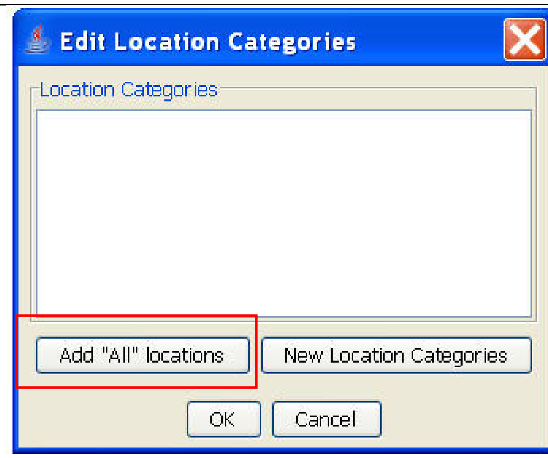
The figure shows that 21 sensor designs will be generated (one for each combination of the seven sensor set sizes and three response times). Note here that sensor network designs based on dose thresholds will not be created – *because* PD was not included as an objective. If PD was included there would be a total of 63 sensor designs!	
5.6. Specifying the Constraint Sets Click the **Edit** button to the right of the **Constraints** text box. The **Edit Constraints** dialog box opens. Click on **OK** button as this is Optional. **Constraints** can be specified in the same manner as objectives. Constraints restrict any sensor design to a solution described by the constraint.	

5.7. Specifying the Location Categories Sets

Click the **Edit** button to the right of the **Location Categories** text box.

The **Edit Location Categories** dialog box opens. Click the **Add "ALL" locations** button.

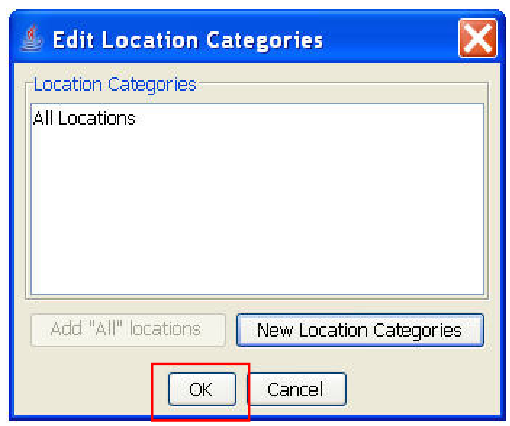
Selecting "**New Location Categories**" button brings up a dialogue box where the user can browse to a sensor file which defines *feasible, infeasible, fixed, and unfixed* sensor locations. See Appendix A, Table 3 for formatting of the sensor table.

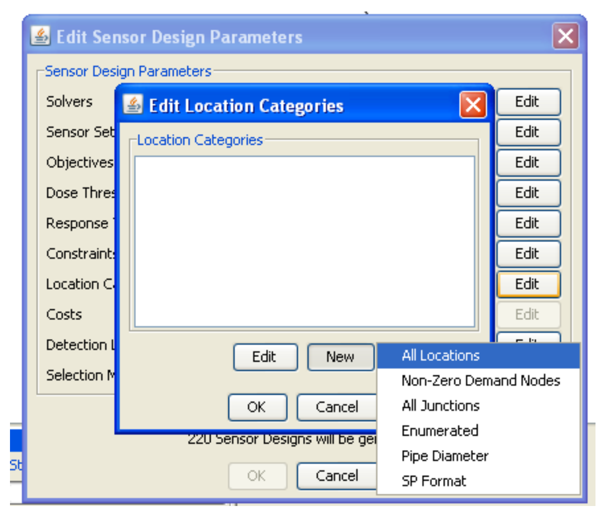


Note that after clicking "**New Location Categories**" the box expands and default options are available for specifying feasible sensor locations for the algorithm selected to choose from.

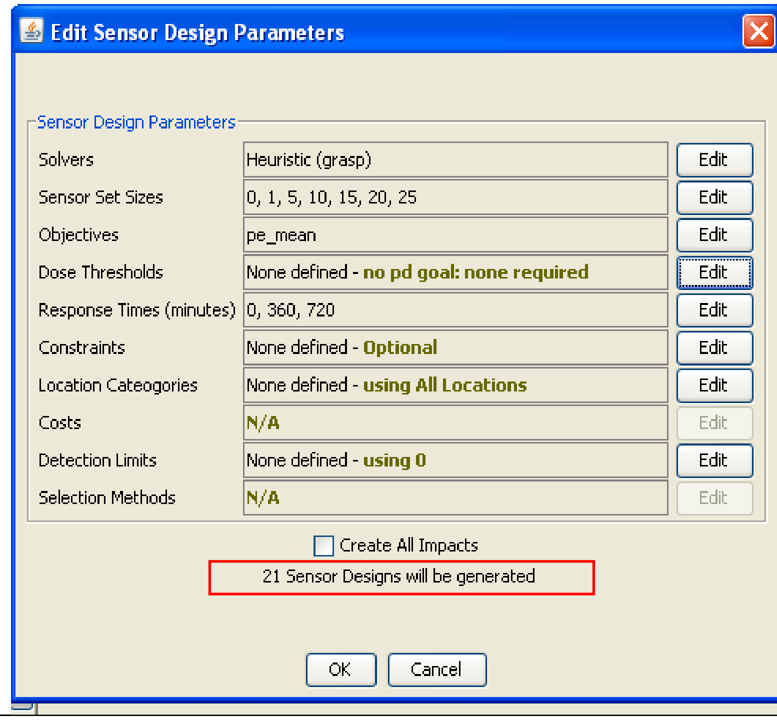
The default options are: All Locations, Non-Zero Demand Nodes, All Junctions, Enumerated (User Selected), Pipe Diameter, and SP (Sensor Placement) format. The SP format provides for uploading a text file specifying sensor locations.

Select an appropriate option and Click the **OK** button to accept the changes to the **Location Categories**.





The figure shows that 21 sensor designs will be generated (one for each combination of the seven sensor set sizes and three response times).



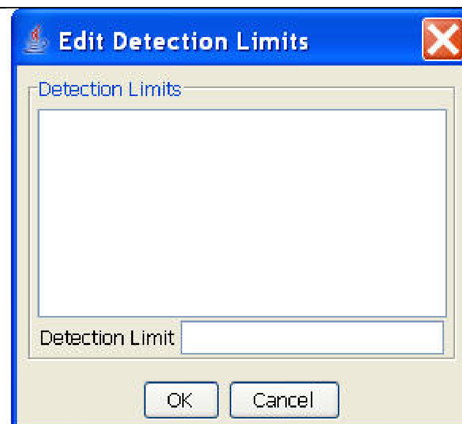
5.8. *Specifying the Costs*

This feature is currently not available.

5.9. *Specifying the Detection Limits*

Click the **Edit** button to the right of the **Detection Limits** text box.

The **Edit Detection Limits** dialog box opens. If no detection limit is entered, the default is zero.

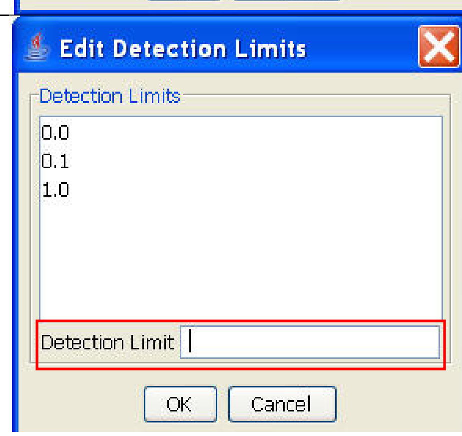


Type **0.0** in the **Detection Limit** textbox and click **Enter**.

Repeat this process for **0.1** and **1.0**, remembering to press the **Enter** key after each entry.

Click the **OK** button to accept the changes to the **Detection Limits**.

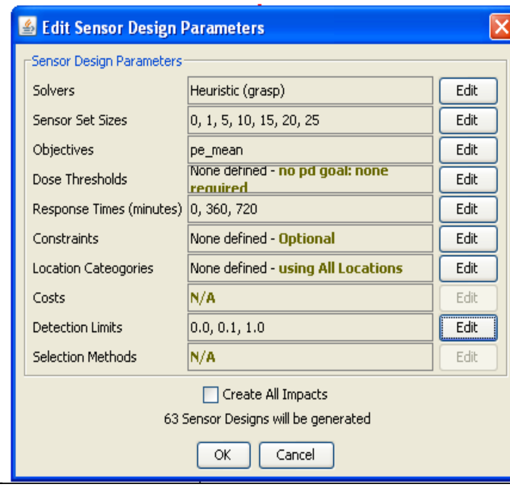
The **Edit Detection Limits** dialog box closes, and the changes become effective.



5.10. Specifying the Selection Method

This feature is currently not available.

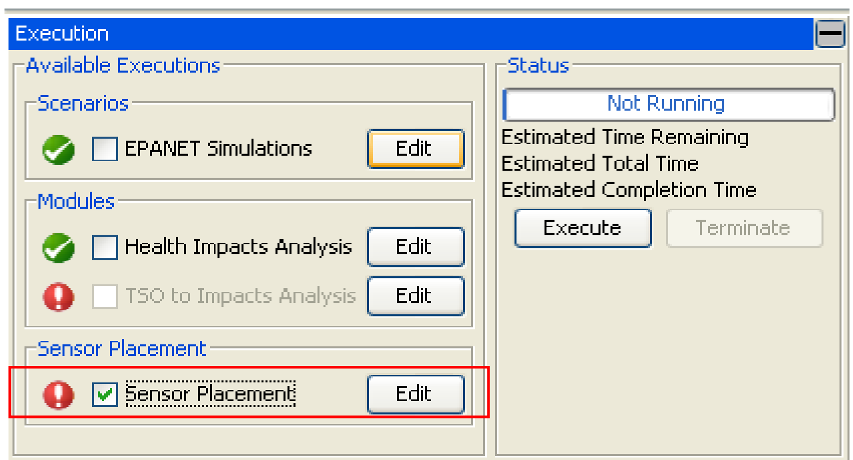
The figure shows that 63 sensor designs will be generated (one for each combination of the seven sensor set sizes and three response times, and three detection limits).



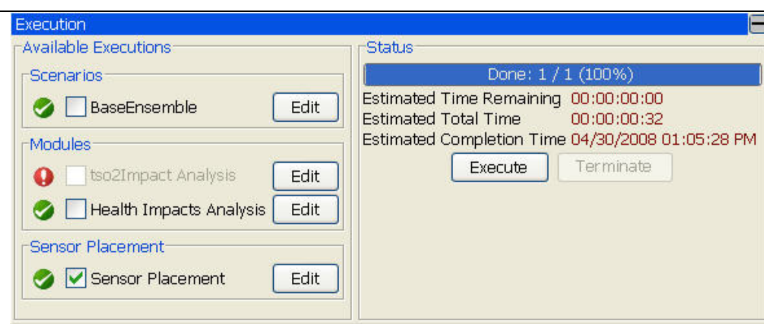
5.11. Sensor Placement Execution

To determine the sensor placements, click the **Sensor Placement** check box.

Click the **Execute** button. Note that run times can be quite long.



At the completion of the execution, Sensor Placement will be highlighted with a green check.

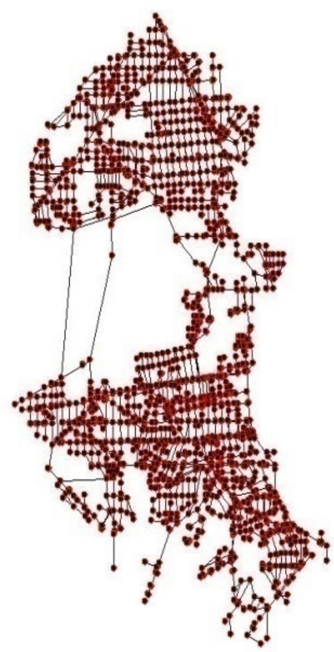


6. Maps

Output maps are produced in ensemble analysis mode by performing a health impacts analysis and by running the sensor placement algorithm.

6.1. Default Map

The water network map of the currently loaded ensemble is identified as Default in the pull-down list of maps.



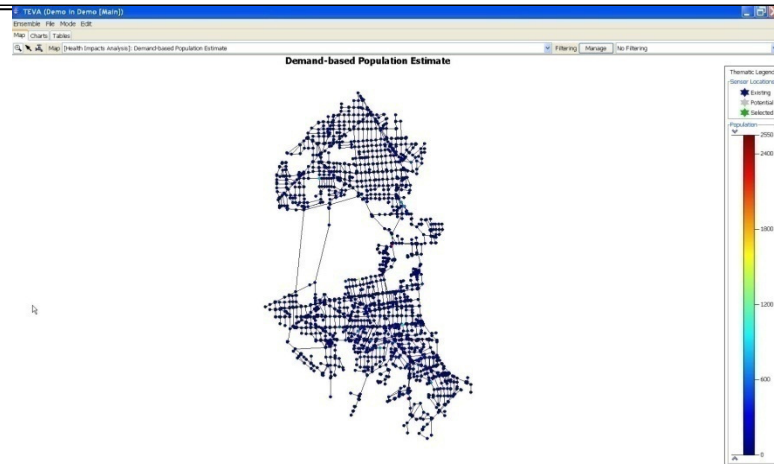
6.2. Maps Produced by Health Impacts Analysis

In the pull-down list of maps, the names of all the maps produced by performing the health impacts analysis start with the prefix [Health Impacts Analysis].

6.2.1. *Demand-Based Population Estimate*

Choose [Health Impact Analysis]: Population Estimate.

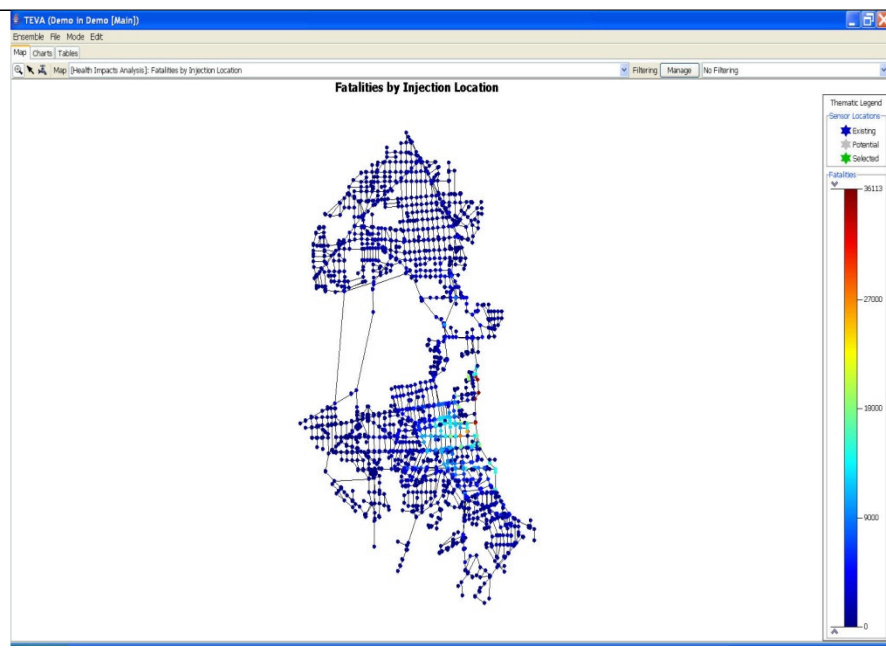
The Demand-based Population Estimate map depicts the population estimated at each node based on the demand at the node.



6.2.2. *Estimated fatalities by Injection Location*

Choose [Health Impact Analysis]: Estimated Fatalities by Injection Location.

The Estimated Fatalities by Injection Location map depicts the total estimated fatalities attributable to each possible injection. The data are depicted at the single node where the injection occurs.



Note that this map indicates "Fatalities by Injection Location," a software update now titles all such maps with "estimated" before facilities.

6.2.3. Additional Maps

TEVA-SPOT also produce the following maps which can be displayed by choosing the appropriate function:

Estimated Fatalities by Injection Location — Logarithmic: Depicts the same data as the Estimated Fatalities by Injection Location map, but with the colors distributed on a logarithmic, rather than a linear, scale.

Dosage by Injection Location: Depicts the total ingested dosage attributable to each possible injection. The data are depicted at the single node where the injection occurs.

Response by Injection Location: Depicts the total response (number of individuals who become diseased) attributable to each possible injection. The data are depicted at the single node where the injection occurs.

Estimated Fatalities by Receptor Location — 10th Percentile: Depicts the estimated fatalities at each node attributable to the injection or injection combination ranked at the 10th percentile of total estimated fatalities.

Estimated Fatalities by Receptor Location — 25th Percentile: Depicts the estimated fatalities at each node attributable to the injection or injection combination ranked at the 25th percentile of total estimated fatalities. It also identifies that injection or injection combination and the total estimated fatalities attributable to it.

Estimated Fatalities by Receptor Location — 50th Percentile: Depicts the estimated fatalities at each node attributable to the injection or injection combination ranked at the 50th percentile of total estimated fatalities. It also identifies that injection or injection combination and the total estimated fatalities attributable to it.

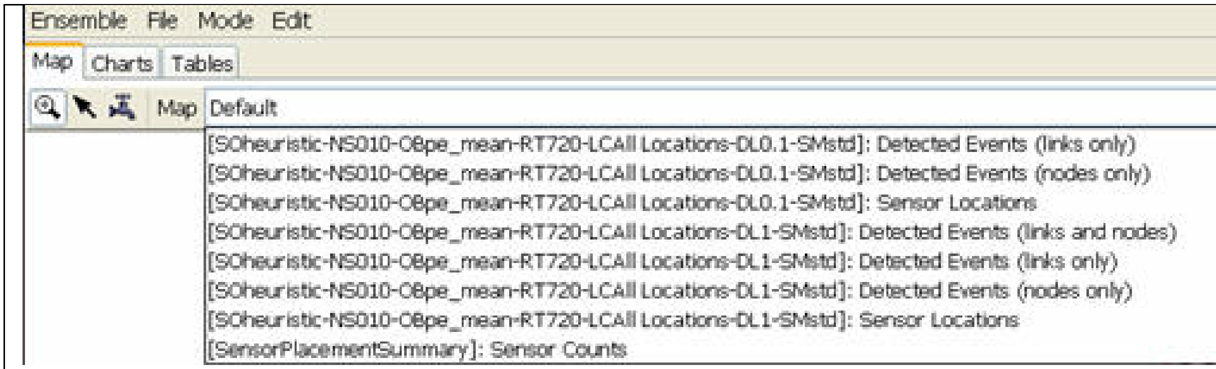
Estimated Fatalities by Receptor Location — 75th Percentile: Depicts the estimated fatalities at each node attributable to the injection or injection combination ranked at the 75th percentile of total estimated fatalities. It also identifies that injection or injection combination and the total estimated fatalities attributable to it.

Estimated Fatalities by Receptor Location — 90th Percentile: Depicts the estimated fatalities at each node attributable to the injection or injection combination ranked at the 90th percentile of total estimated fatalities.

Estimated fatalities by Receptor Location — 100th Percentile: Depicts the estimated fatalities at each node attributable to the injection or injection combination ranked at the 100th percentile of total estimated fatalities (i.e., to the most lethal scenario). It also identifies that injection or injection combination and the total estimated fatalities attributable to it.

All of the maps mentioned above have associated logarithmic maps which depict the same data but with the colors distributed on a logarithmic, rather than a linear, scale.

6.3. Maps Produced by the Sensor Placement Algorithm



The map naming convention follows a specific pattern. The first part of the name refers to the solver chosen for the optimization. The rest of the name refers to the number of sensors, the objective of the optimization, the response time, the location categories, the detection limit, and finally the selection method. Selection method has no specific meaning now, but is a place holder for future development.

For example, SOheuristic-NS025-OBpe_mean-RT720-LCAllLocations-DL0-SMstd refers to the sensor design that was created using the following sensor design parameters: SO refers to solver = heuristic, NS or number of sensors = 25, OB or objective = mean estimated population exposed, RT or response time = 720 minutes, LC or location category = all locations, DL or detection limit = 0 and SM or selection method = standard.

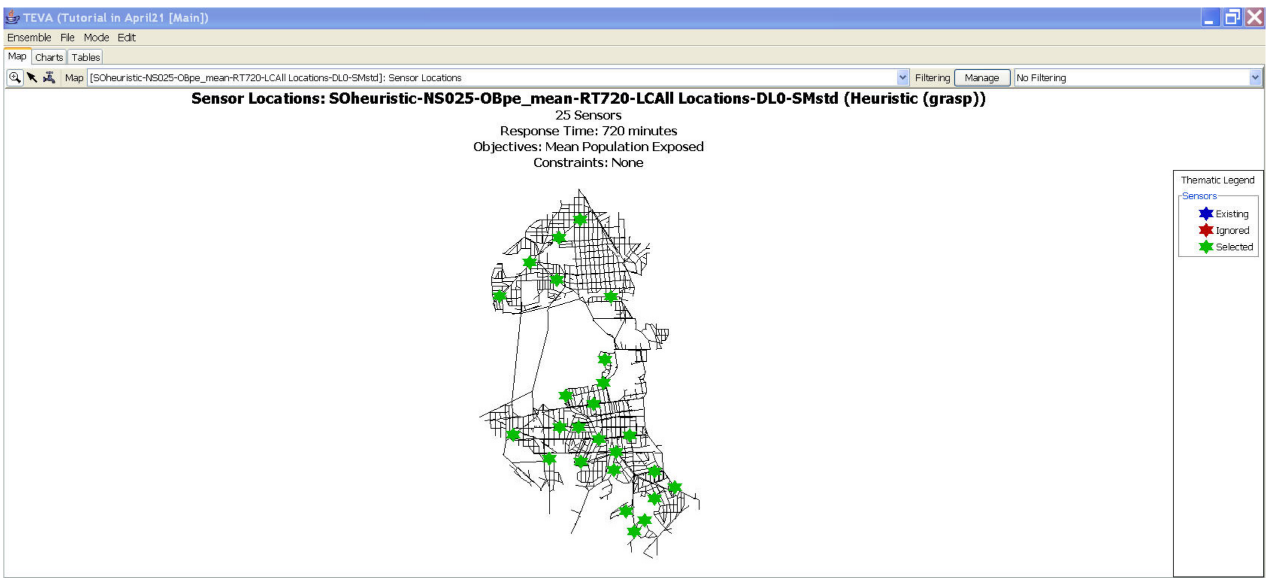
All of the sensor designs created will have the following maps associated with them: Sensor Locations, Detected Events (nodes only), Detected Events (links and nodes), and Detected Events (links only). Each map is described in more detail in the following sections.

6.3.1. *Sensor Locations*

The locations of the sensors are marked by stars. Three categories (Existing, Selected, and Ignored) of sensor locations are assigned different colors, according to the legend in the map. Right clicking on the legend of a particular sensor removes or adds that type from or to the map.

Examine the map of sensor locations for 25 sensors at a response time of 720 minutes.

From the Map pull-down list, select the map entitled [SOheuristic-NS025-OBpe_mean-RT720-LCAllLocations-DL0-SMstd]: Sensor Locations. The map below will be displayed with the 25 sensors being identified with green stars.

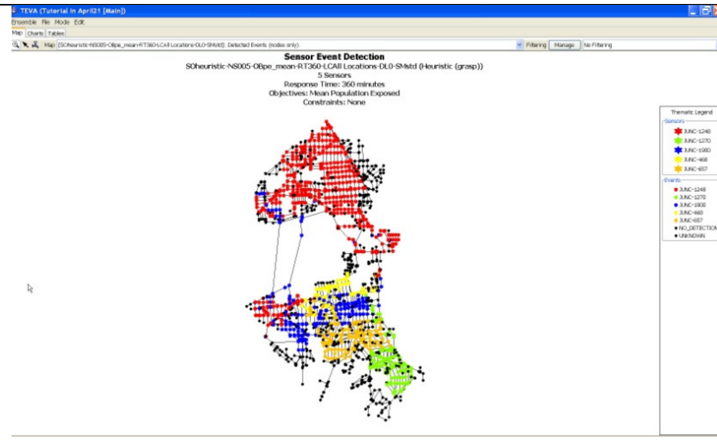


6.3.2. *Detected Events (Nodes Only)*

Now examine the map of the detected events for nodes only associated with 5 sensors and a response time of 360 minutes.

From the Map pull-down menu, select the map entitled [SOheuristic-NS005-OBpe_mean-RT360-LCAllLocations-DL0-SMstd]: Detected Events (nodes only).

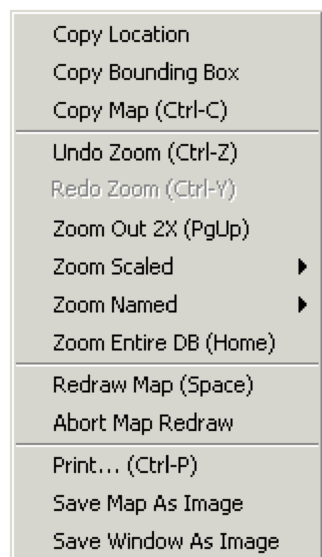
Although it is difficult to see at the whole-network scale, this map also depicts the 5 sensors placed by the Sensor Placement algorithm, each colored with a different color identified in the legend.

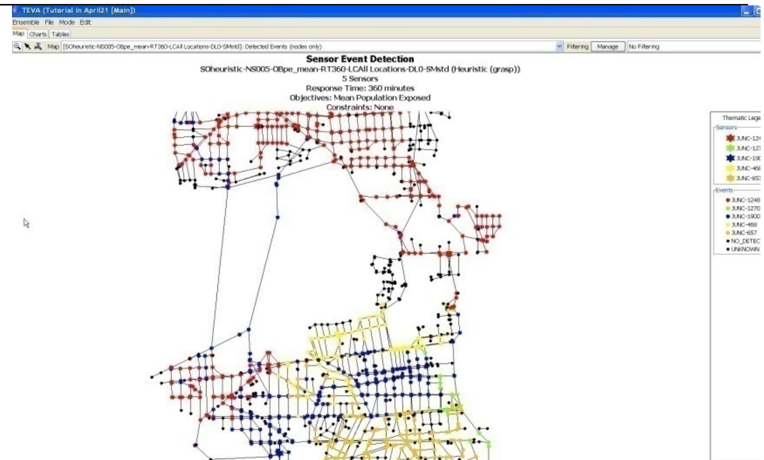


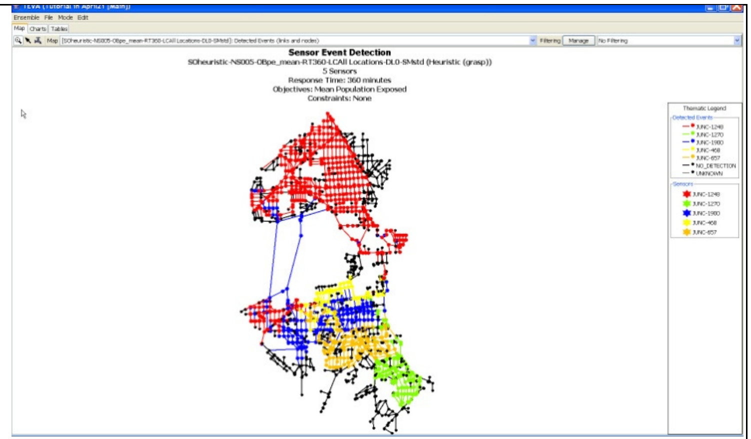
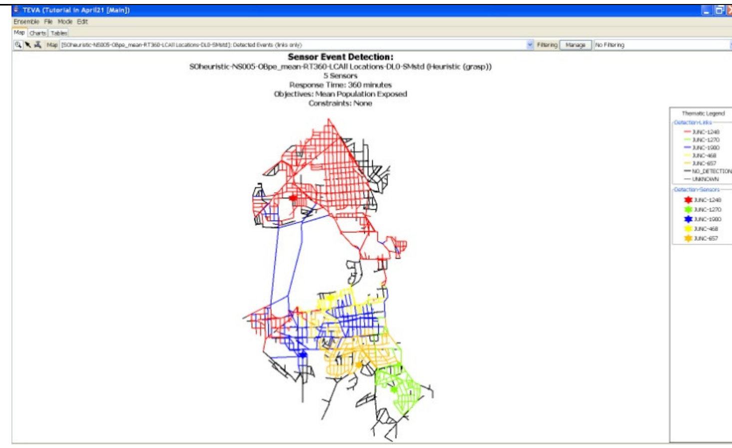
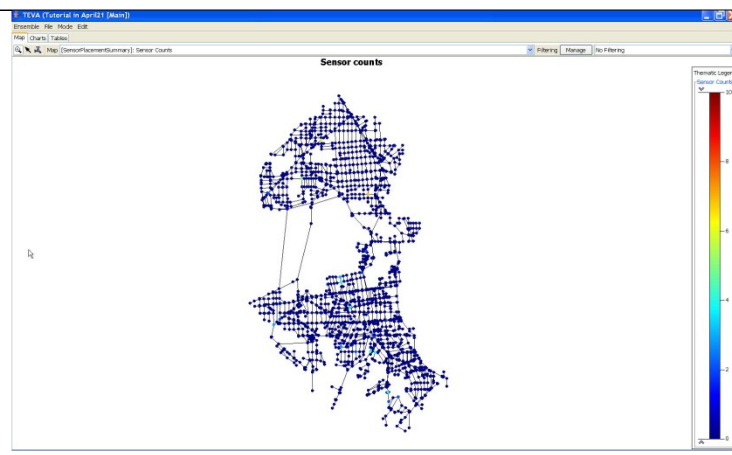
To see the sensors, zoom in to a part of the map.

To zoom, right click on the map to get the Map Pop Up Window as shown.

From Zoom Scaled, select Zoom In 2X Pg Down.



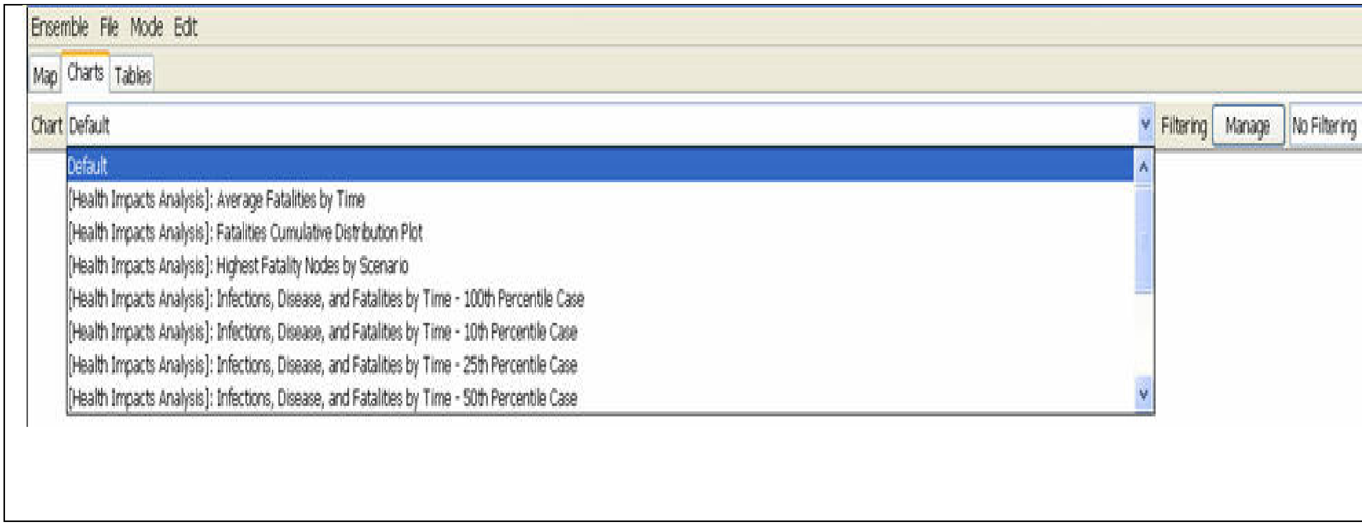
This zoomed map is then displayed. Note: To remove the zoom, right click on the map and select Undo Zoom.	

6.3.3. ***Detected Events (Links and Nodes)*** Now examine the map of the detected events for links and nodes associated with 5 sensors and a response time of 360 minutes. From the Map pull-down menu, select the map entitled [SOheuristic-NS005-OBpe_mean-RT360-LCAllLocations-DL0-SMstd]: Detected Events (links and nodes).	
6.3.4. ***Detected Events (Links Only)*** Now examine the map of the detected events for links only associated with 5 sensors and a response time of 360 minutes. From the Map pull-down menu, select the map entitled [SOheuristic-NS005-OBpe_mean-RT360-LCAllLocations-DL0-SMstd]: Detected Events (links only).	
6.3.5. ***Sensor Counts*** Select [SensorPlacementSummary]: Sensor Counts. By coloring its nodes appropriately, the Sensor Counts map shows the number of sensor designs that placed a sensor at the node. For all sensor network designs created, this map shows which locations were selected most often.	

6.4. Charts

Charts are produced in ensemble analysis mode by performing a health impacts analysis and are not produced by running the sensor placement algorithm. No chart has been designated as the default chart.

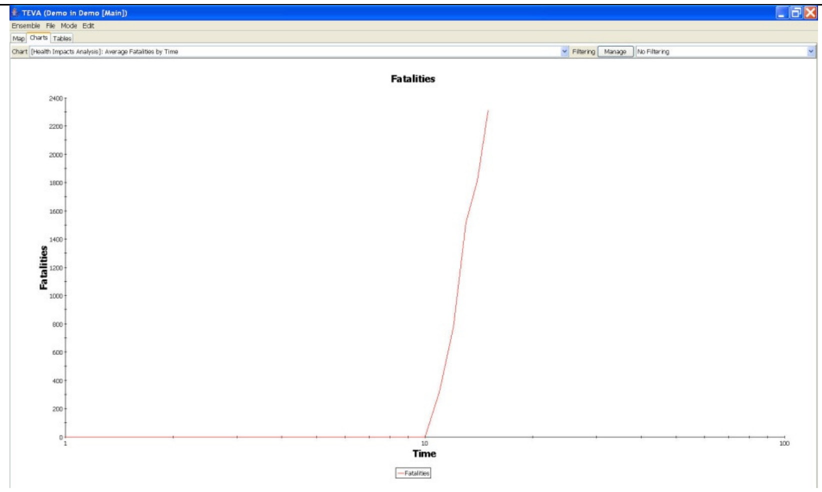
By clicking on the Charts tab, a Chart pull-down list will appear with the names of all the charts produced by performing a health impacts analysis starting with the prefix [Health Impacts Analysis]. These charts present health impacts either as a time series (i.e., a function of time), as a cumulative distribution function, or by scenario (i.e., injection location or injection combination, in rank order). <u>For this tutorial only one chart will be discussed</u>.



6.4.1. *Average Estimated Fatalities by Time*

Select [Health Impacts Analysis]: Average Estimated Fatalities by Time.

This chart depicts estimated fatalities averaged over all the possible injections or injection combinations defined by the contaminant release scenario, as a function of time in hours.



6.4.2. *Additional Charts*

TEVA-SPOT also produces the following charts which can be displayed by choosing the appropriate function:

Total Estimated Fatalities by Scenario: Depicts the estimated fatalities resulting from each injection or injection combination, sorted in order of increasing lethality. The curve in this chart is obtained by sorting the rows of the Ensemble Summary table in increasing order of the data in the Number of Estimated Fatalities column, then plotting the data in that column.

Maximum Concentration by Scenario: Depicts the maximum concentration attributable to each injection or injection combination, sorted in order of increasing concentration. The curve in this chart is obtained by sorting the rows of the Ensemble Summary table in increasing order of the data in the Max Concentration column, then plotting the data in that column.

Maximum Individual Dose by Scenario: Depicts the maximum individual dose attributable to each injection or injection combination, sorted in order of increasing dose. The curve in this chart is obtained by sorting the rows of the Ensemble Summary table in increasing order of the data in the Max Individual Dose column, then plotting the data in that column.

Total Infected Population by Scenario: Depicts the number of infected individuals attributable to each injection or injection combination, sorted in order of increasing infections. The curve in this chart is obtained by sorting the rows of the Ensemble Summary table in increasing order of the data in the Number of Infected column, then plotting the data in that column.

Highest Fatality Nodes by Scenario: Depicts the minimum number of nodes whose populations have to be combined to yield 90% of the estimated fatalities attributable to the injection or injection combination, sorted by increasing effect. The curve in this chart is obtained by sorting the rows of the Ensemble Summary table in increasing order of the data in the Nodes for 90% Estimated Fatalities column, then plotting the data in that column.

Estimated Fatalities Cumulative Distribution Plot: Depicts the cumulative probability distribution of the estimated fatalities attributable to each injection or injection combination, sorted by increasing lethality. The curve in this chart is obtained by sorting the rows of the Ensemble Summary table in increasing order of the data in the Number of Estimated Fatalities column, then plotting essentially the row number (or, more precisely, the fractional position of the row within the table) as a function of the row's datum in that column.

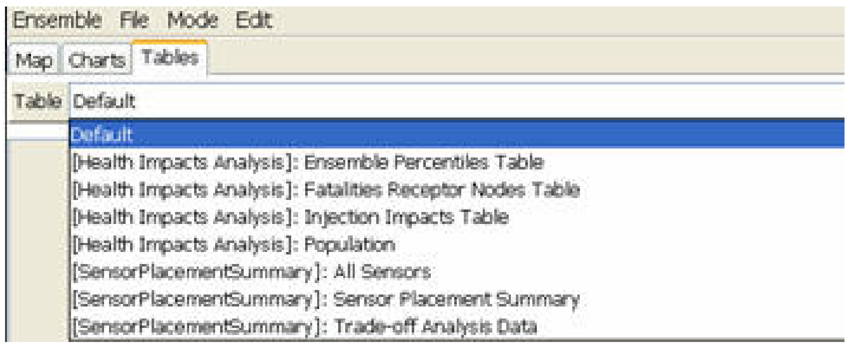
Estimated Infections, Disease, and Fatalities by Time — 10th Percentile Case: Depicts, for the injection or injection combination yielding estimated fatalities ranked at the 10th percentile level, the growth and decay over time of the estimated number of infected (i.e., individuals exposed but not yet diseased), the estimated number of diseased (i.e., individuals showing symptoms but not yet deceased), and the estimated number of fatalities. It also identifies the injection or injection combination yielding the 10th percentile case and the number of estimated fatalities in that case.

The same chart can be displayed for the 25th, 50th, 75th, 90th, and 100th Percentile Cases.

6.5. Tables

By clicking on the Tables tab, a Tables pull-down list will appear with the names of all the tables produced by executing the health impacts analysis and sensor placement.

No table has been designated as the default table. Note that all tables can be output to Microsoft Excel by choosing the **Table** pull down menu when on the "**Table**" tab is selected. Alternatively, data from tables can be copied (select row, hit control-A, then Control C) and pasted (control V) into a spreadsheet or other document.



6.5.1. ***Health Impacts Analysis - Injection Impact Table***

The Injection Impact Table shows, for each possible injection or injection combination (i.e., scenario):

- the maximum concentration attributable to the scenario,
- the maximum individual dose attributable to the scenario,
- the number of infected individuals attributable to the scenario,
- the number of estimated fatalities attributable to the scenario,
- the minimum number of nodes whose populations have to be combined to yield 90% of the estimated fatalities attributable to the scenario, and
- the number of nodes with estimated fatalities attributable to the scenario.

TEVA (Demo in Demo [Main])

Ensemble File Mode Edit

Map Charts Tables

Table [Health Impacts Analysis]: Injection Impacts Table

Summary Table

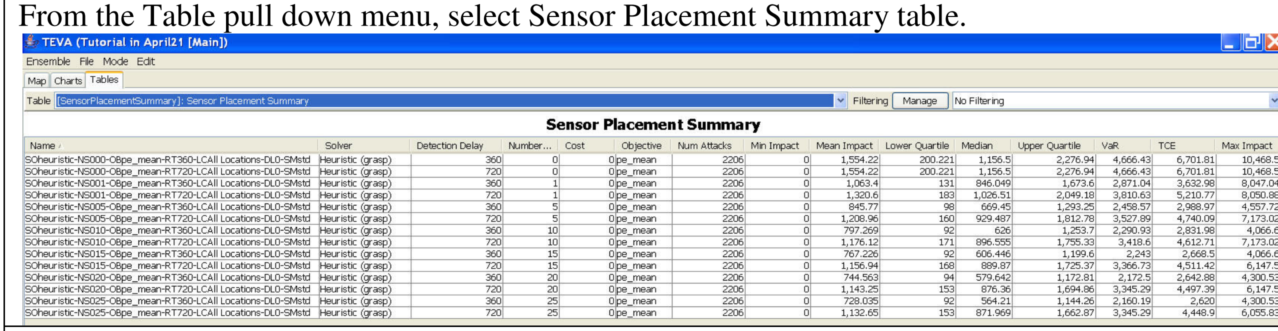
Injectio...	Max Concentration	Max Individual Dose	Number of Infected	Number of Fatalities	Nodes for 90% Fatalities	Nodes with Fatalities
JUNC-1	0	0	0	0	0	0
JUNC-1000	274.243	46.304	7,425.141	7,425.141	64	287
JUNC-100	951.332	83.667	434.991	434.991	7	8
JUNC-1001	706.959	105.423	498.738	498.738	11	19
JUNC-1002	159.102	27.477	14,086.864	14,086.864	97	320
JUNC-1003	335.12	18.508	12,816.36	12,816.36	93	307
JUNC-1005	478.941	52.999	3,577.147	3,577.147	52	295
JUNC-1004	658.404	9.19	9,338.417	9,338.417	75	297
JUNC-1006	481.581	61.072	3,472.211	3,472.211	50	291
JUNC-1007	310.575	7.542	10,694.095	10,694.095	84	297
JUNC-1008	3.144	0.386	21,054.131	21,054.131	139	411
JUNC-1009	17.775	2.306	18,622.463	18,622.463	137	414
JUNC-101	261.196	14.49	172	172	5	7
JUNC-1010	391.281	42.609	13,947.548	13,947.548	79	386
JUNC-1011	175.014	24.196	11,685.573	11,685.573	89	326
JUNC-1012	1,401.841	28.611	86	86	2	2
JUNC-1013	408.611	37.599	12,425.067	12,425.067	94	421
JUNC-1014	4.729	0.526	20,837.473	20,837.473	141	423
JUNC-1016	513.76	10.631	9,924.442	9,924.442	79	308
JUNC-1015	4,575.001	810.468	19	19	1	1
JUNC-1017	17.615	0.829	19,897.23	19,897.23	143	420
JUNC-1018	563.662	42.307	3,268.71	3,268.71	49	287
JUNC-102	374.852	17.518	417	417	6	9
JUNC-1019	738.753	109.497	1,655.354	1,655.354	24	259
JUNC-1020	0	0	0	0	0	0
JUNC-1021	17.78	0.882	19,458.252	19,458.252	140	410
JUNC-1023	1,202.154	8.6	77	77	2	2
JUNC-1024	0	0	0	0	0	0
JUNC-1025	0	0	0	0	0	0
JUNC-1026	0	0	0	0	0	0
JUNC-1027	586.72	106.122	2,444.479	2,444.479	43	280
JUNC-1028	0	0	0	0	0	0
JUNC-1029	658.808	71.427	2,253.641	2,253.641	28	302
JUNC-103	496.67	19.345	86	86	3	4
JUNC-1030	0	0	0	0	0	0
JUNC-1031	632.692	7.115	6,709.184	6,709.184	64	281
JUNC-1032	190.021	23.893	2,783.34	2,783.34	33	339
JUNC-1033	159.482	31.241	3,184.594	3,184.594	29	160
JUNC-1034	790.328	107.277	57	57	2	2
JUNC-1035	46.098	2.818	8,597.085	8,597.085	41	337
JUNC-1036	2,595.901	25.164	1,963.842	1,963.842	25	259
JUNC-1037	267.399	11.497	2,673.193	2,673.193	31	335
JUNC-1038	43.45	5.612	8,596.776	8,596.776	41	335
JUNC-1039	18.256	1.401	18,855.621	18,855.621	145	478
JUNC-1040	0	0	0	0	0	0
JUNC-1041	20.264	0.455	19,313.893	19,313.893	127	512
JUNC-1042	70.717	0.455	18,801.719	18,801.719	123	507
JUNC-1044	20.03	0.777	11,279.837	11,279.837	61	355
JUNC-1043	101.42	5.699	9,088.63	9,088.63	44	338
JUNC-1046	28.882	1.07	18,295.936	18,295.936	142	498
JUNC-1045	49.733	7.105	1,439.399	1,439.399	24	44
JUNC-1047	296.389	17.474	2,196.097	2,196.097	16	43
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

6.5.2. ***Health Impacts Analysis - Additional Tables***

- **Estimated fatalities Receptor Nodes Table** - The Estimated fatalities Receptor Nodes table shows, for each node, the number of estimated fatalities at that node attributable to six specific injections or injection combinations (i.e., scenarios): the ones whose consequent total estimated fatalities are ranked at the 10th, 25th, 50th, 75th, 90th, and 100th percentiles (the last of these six is the most lethal scenario).
- **Ensemble Percentiles Table** - The Ensemble Percentiles table shows the maximum concentration, maximum individual dose, number of infected individuals, and number of estimated fatalities attributable to the injection or injection combination at the 10th, 25th, 50th, 75th, 90th, and 100th percentile levels, as well as the average of those quantities over all the injections or injection combinations.
- **Population** - The Population Table shows the population at each node. If the Population Model HIA parameter is set to From Scenario, the map shows the population data imported into the currently loaded ensemble; if it is set to Demand-based, the map shows the population deduced from the demand for water at each node of the water network.
- **Tables Produced by the Sensor Placement Algorithm** - In the output products pull-down list on the control bar, the names of all the tables produced by performing a sensor design start with the prefix [SensorPlacementSummary]. These tables present either summary data resulting from the sensor design or its trade-off analyses.

6.5.3. ***Sensor Placement Summary***

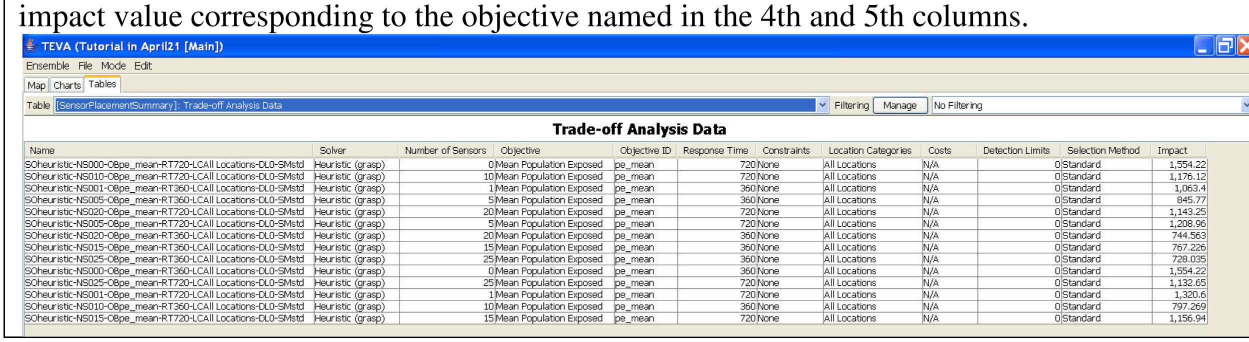
From the Table pull down menu, select Sensor Placement Summary table.



Name	Solver	Detection Delay	Number...	Cost	Objective	Num Attacks	Min Impact	Mean Impact	Lower Quartile	Median	Upper Quartile	VaR	TCE	Max Impact
SOheuristic-NS000-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	360	0	0	pe_mean	2206	0	1,554.22	200.221	1,156.5	2,276.94	4,666.43	6,701.81	10,468.5
SOheuristic-NS000-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	720	0	0	pe_mean	2206	0	1,554.22	200.221	1,156.5	2,276.94	4,666.43	6,701.81	10,468.5
SOheuristic-NS001-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	360	1	0	pe_mean	2206	0	1,063.4	131	846.049	1,673.6	2,871.04	3,632.98	8,047.04
SOheuristic-NS001-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	720	1	0	pe_mean	2206	0	1,320.6	183	1,026.51	2,049.18	3,810.63	5,210.77	8,050.88
SOheuristic-NS005-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	360	5	0	pe_mean	2206	0	845.77	98	669.45	1,293.25	2,458.57	2,988.97	4,557.72
SOheuristic-NS005-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	720	5	0	pe_mean	2206	0	1,208.96	160	929.487	1,812.78	3,527.89	4,740.09	7,173.02
SOheuristic-NS010-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	360	10	0	pe_mean	2206	0	797.269	92	626	1,253.7	2,290.93	2,831.98	4,066.6
SOheuristic-NS010-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	720	10	0	pe_mean	2206	0	1,176.12	171	896.555	1,755.33	3,418.6	4,612.71	7,173.02
SOheuristic-NS015-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	360	15	0	pe_mean	2206	0	767.226	92	606.446	1,199.6	2,243	2,668.5	4,066.6
SOheuristic-NS015-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	720	15	0	pe_mean	2206	0	1,156.94	168	889.87	1,725.37	3,366.73	4,511.42	6,147.5
SOheuristic-NS020-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	360	20	0	pe_mean	2206	0	744.563	94	579.642	1,172.81	2,172.5	2,642.88	4,300.53
SOheuristic-NS020-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	720	20	0	pe_mean	2206	0	1,143.25	153	876.36	1,694.86	3,345.29	4,497.39	6,147.5
SOheuristic-NS025-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	360	25	0	pe_mean	2206	0	728.035	92	564.21	1,144.26	2,160.19	2,620	4,300.53
SOheuristic-NS025-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	720	25	0	pe_mean	2206	0	1,132.65	153	871.969	1,662.87	3,345.29	4,448.9	6,055.83

6.5.4. ***Trade-off Analysis Data***

This table shows the name of the sensor design, the solver that produced the design, the number of sensors, the objective, the abbreviated form of the objective, the response time in minutes, the constraint, the location categories, the cost, the detection limit, the selection method, and the impact value corresponding to the objective named in the 4th and 5th columns.

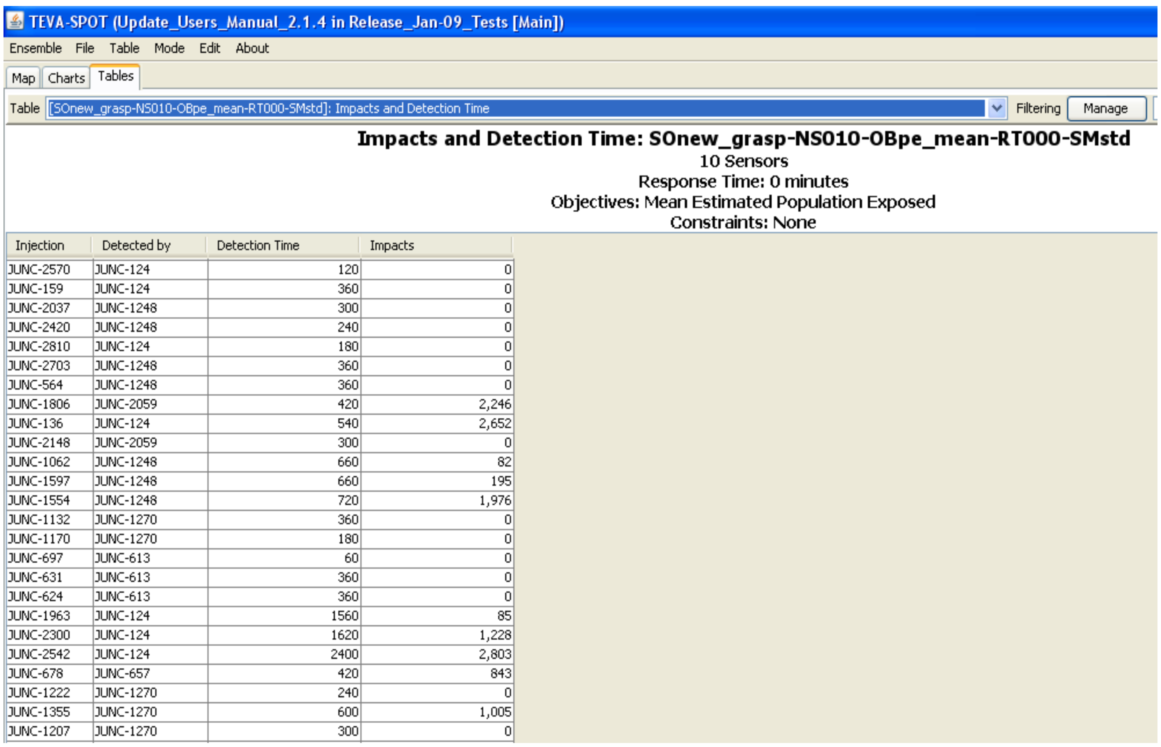


Name	Solver	Number of Sensors	Objective	Objective ID	Response Time	Constraints	Location Categories	Costs	Detection Limits	Selection Method	Impact
SOheuristic-NS000-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	0	Mean Population Exposed	pe_mean	720	None	All Locations	N/A	0	Standard	1,554.22
SOheuristic-NS010-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	10	Mean Population Exposed	pe_mean	720	None	All Locations	N/A	0	Standard	1,176.12
SOheuristic-NS001-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	1	Mean Population Exposed	pe_mean	360	None	All Locations	N/A	0	Standard	1,063.4
SOheuristic-NS005-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	5	Mean Population Exposed	pe_mean	360	None	All Locations	N/A	0	Standard	845.77
SOheuristic-NS020-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	20	Mean Population Exposed	pe_mean	720	None	All Locations	N/A	0	Standard	1,143.25
SOheuristic-NS005-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	5	Mean Population Exposed	pe_mean	720	None	All Locations	N/A	0	Standard	1,208.96
SOheuristic-NS020-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	20	Mean Population Exposed	pe_mean	360	None	All Locations	N/A	0	Standard	744.563
SOheuristic-NS015-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	15	Mean Population Exposed	pe_mean	360	None	All Locations	N/A	0	Standard	767.226
SOheuristic-NS025-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	25	Mean Population Exposed	pe_mean	360	None	All Locations	N/A	0	Standard	728.035
SOheuristic-NS000-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	0	Mean Population Exposed	pe_mean	360	None	All Locations	N/A	0	Standard	1,554.22
SOheuristic-NS025-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	25	Mean Population Exposed	pe_mean	720	None	All Locations	N/A	0	Standard	1,132.65
SOheuristic-NS001-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	1	Mean Population Exposed	pe_mean	720	None	All Locations	N/A	0	Standard	1,320.6
SOheuristic-NS010-OBpe_mean-RT360-LCAll Locations-DL0-SMstd	Heuristic (grasp)	10	Mean Population Exposed	pe_mean	360	None	All Locations	N/A	0	Standard	797.269
SOheuristic-NS015-OBpe_mean-RT720-LCAll Locations-DL0-SMstd	Heuristic (grasp)	15	Mean Population Exposed	pe_mean	720	None	All Locations	N/A	0	Standard	1,156.94

6.5.5. *Impacts and Detection Time Tables*

An “Impacts and Detection Time” table appears for each sensor network design. The description for each sensor network design appears in the table pull down menu followed by the name of the table, i.e., Impacts and Detection Time.

Each row provides by **Injection Location** (node name) the sensor that detected the event (if detected), **detection time** when detected (length of the simulation time if undetected, time in seconds), and the **impact** associated with the event after detection. Units of the impacts are defined by the objective used for the sensor network design.

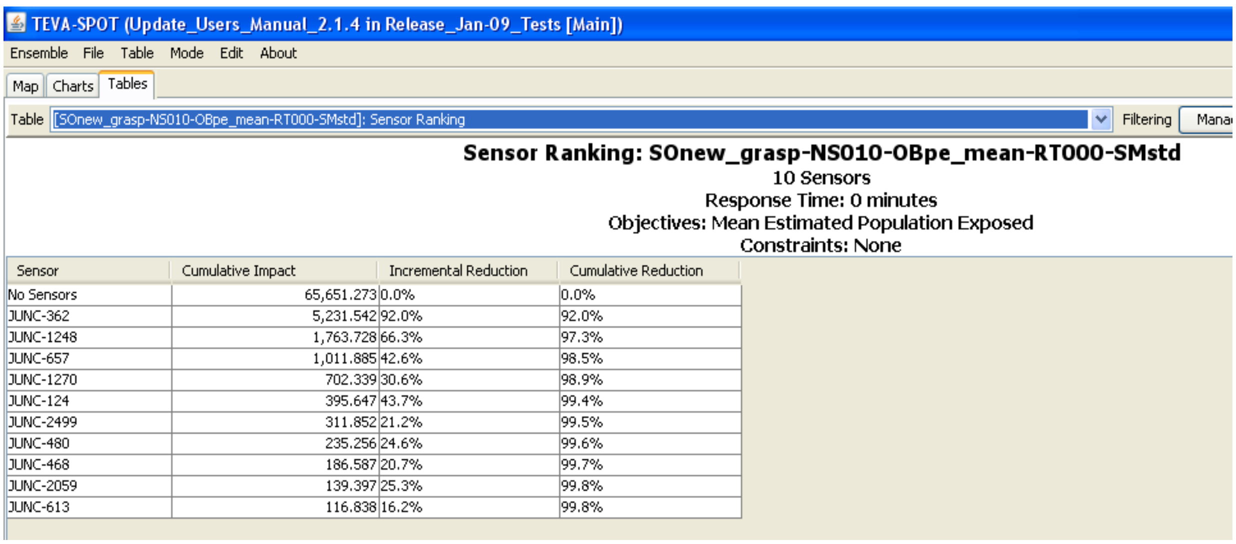


Injection	Detected by	Detection Time	Impacts
JUNC-2570	JUNC-124	120	0
JUNC-159	JUNC-124	360	0
JUNC-2037	JUNC-1248	300	0
JUNC-2420	JUNC-1248	240	0
JUNC-2810	JUNC-124	180	0
JUNC-2703	JUNC-1248	360	0
JUNC-564	JUNC-1248	360	0
JUNC-1806	JUNC-2059	420	2,246
JUNC-136	JUNC-124	540	2,652
JUNC-2148	JUNC-2059	300	0
JUNC-1062	JUNC-1248	660	82
JUNC-1597	JUNC-1248	660	195
JUNC-1554	JUNC-1248	720	1,976
JUNC-1132	JUNC-1270	360	0
JUNC-1170	JUNC-1270	180	0
JUNC-697	JUNC-613	60	0
JUNC-631	JUNC-613	360	0
JUNC-624	JUNC-613	360	0
JUNC-1963	JUNC-124	1560	85
JUNC-2300	JUNC-124	1620	1,228
JUNC-2542	JUNC-124	2400	2,803
JUNC-678	JUNC-657	420	843
JUNC-1222	JUNC-1270	240	0
JUNC-1355	JUNC-1270	600	1,005
JUNC-1207	JUNC-1270	300	0

6.5.6. ***Sensor Ranking***

A "Sensor Ranking" table appears for each sensor network design. The description for each sensor network design appears in the table pull down menu followed by the name of the table, in this case Sensor Ranking. Each row provides the prioritized sensor location, starting with the most effective sensor location to reduce impacts and ending with the least effective for the given sensor network design.

The column headings consist of sensor (node ID), cumulative impact, incremental impact reduction (percentage), and cumulative impact reduction (percentage). The units of impact are specified by the objective selected for the sensor network design. The first row provides the base, no sensors impact. Impact is mean impact.



Sensor	Cumulative Impact	Incremental Reduction	Cumulative Reduction
No Sensors	65,651.273	0.0%	0.0%
JUNC-362	5,231.542	92.0%	92.0%
JUNC-1248	1,763.728	66.3%	97.3%
JUNC-657	1,011.885	42.6%	98.5%
JUNC-1270	702.339	30.6%	98.9%
JUNC-124	395.647	43.7%	99.4%
JUNC-2499	311.852	21.2%	99.5%
JUNC-480	235.256	24.6%	99.6%
JUNC-468	186.587	20.7%	99.7%
JUNC-2059	139.397	25.3%	99.8%
JUNC-613	116.838	16.2%	99.8%

7. Filtering Criteria

Output products (i.e., maps, charts, and tables) are displayed in TEVA-SPOT's main window. Without filtering, the universe of available choices presented to the user in the output products pull-down list box on the control bar is often very large. By reducing the number of choices, the filtering controls make it easier to focus on those that meet particular criteria.

<table>
<tr><td>

7.1. Filtering Controls

The Filtering Controls are located in the right half of the control bar and include the **Manage** button and filter specification pull down list box.

</td><td>

</td></tr>
<tr><td>

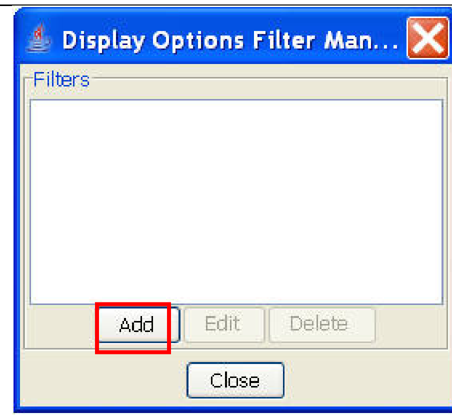
7.2. Manage Button

Click the **Manage** button.

The **Display Options Filter Management** dialog box opens.

Click the **ADD** button in the Display **Options Filter Management** dialog box.

</td><td>



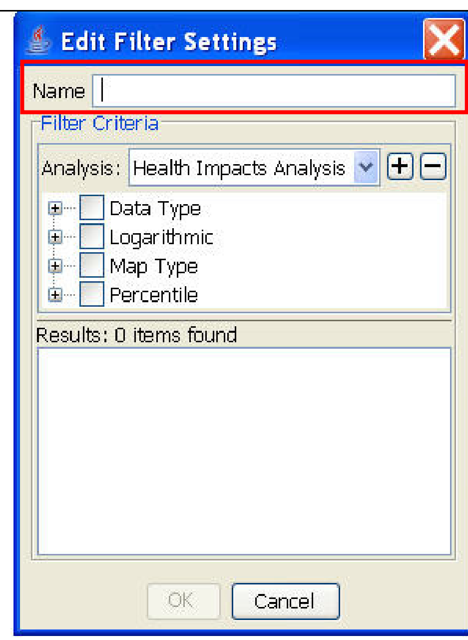
</td></tr>
<tr><td>

7.3. Creating a Filter Specification

The **Edit Filter Settings** dialog box opens.

The cursor is initially positioned in the **Name** text box, which is initially empty.

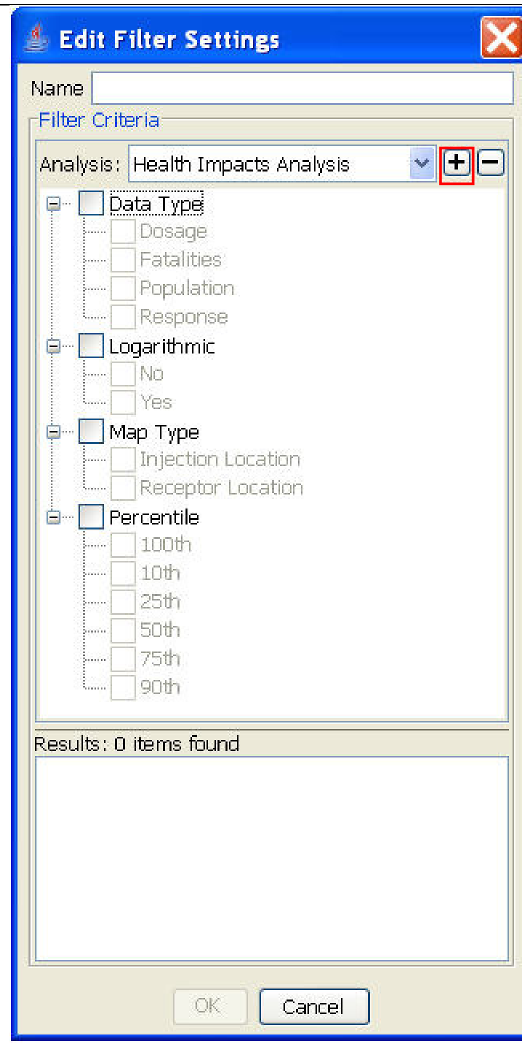
</td><td>

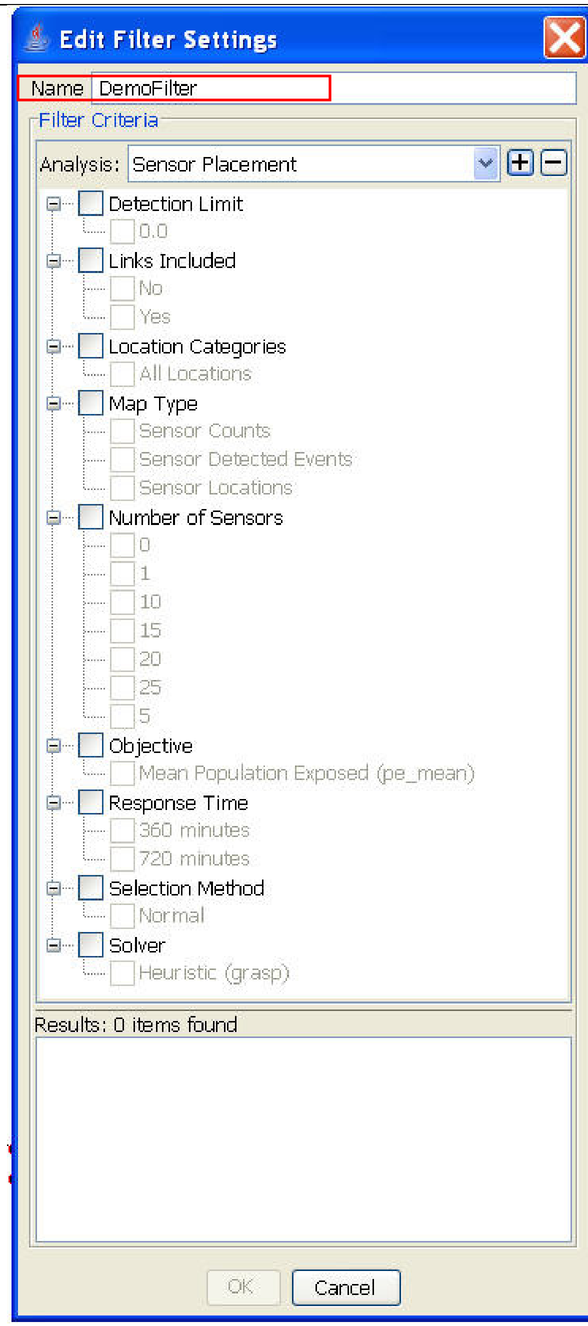


</td></tr>
<tr><td colspan="2">

At anytime, the user can click the plus button + to the right of the Analysis pull-down list box to fully expand the filtering tree, or adjacent minus button – to fully collapse it.

</td></tr>
</table>

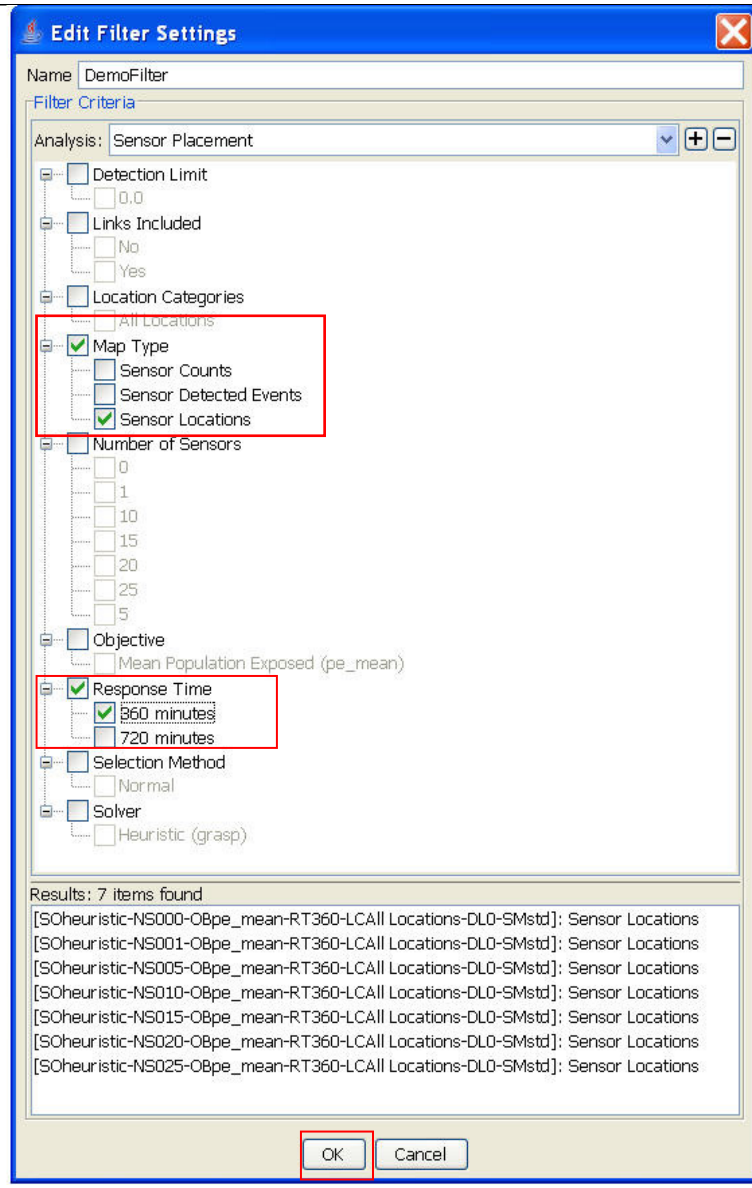
Click the plus button + to the right of the **Analysis** pull-down list box to fully expand the filtering tree. Then move and resize the dialog box until the whole filtering tree is visible. Because none of the attribute check boxes are checked initially, the value checkboxes are all initially disabled.	
At all times, the "Results: __items found" list box displays the output products selected by the current tree of filtering criteria, and the number of those products is indicated. Initially the tree selects no output products and the current count is 0. When attribute or value nodes are checked or unchecked in the filtering tree, the contents of the Results list box are recomputed and redisplayed, and the count is updated.	

Click the Name textbox and type the name **DemoFilter.** Click the Analysis pull-down list box in the Filter Criteria pane and select the Sensor Placement analysis type. A new filtering tree is displayed.	

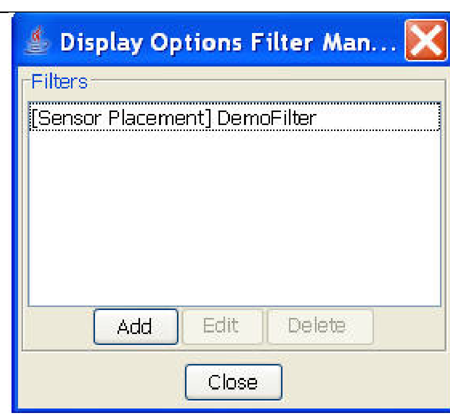
<table>
<tr>
<td>
Within the filtering tree, click check boxes

Map Type [Sensor Locator] and Response Time [360 minutes]

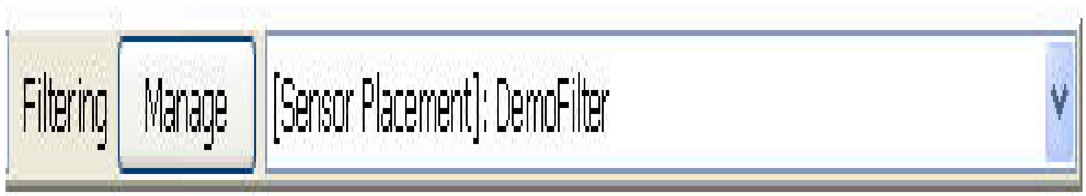
The OK button becomes enabled whenever the count becomes non-zero.

Click the OK button to accept the newly created filter specification
</td>
<td>


</td>
</tr>
<tr>
<td>
The Edit Filter Settings dialog box closes and the filter specifications are created.

The Display Options Filter Management dialog box is redisplayed to include the complete name of the new filter specification in the Filters list.
</td>
<td>


</td>
</tr>
</table>

Use the **Edit** button to change a **Filter Specification** and use the **Delete** button to delete a **Filter Specification.**
Current Filter Selections Pull Down List Box Under the Map Pull Down menu, only seven maps are available for display after the filtering.


8. Regret Analysis Mode

Regret Analysis provides a means to select the best sensor design among many. Multiple ensembles are created, e.g., different contaminants, release times, mass release rates, response delays, detection limits, and with each of these ensembles sensor designs are created. The impact files and sensor designs are loaded into the Regret Analysis and ***Evaluate Sensor*** (see TEVA-SPOT Toolkit) is used to compute the matrix of impacts. Every sensor design chosen is evaluated against every impact. The performance measures (*Preferred Overall Design and Preferred Design to Minimize Maximum Deviation*) are used to compute the difference between the best design (which is the design created for the particular impact) and all the other designs. There are no parameters to enter like there is in the Ensemble Analysis Mode.

The ***Preferred Overall Design and the Preferred Design to Minimize Maximum Deviation*** provide two indices of a sensor network design's overall performance. The ***Preferred Overall Design*** is determined by minimizing the square root of the sum of the squared deviations for a sensor design from the best case sensor design across all scenarios. The ***Preferred Design to Minimize Maximum Deviation*** is determined by minimizing the maximum deviation from the best case for a particular sensor design, across all scenarios.

It is important to understand the Regret Analysis prior to execution. Regret Analysis serves as a means to select a preferred sensor network design among many developed. Regret Analysis can be used to select a preferred sensor network design among different contaminants, release times or mass release rates (setup through different ensembles) and different response times and different detection limits. A single set of sensors should be selected, e.g., 10 sensors, in performing a Regret Analysis. <u>Sensor designs developed using **Population Dosed** (**PD**) with **Dose Thresholds** can now be used in the Regret Analysis, they could not be used with some earlier versions TEVA-SPOT</u>.

Using Regret Analysis to determine a preferred sensor network design among different objectives should be done with caution.

8.1. Input Data for Regret Analysis

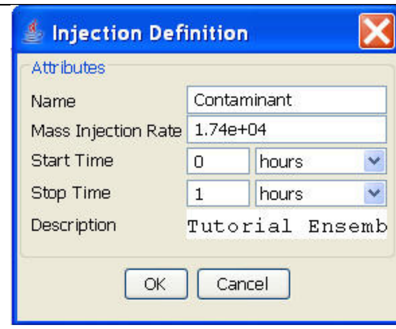
Setup and run Ensemble Analyses for two different mass injection rates using the data below. The ensembles will be distinguished by the two mass release rates below, please name the ensembles “**April30”** and “**low**,” to represent the higher mass loading and lower mass loading ensembles, respectively. Save each ensemble to the **Collection** named **Tutorial**. Run all three modules in each ensemble, i.e., EPANET Simulations, Health Impact Analysis, and Sensor Placement.

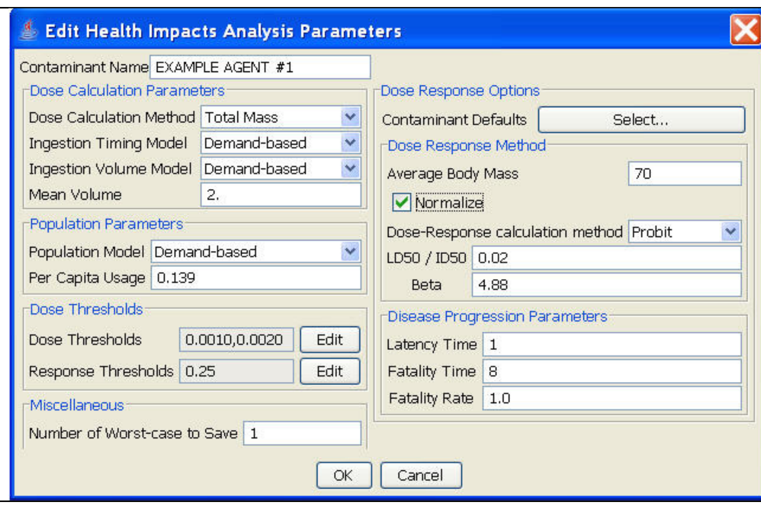
<table>
<tr><td>EPANET Simulations

Two different ensembles:

Mass Injection Rate:

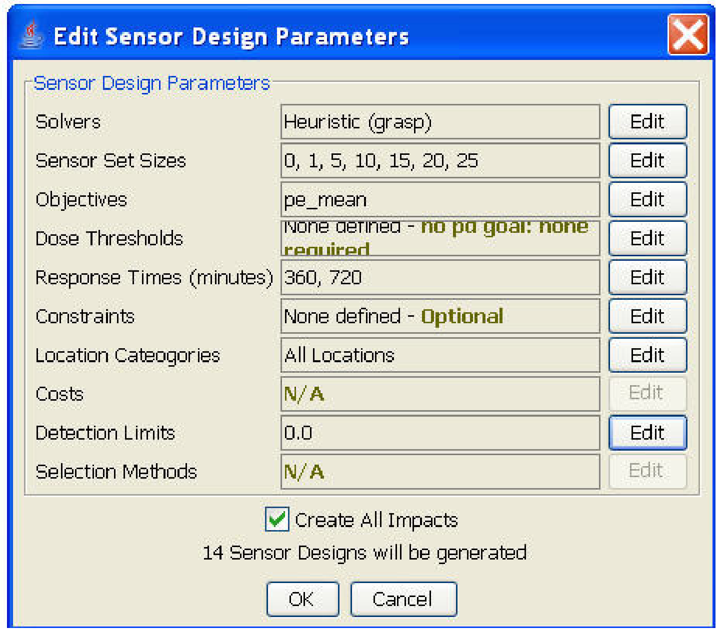
1.74E+04 mg/min for 1 hr

4.34E+03 mg/min for 1 hr</td><td>
</td></tr>
<tr><td>Health Impact Analysis

All parameters remain the same.</td><td>
</td></tr>
</table>

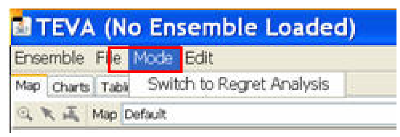
Sensor Placement

All parameters remain the same.



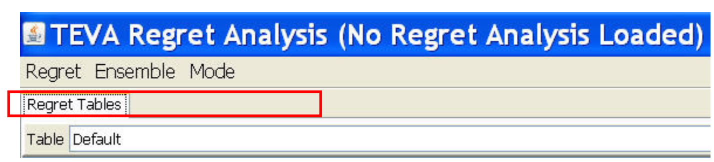
8.2. Mode Menu

The Mode menu is used to toggle back and forth between the two processing modes: ***Regret Analysis Mode*** and ***Ensemble Analysis Mode***. Clicking Mode in the menu bar displays the Mode menu.



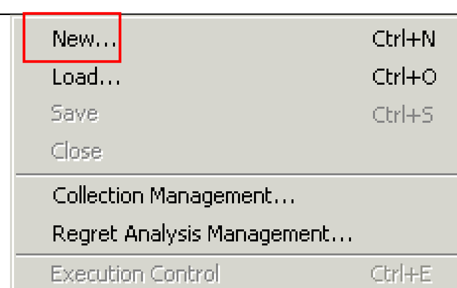
8.3. Regret Menu

Clicking Regret in the menu bar displays the Regret menu. Three menus (Regret, Ensemble, and Mode) are anchored on the menu bar in regret analysis mode.



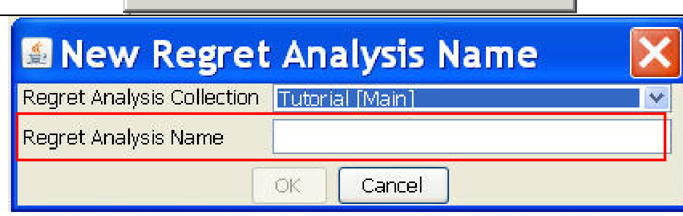
8.4. New

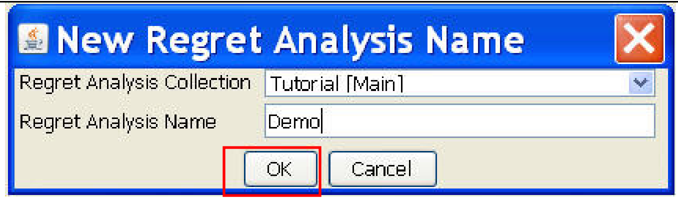
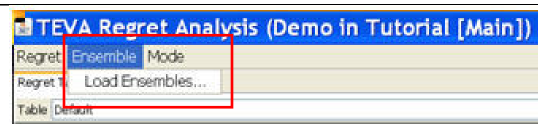
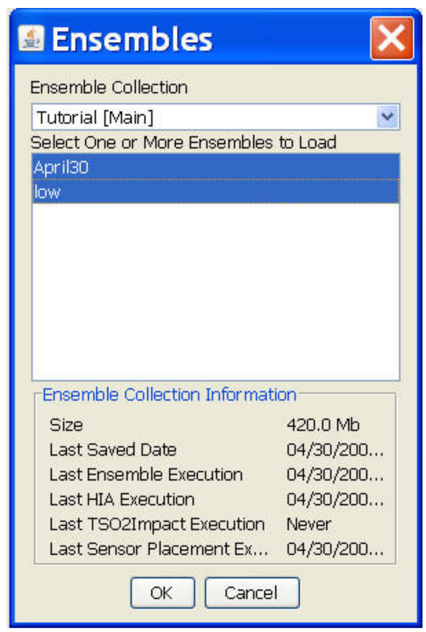
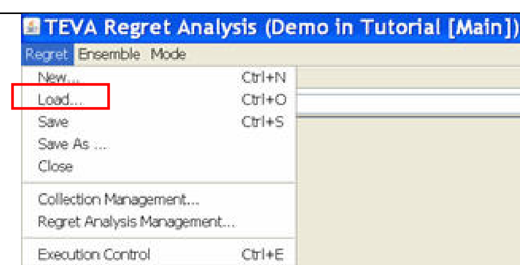
Click New… in the Regret menu.



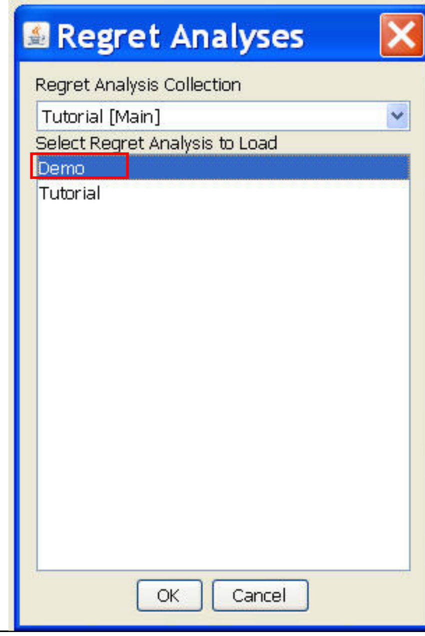
The New Regret Analysis Name dialogue box opens.

Click the Regret Analysis Name text box and type the name Demo



The OK button becomes enabled.	
8.5. Ensemble Menu Clicking Ensemble in the menu bar displays the Ensemble menu. Click **Load Ensembles**… in the Ensemble menu. Opens Ensembles dialogue.	
Click the list box and select a collection name: **Tutorial**. Ensemble **April30** is for high mass loading contaminant. Ensemble **low** is for low contaminant. Select both Ensembles from load list box to load the then click their names while holding the Ctrl key down. The OK button becomes enabled. Click Okay.	
8.6. Load Click Load… in the Regret menu, The Regret Analyses dialogue box opens.	

Select Demo and Click the **OK** button.



8.7. Save

The Save command is only enabled when a regret analysis group is in memory. Click Save in the Regret menu. , or press Ctrl+S. There is no response from the system after a successful save.

8.8. Close

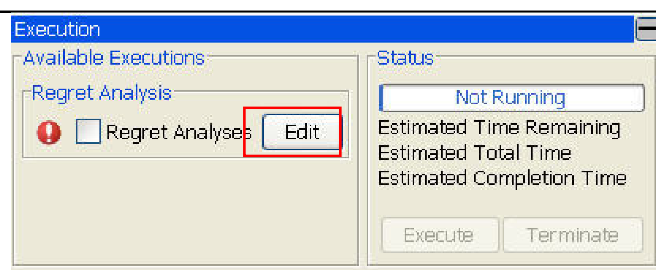
Clicking **Close** in the Regret menu will close the currently loaded regret analysis group, i.e., it will no longer be loaded. Its name, and that of the containing collection, are removed from the name stripe and replaced by the legend ***No Regret Analysis Loaded***. If the Execution panel is being displayed, it is removed from the display. **Do Not Close Now**.

8.9. Execution Control

Click **Execution Control** in the Regret menu. The Execution panel is added. To close, Click the **Close** button in the upper right-hand corner of the panel to remove it. **Do Not Close Now.**

In the Execution panel, click the **Edit** button to the right of the Regret Analyses check box.

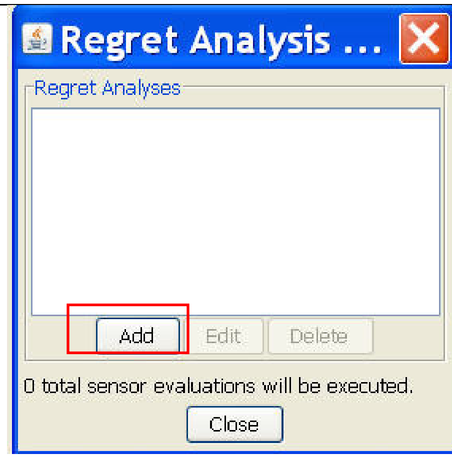
The Regret Analysis Management dialogue box opens. (See next screen).



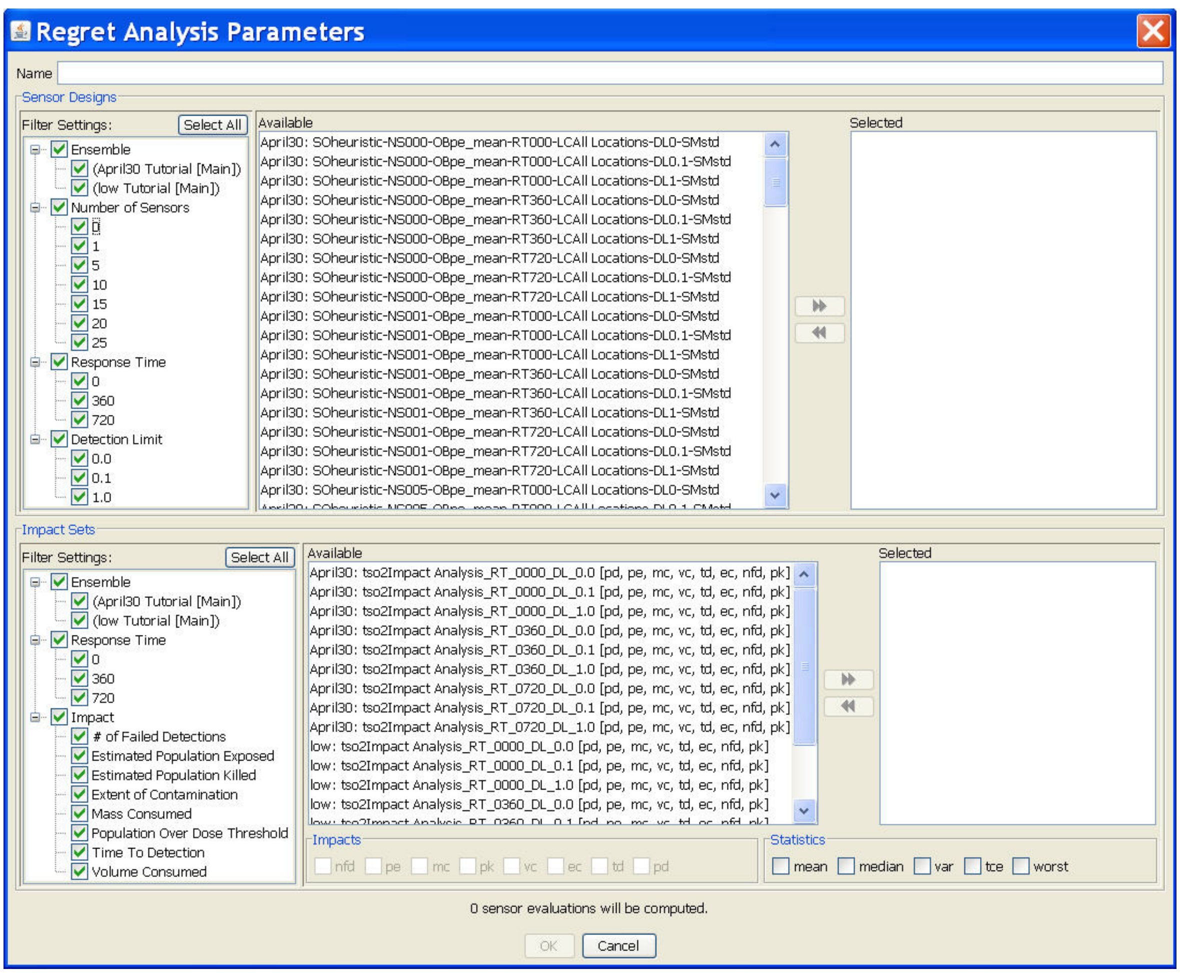
8.10. Specifying the Parameters for Regret Analyses

Click the **Add** button. It will open the Regret Analysis Parameters box which is displayed in the pane below.

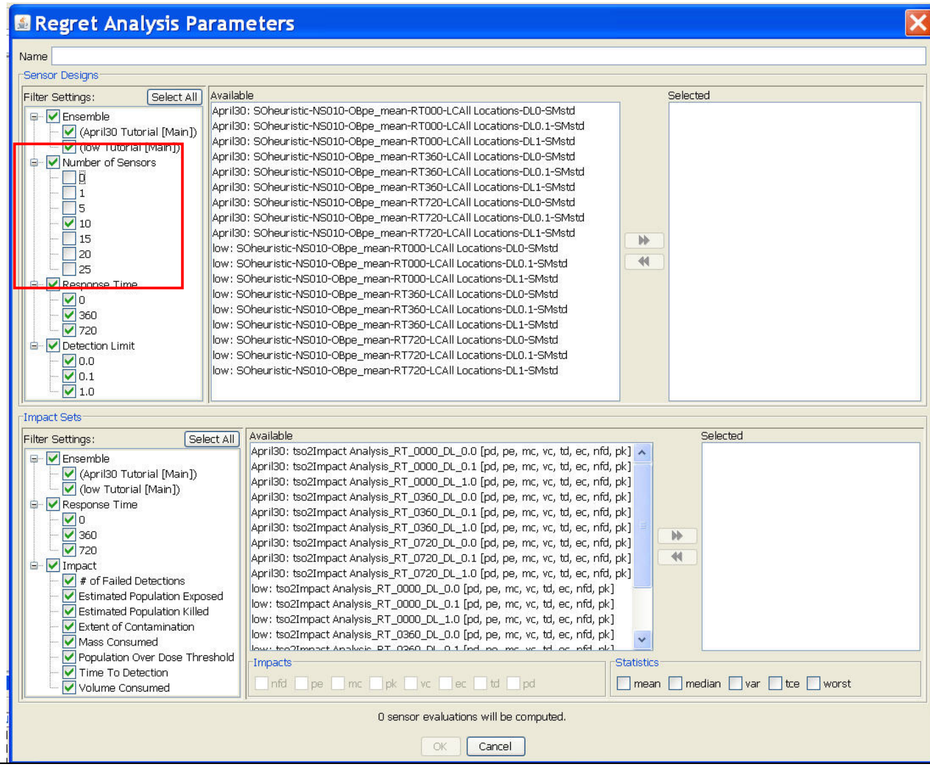
When the Regret Analysis Parameters box (below) opens it may be necessary to resize the box using the mouse cursor in order to view the parameters, e.g. OK box and Name.



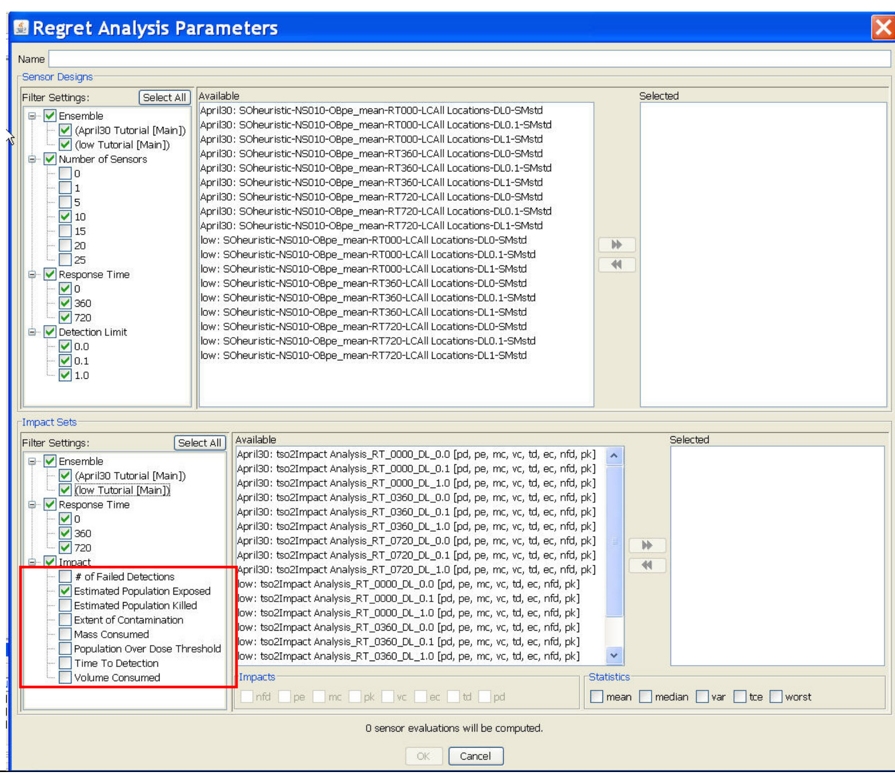
Display of Regret Analysis Parameters



Initially all boxes are checked. Uncheck all sensor set sizes except 10 in the Sensor Design Filter Settings



In the Impact Set Filter Setting uncheck all except Estimated Population Exposed



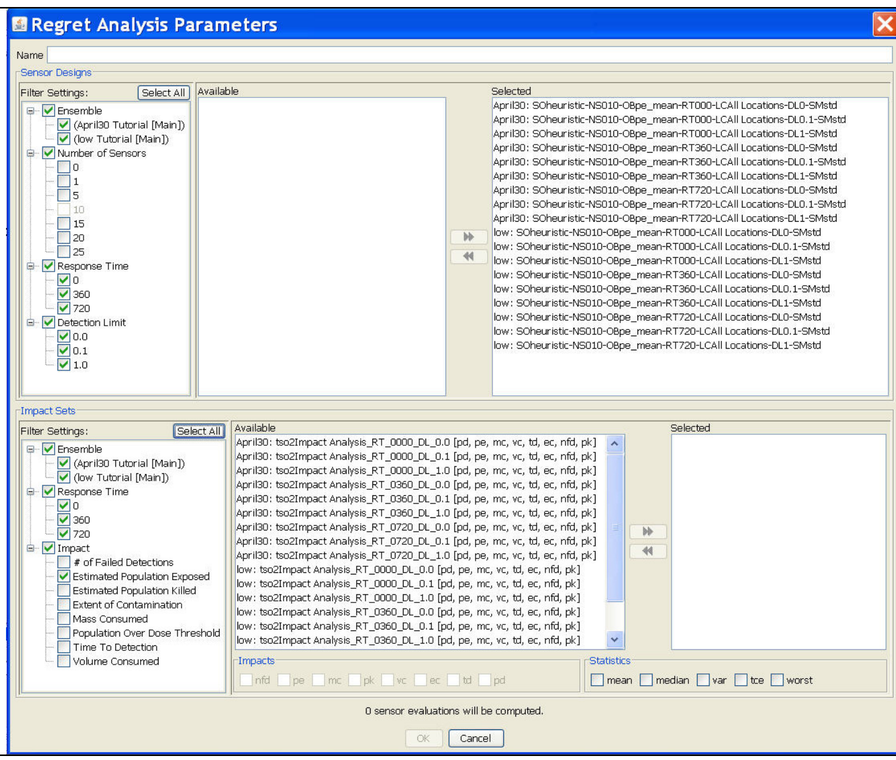
8.11. Add sensor designs

Multi-select one or more sensor designs in the Available list box of the Sensor Designs pane by clicking them (with the Shift and/or Ctrl keys held down, if necessary). The selected sensor designs become highlighted, and the right transfer button becomes enabled.

Click the right transfer button. The highlighted sensor designs in the Available list box of the Sensor Designs pane are transferred to the Selected list box, and the button becomes disabled.

[Remove sensor designs.] Multi-select one or more sensor designs in the Selected list box of the Sensor Designs pane by clicking them (with the Shift and/or Ctrl keys held down, if necessary). The selected sensor designs become highlighted, and the left transfer button becomes enabled.

Click the left transfer button. The highlighted sensor designs in the Selected list box of the Sensor Designs pane are transferred to the Available list box, and the button becomes disabled.

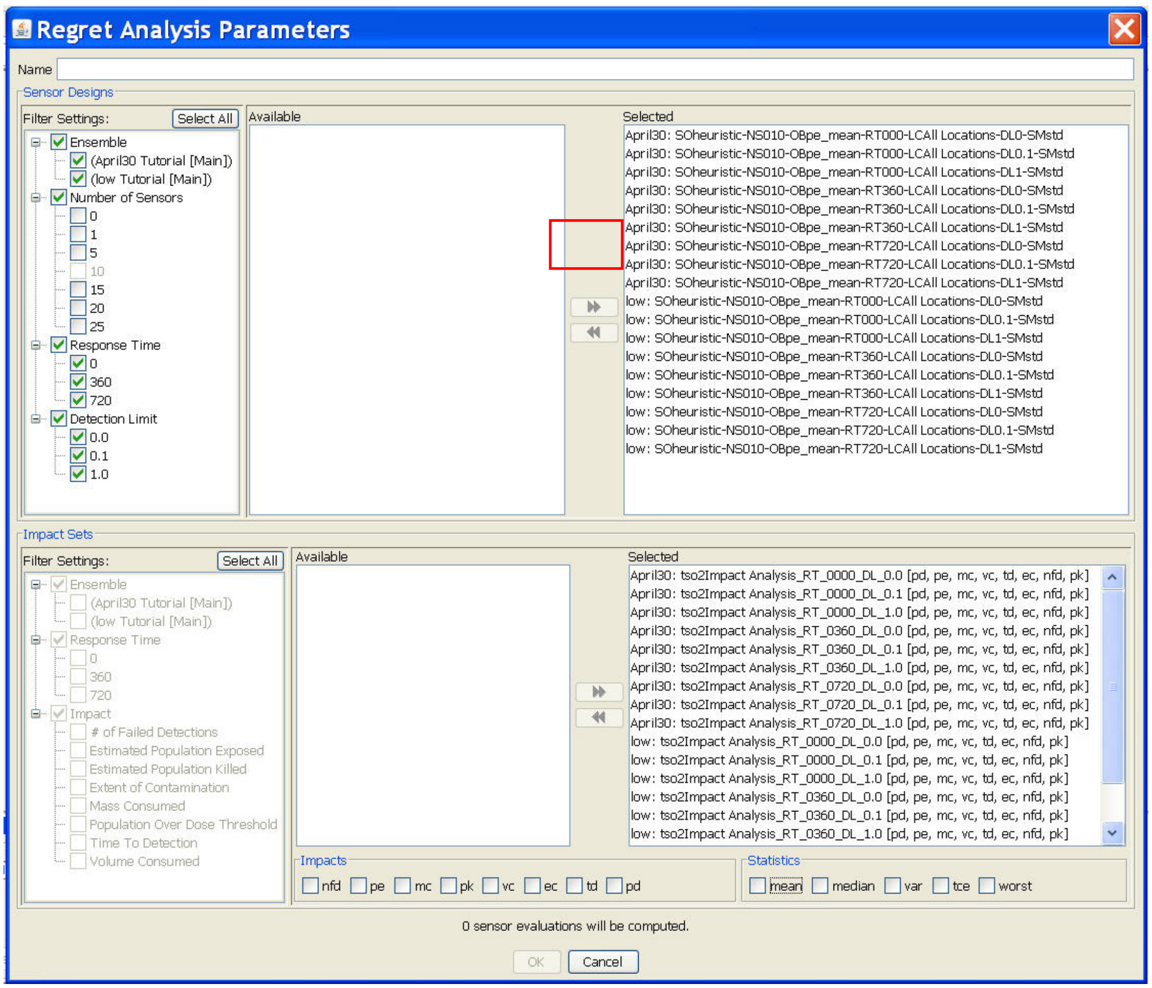


8.12. Selecting Impact Sets

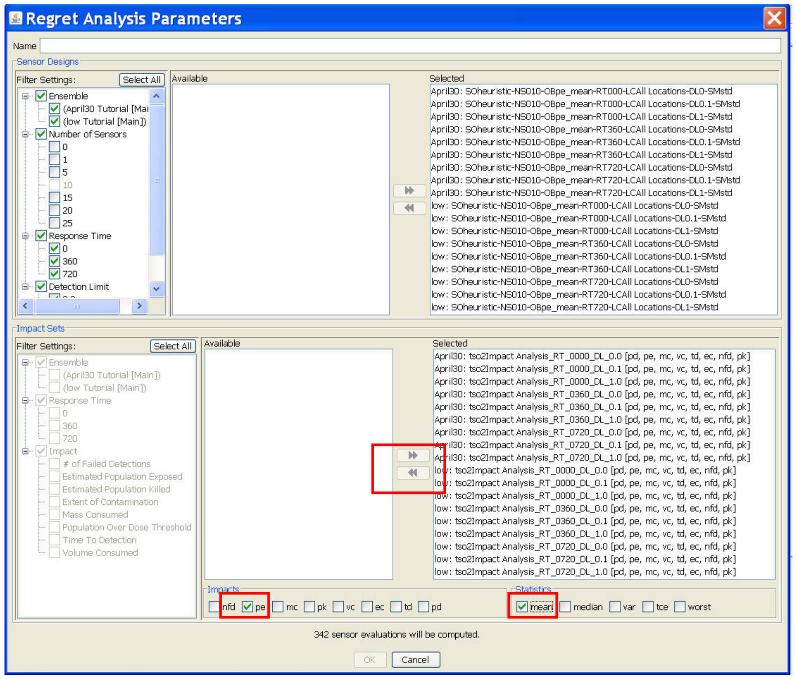
[**Add impact sets**.] Multi-select one or more impact sets in the Available list box of the Impact Sets pane by clicking them (with the Shift and/or Ctrl keys held down, if necessary). The selected impact sets become highlighted, and the right transfer button becomes enabled.

Click the right transfer button. The highlighted impact sets in the Available list box of the Impact Sets pane are transferred to the Selected list box, and the button becomes disabled.

[Remove impact sets.] Multi-select one or more impact sets in the Selected list box of the Impact Sets pane by clicking them (with the Shift and/or Ctrl keys held down, if necessary). The selected impact sets become highlighted, and the left transfer button becomes enabled.



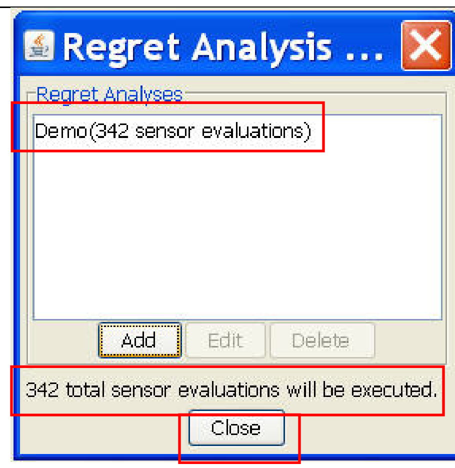
Select **pe (population exposed)** under Impacts and Mean for Statistics



This dialogue box contains the name of the Regret Analyses (Demo), multiple Regret Analyses can be setup and run at the same time

This dialogue box also displays the total number of sensor evaluations in parentheses.

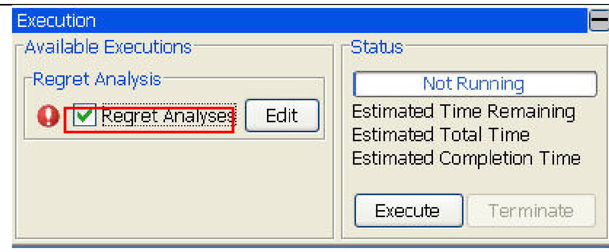
Click **Close**



8.13. Scheduling the Available Executions

Click the **Regret Analyses** check box and a green check mark appears.

TEVA-SPOT enables the Execute button (in the Status pane). If that button remains disabled, it means that the user must enter missing execution parameters (i.e., create one or more regret analysis parameter sets) before the executions can be started.

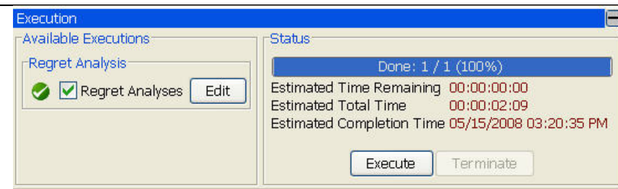


Click the **Execute** button in the Execution Control Panel.

At the top of the pane is an indicator showing the status of the current execution. Before the Execute button is clicked, this indicator shows a status of Not Running.

If execution terminates normally, the indicator changes to Done.

Regret Analyses should generally run quickly.



9. Regret Analysis Output - Tables

Unlike the output tables produced in ensemble analysis mode, those produced in Regret Analysis Mode cannot be sorted by clicking a column head. In the output products pull-down list on the control bar, the names of all the regret tables start with a prefix of the form [<name> <impact>_<statistic>] = [Demo pe_mean]. Here, <name> is the name given to a regret analysis parameter set (of the regret analysis group whose execution produced the regret tables) when the parameter set was created, and <impact> and <statistic> are respectively one of the impacts and one of the statistics whose check boxes were checked in that parameter set.

For the Demo example, this is the regret analysis which evaluated all of the optimal sensor network designs from the "**April30"** and "**low"** ensembles of threats for 10 locations and determines which sensor network design(s) performs best.

It is helpful to export the table of data to a spreadsheet. Here is how export the data manually:

- Click on an individual cell which highlights an entire row.
- Next, holding the control key of your keyboard press the letter "A".
- Next, holding the control key of your keyboard, press the letter "C".
- Open a spreadsheet (Microsoft EXCEL) and press control-V and paste the Regret Analysis table below into an empty spreadsheet. Conversely, the Regret Analysis table can be exported to Excel via the export command under the Table menu.

The table of regret data can also be exported to EXCEL automatically. While under the Tables Tab, select Table/Export to EXCEL and follow the instructions.

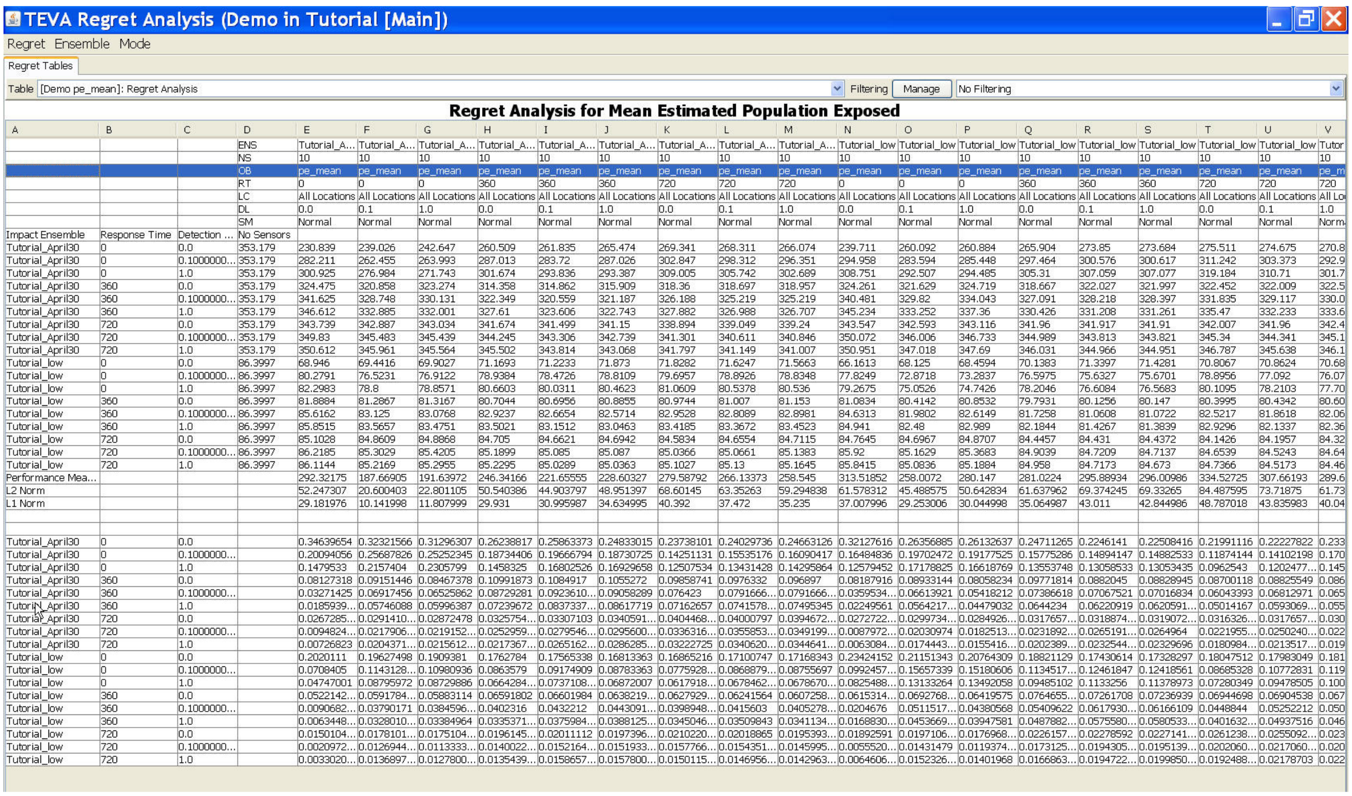
The table is composed of two sections of data:

- Top portion of data table corresponding to the first set of impact files evaluated are the impacts data output from the sensor network designs evaluations. In the Demo example, these data are Population Exposed.
- Lower portion of data table corresponding to the second set of impact files evaluated are the impacts data represented as a difference from the no sensors baseline case. For instance, notice column D (first row below no sensors) has a value of 353.179. This corresponds to the no-sensors case for the indicated ensemble. Column E, the first sensor design moving from left to right, same row shows an impact value of 230.839. The corresponding value to the column E value of 230.839 in the lower portion of data table has a value of 0.346397. The value of 0.34697 was found by subtracting the quantity of (230.839 divided by 353.179) from 1. In other words, the data in the lower portion of the table represents the percent difference for each design from the baseline, no-sensors case.

Across the top of the spreadsheet (columns) are the sensor network designs corresponding to each set of data. In the spreadsheet highlight the row which is identified by "ENS". ENS is short for Ensemble. Format the highlighted row for wrap-around text. This will highlight the sensor network design names.

In rows down the spreadsheet are the impact files for which the sensor designs are evaluated against. The data in the table are the impact values, i.e., population exposed health impact values. At the bottom of the spreadsheet are the performance metrics. The far right hand column is labeled "BEST". For each row, BEST represents the lowest value (e.g., number of people exposed) for the sensor network design evaluated given the impact measure defined in the row of the spreadsheet. At the bottom of the BEST column are the performance metrics, i.e., lowest values, determined from all the sensor network designs. The preferred designs are color-coded. **The *Preferred Overall Design(s)* is highlighted green** and the ***Preferred Design(s) to Minimize Maximum Deviation* is highlighted blue**.

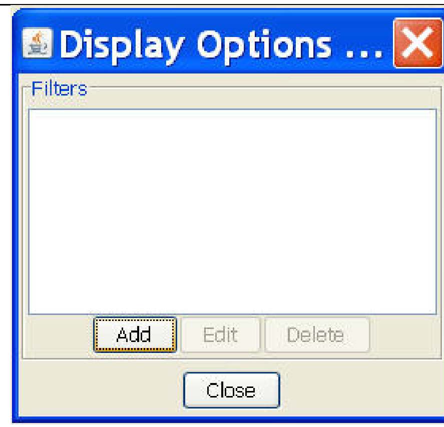
Ultimately, utility personnel should use the information gained from TEVA-SPOT to inform the decision for placing sensors in the distribution system.



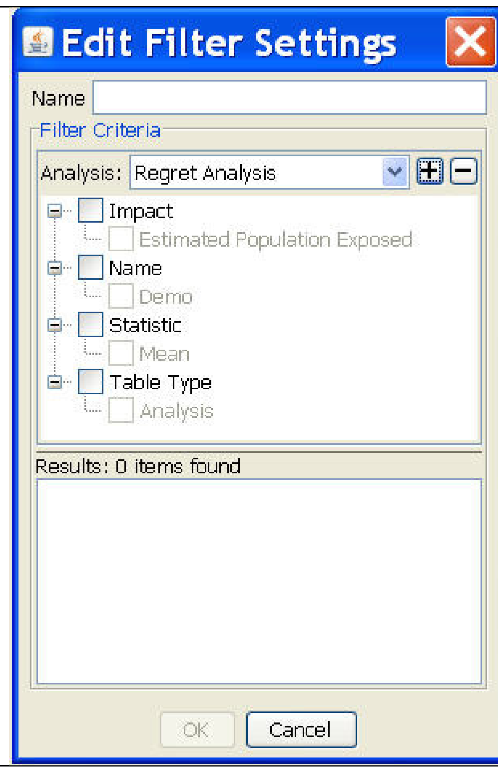
10. Regret Analysis Mode: Filtering Criteria

For basic filtering functionality, refer to section 7.

<table>
<tr><td>Click the Manage button.

The Display Options Filter Management dialog box opens.</td><td>
</td></tr>
<tr><td>Name Attribute - To select the Regret Analysis output tables yielded by regret analyses associated with a regret analysis parameter set having a particular name, check the Name attribute and the value identifying the desired name.

Impact Attribute - To select the Regret Analysis output tables yielded by regret analyses associated with a regret analysis parameter set specifying a particular impact, check the Impact attribute and the desired value identifying the desired impact.

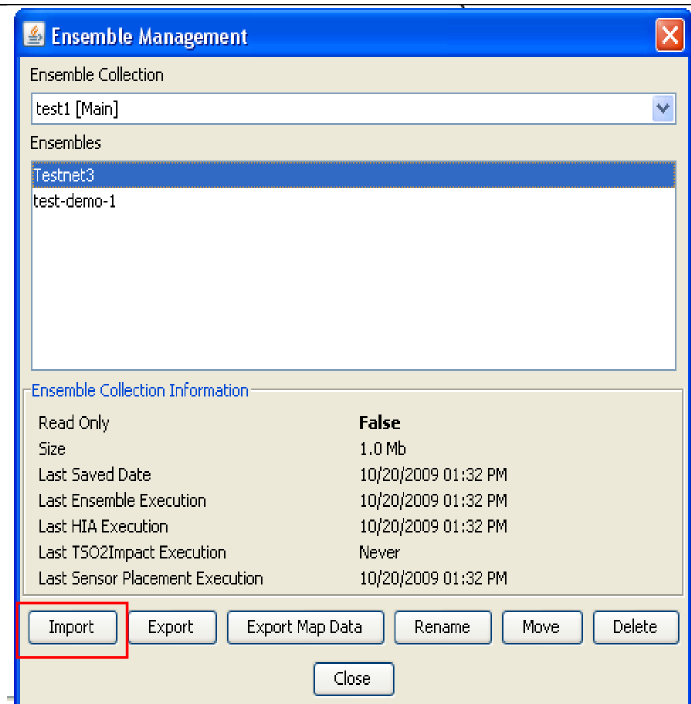
Statistic Attribute - To select the Regret Analysis output tables yielded by regret analyses associated with a regret analysis parameter set specifying a particular statistic, check the Statistic attribute the value identifying the desired statistic.</td><td>
</td></tr>
<tr><td colspan="2">Filtering Regret Analysis Output Tables - Each Regret Analysis output table possesses a set of attributes that characterize the table, and each attribute that a regret table possesses assumes exactly one value. Filter specifications designed to select Regret Analysis output tables contain attribute nodes for all the attributes possessed by the existing Regret Analysis output tables and value nodes for all the values that those attributes assume in the existing tables.</td></tr>
<tr><td colspan="2">Regret Analysis Value - To select the Regret Analysis output tables that are regret tables (tables of regret analysis results), check the Table Type attribute and the Regret Analysis value.</td></tr>
</table>

11. Ensemble Management: Export Capabilities

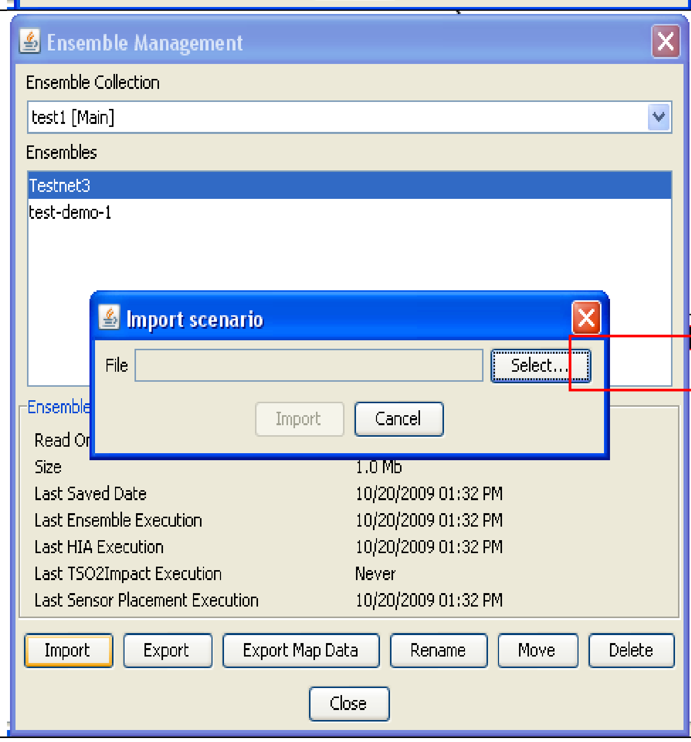
The Ensemble Management dialogue box provides the ability to Import, Export, Export Map Data, Rename, Move, and Delete ensembles.

11.1. Import Ensemble

Import Ensemble provides the ability to import an ensemble created by another user and on a different computer.



Clicking “Import” brings up a dialogue box to navigate to the location of the ensemble. The **Select** button allows the user to browse to the location where the ensemble is located. Ensembles are imported and exported as a compressed ZIP file.



11.2. Export Ensemble

Clicking **EXPORT** opens the dialogue box as shown.

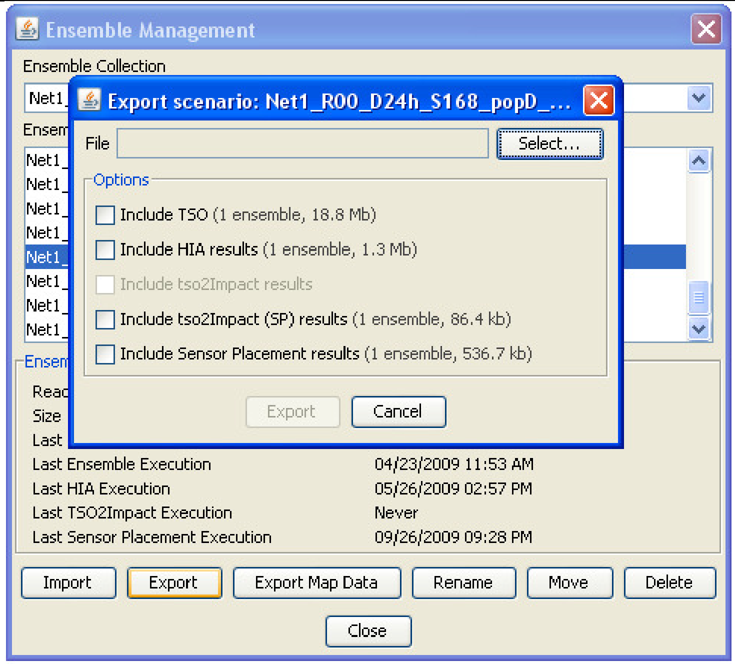
Choices include:

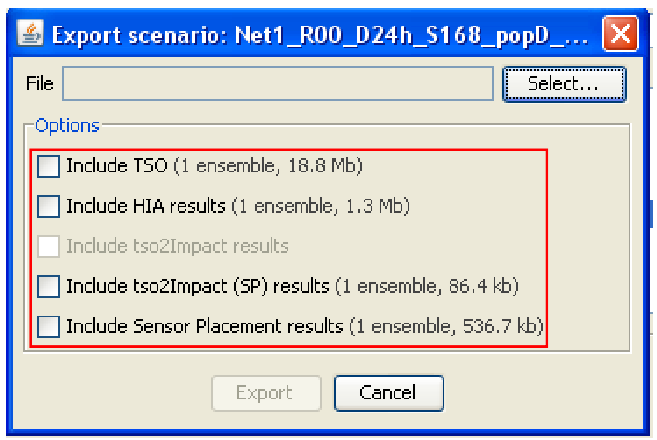
- Include TSO
- Include HIA Results
- Include tso2Impact results
- Include tso2Impact (SP) results
- Include Sensor Placement results

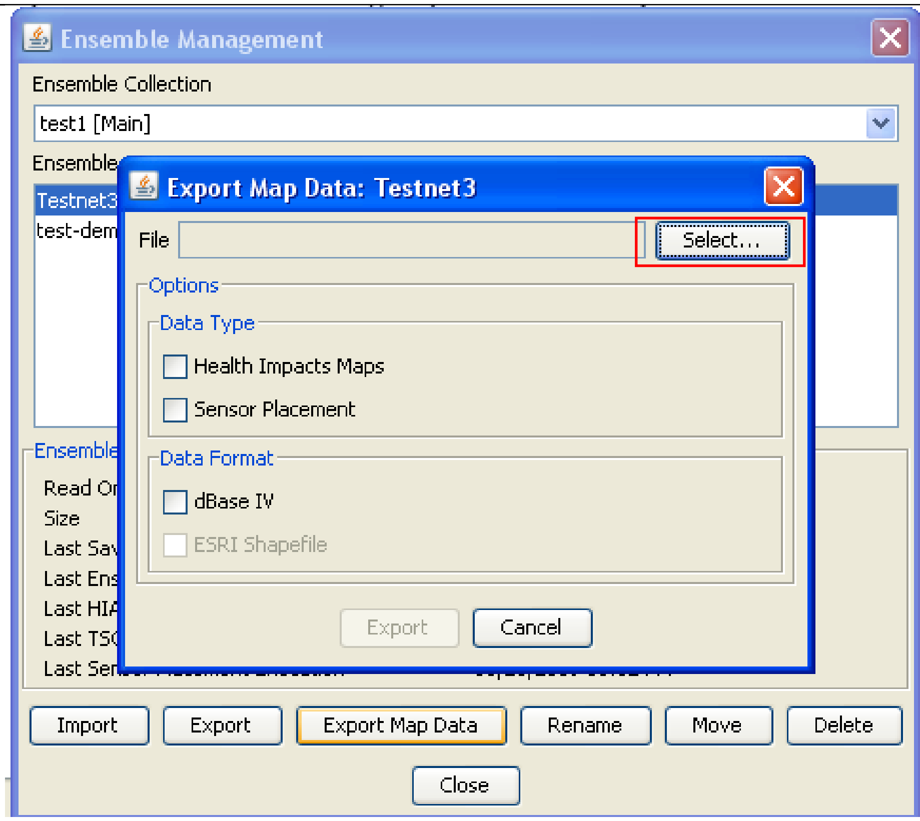
If no boxes are checked, then just the ensemble definition will be exported.

Checking the "Include TSO" box results in the export of the entire ensemble of results, including the binary contaminant concentration data from EPANET. The resulting ZIP file may be very large!

Checking the "Include HIA Results" will provide an export of only the HIA results. Checking additional will include identified items.

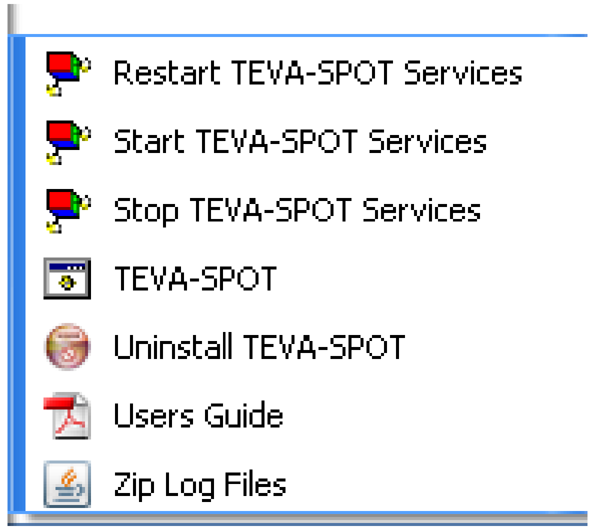




11.3. Export Map Data Exporting Map Data provides easy incorporation into ArcGIS. Results are saved in the dBaseIV format. All results are exportable except the sensor placement results dealing with detection events on links. These maps will require topology information, e.g., ESRI shapefile which is currently not available. Map Export data are exported as ZIP Files. **Select** allows the user to select the export destination for the ZIP file	 For the dbf files which appear in the ZIP file, **"Inj"** refers to the injection scenarios data**.** For example, **Inj_fatalities.dbf** provides the number of estimated fatalities by injection scenario (node ID) along with x and y coordinates data for each contaminant injection. **"Rec"** refers to receptors. **"Dot"** refers to dose-over-threshold data which is followed in the file name by the respective threshold.
12. Trouble-Shooting	TEVA-SPOT GUI generates numerous log files to help the user identify problems. However, to view the log files a live or real-time editor is needed. Windows notepad is a live editor but is not compatible with the log files output by TEVA-SPOT, i.e., everything looks jumbled. An open source program called emacs can be downloaded from the link below. Installing emacs on the desktop will allow a drag and drop approach for viewing each of the log files. • http://www.xemacs.org/Download/win32/index.html#InnoSetup-Stable-Download The log files are located in the following directory: C:\Program Files\TEVA-SPOT\tevaLogs. Within the "tevaLogs" folder are additional folders with the logs separated by each TEVA-SPOT process. The TEVA-SPOT processes include: (1) AnalysisServer, (2) DBServer, (3) ExecutionController, (4) Server, and (5) ServerBroker

12.1 Stop & Restart TEVA-SPOT Services

Under the START Menu/TEVA-SPOT are programs for managing TEVA-SPOT executions.



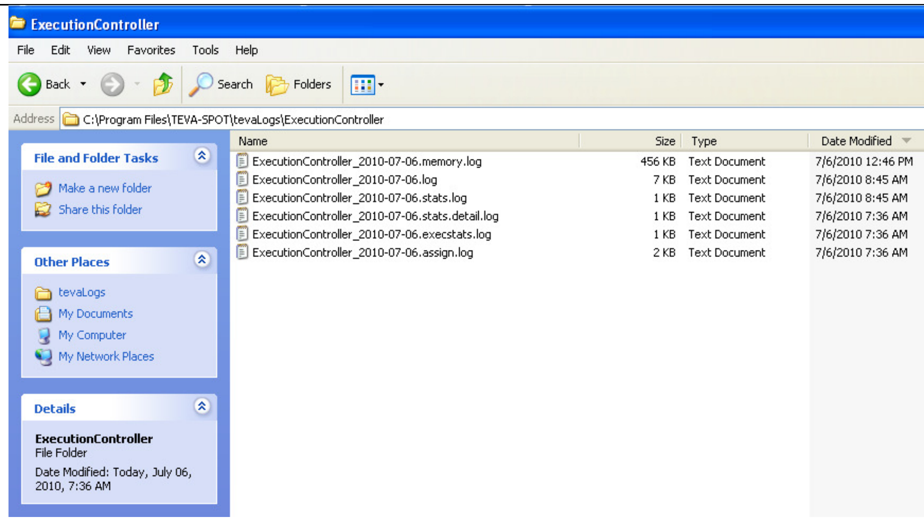
If TEVA-SPOT seems held up or frozen for an extended period of time, RESTART TEVA-SPOT Services can be selected. "Restart" or "Stop/Start" TEVA-SPOT Services will stop all simulations and ready TEVA-SPOT for re-execution of simulations and analyses.

Prior to choosing "Restart" or "Stop/Start" TEVA-SPOT services ensure that TEVA-SPOT simulations and analyses (executions) are indeed stopped and not just running slowly due to a difficult sensor placement problem. It is easiest to check if TEVA-SPOT is running by examining the Windows Task Manager (right click Windows Start Menu bar and choose Task Manager). Examine Task Manager to determine if any TEVA-SPOT Services are running (you may need to check box "show processes from all users). Processes for TEVA-SPOT include:

- java.exe
- tevaAnalysisServer.exe
- tevaBroker.exe
- tevaDBServer.exe
- tevaExecCtlr.exe
- tevaRMIRegistry.exe
- tevaServer.exe (multiples of these depending the number of Server folders under c:/Program Files/TEVA-SPOT/Server
- randomsample.exe

12.2. Log Files

For the more experienced user, log files can be examined to determine the possible problem. The execution log files appear within the "Execution-Controller" folder. Similar files are available for the other TEVA-SPOT processes.



12.3. Example Log File

Examine the Execution-Controller log files first for problems. Below are descriptions of selected log files.

Look for "Severe Exceptions" in the ExecutionController…log" file, except ignore the following error: "Execption occurred while retrieving DB Server: java.rmi.NotBoundException: TEVADatabaseServer"

Example ExecutionController…stats.log file: EPANET/HIA simulation. The three "…" will display the date for the log file.

INFO:	*(07/06/2010 15:28:07.981):*	*executionName*	*execution Time*	*successful completion*	*Server name*
INFO:	*(07/06/2010 15:28:07.981):*	*executionName*	*execution Time*	*successful completion*	*Server name*
INFO:	*(07/06/2010 15:28:07.997):*	*11 8330.0 (0 hours - 1 hour)*	*4.172*	*true*	*COMPUTERNAME[204.47.178.206]-1*
INFO:	*(07/06/2010 15:28:07.997):*	*12 8330.0 (0 hours - 1 hour)*	*4.172*	*true*	*COMPUTERNAME[204.47.178.206]-2*
INFO:	*(07/06/2010 15:28:08.497):*	*13 8330.0 (0 hours - 1 hour)*	*0.5*	*true*	*COMPUTERNAME[204.47.178.206]-1*
INFO:	*(07/06/2010 15:28:08.559):*	*21 8330.0 (0 hours - 1 hour)*	*0.546*	*true*	*COMPUTERNAME[204.47.178.206]-2*
INFO:	*(07/06/2010 15:28:09.059):*	*22 8330.0 (0 hours - 1 hour)*	*0.546*	*true*	*COMPUTERNAME[204.47.178.206]-1*
INFO:	*(07/06/2010 15:28:09.106):*	*23 8330.0 (0 hours - 1 hour)*	*0.531*	*true*	*COMPUTERNAME[204.47.178.206]-2*
INFO:	*(07/06/2010 15:28:09.544):*	*31 8330.0 (0 hours - 1 hour)*	*0.469*	*true*	*COMPUTERNAME[204.47.178.206]-1*
INFO:	*(07/06/2010 15:28:09.591):*	*32 8330.0 (0 hours - 1 hour)*	*0.469*	*true*	*COMPUTERNAME[204.47.178.206]-2*

Time is execution time in seconds. "True" indicates that the simulation executed correctly to completion. A "False" here indicates a problem. "ComputerName" will be replaced by the name of the computer that TEVA-SPOT is running on. Under "ExecutionName" the first number refers to the EPANET model node ID, in this case "11".

Example ExecutionController…stats.log file: TSO-2-Impact simulation. ModuleRunner refers to each TSO-2-Impact analysis.

(07/06/2010 15:28:14.966):		executionName	execution Time	successful completion	Server name
INFO:	(07/06/2010 15:28:14.966):	ModuleRunner0	0.266	true	COMPUTERNAME[204.47.178.206]-1
INFO:	(07/06/2010 15:28:14.966):	ModuleRunner1	0.25	true	COMPUTERNAME[204.47.178.206]-2
INFO:	(07/06/2010 15:28:15.012):	ModuleRunner4	0.031	true	COMPUTERNAME[204.47.178.206]-2
INFO:	(07/06/2010 15:28:15.028):	ModuleRunner3	0.062	true	COMPUTERNAME[204.47.178.206]-1
INFO:	(07/06/2010 15:28:15.044):	ModuleRunner2	0.032	true	COMPUTERNAME[204.47.178.206]-2
INFO:	(07/06/2010 15:28:15.059):	ModuleRunner6	0.031	true	COMPUTERNAME[204.47.178.206]-1
INFO:	(07/06/2010 15:28:15.075):	ModuleRunner5	0.016	true	COMPUTERNAME[204.47.178.206]-2
INFO:	(07/06/2010 15:28:15.075):	ModuleRunner7	0.016	true	COMPUTERNAME[204.47.178.206]-1

Example **ExecutionController…stats.log** file: Sensor network design analysis

INFO:	(07/06/2010 15:28:41.043):	executionName	execution Time	successful completion	Server name
INFO:	(07/06/2010 15:28:41.043):	SOgrasp-NS010-OBpe_mean-RT000-SMstd	23.702	true	#[204.47.178.206]-2
INFO:	(07/06/2010 15:28:45.012):	SOgrasp-NS010-OBpd_mean_00-RT000-SMstd	3.953	true	#[204.47.178.206]-2
INFO:	(07/06/2010 15:28:48.762):	SOgrasp-NS005-OBpe_mean-RT000-SMstd	3.734	true	#[204.47.178.206]-2
INFO:	(07/06/2010 15:28:52.668):	SOgrasp-NS005-OBpd_mean_00-RT000-SMstd	3.89	true	#[204.47.178.206]-2
INFO:	(07/06/2010 15:28:56.309):	SOgrasp-NS004-OBpe_mean-RT000-SMstd	3.625	true	#[204.47.178.206]-2
INFO:	(07/06/2010 15:28:59.981):	SOgrasp-NS004-OBpd_mean_00-RT000-SMstd	3.672	true	#[204.47.178.206]-2
INFO:	(07/06/2010 15:29:03.652):	SOgrasp-NS001-OBpe_mean-RT000-SMstd	3.656	true	#[204.47.178.206]-2
INFO:	(07/06/2010 15:29:07.262):	SOgrasp-NS001-OBpd_mean_00-RT000-SMstd	3.61	true	#[204.47.178.206]-2
INFO:	(07/06/2010 15:29:09.762):	SOgrasp-NS000-OBpe_mean-RT000-SMstd	2.485	true	#[204.47.178.206]-2
INFO:	(07/06/2010 15:29:12.215):	SOgrasp-NS000-OBpd_mean_00-RT000-SMstd	2.453	true	#[204.47.178.206]-

Here “SO” refers to the sensor placement solver. “GRASP” refers to the heuristic algorithm. “NS” is number of sensors. “OB” refers to the objective for sensor placement, e.g., “pd” is population over dose threshold while “pe” is population exposed. “RT” is response delay time. If a Detection Limit was specified it would be included in the name. Completion time is in seconds. Note that “#” was used to replace “ComputerName” to save space in this manual.

The final step of the ensemble execution will result in the following entry in the ExecutionController…stats.log file:

INFO:	(07/06/2010 15:29:16.246):	executionName	execution Time	successful completion	Server name
INFO:	(07/06/2010 15:29:16.246):	SensorPlacementSummary	3.406	true	#[204.47.178.206]-2

This entry indicates the time taken to write the sensor placement summary results to the graphical user interface.

APPENDIX A Water Utility Requirements for using EPA's TEVA-SPOT software

The Threat Ensemble Vulnerability Assessment Sensor Placement Optimization Tool, TEVA-SPOT, is a software product and decision-making process developed by EPA's TEVA Research program to assist in determining the best location for sensors in a distribution system. TEVA-SPOT software has been applied by EPA staff using models and data provided by utilities. In some cases, significant improvements in the models have been made in order to bring them up to the standards required by the TEVA-SPOT software. In order to streamline the application of TEVA-SPOT, this appendix was developed to describe the requirements and steps that utilities must follow to use TEVA-SPOT.

Table 2 summarizes the data and information required for a water utility to use TEVA-SPOT; each component is described in more detail in the text. In addition to having an appropriate utility network model, utilities will need to make decisions about the nature of the Contamination Warning System they are designing and the types of security incidents that they would like to detect.

Table 2: Information and data required to design sensor networks using TEVA-SPOT

INFORMATION AND DATA NEEDED FOR SENSOR PLACEMENT	DESCRIPTION
Utility Network Model	The model (e.g. EPANET input file) should be up-to-date, capable of simulating operations for a 7-10 day period, and calibrated with field data.
Sensor Characteristics	Type of sensors or sampling program, detection limits, and (if applicable) event detection system
Design Basis Threat	Data describing type of event that the utility would like to be able to detect: specific contaminants, behavior of adversary, and customer behavior
Performance Measures	Utility specific critical performance criteria, such as time to detection, number of illnesses, etc.
Utility Response	Plan for response to a positive sensor reading, including total time required for the utility to limit further public exposure.
Potential Sensor Locations	List of all feasible locations for placing sensors, including associated model node/junction.

Utility Network Model

The TEVA-SPOT software relies upon an EPANET hydraulic model of the network as the mechanism for calculating the impacts resulting from contamination incidents. Therefore, an acceptable model of the distribution system is needed in order to effectively design the sensor system. The following sub-sections describe the various issues/characteristics of an acceptable hydraulic model for use within TEVA-SPOT.

EPANET Software Requirement - TEVA-SPOT uses EPANET, a public domain water distribution system modeling software package. In order to utilize TEVA-SPOT, existing network models that were not developed in EPANET must be converted to and be demonstrated to properly operate within EPANET (Version 2.00.10). Most commercial software packages utilize the basic EPANET calculation engine and contain a conversion tool for creating an EPANET input file from the files native to the commercial package. The user may encounter two potential types of problems when they attempt to make the conversion: (1) some commercial packages support component representations that are not directly compatible with EPANET such as representation of variable speed pumps. The representation of these components may need to be modified in order to operate properly under EPANET; (2) additionally, the conversion programs developed by the commercial software vendors may also introduce some unintended representations within EPANET that may require manual correction. Following conversion, the output from the original model should be compared with the EPANET model output to ensure that the model results are the same or acceptably close (see section on Model Testing).

Extended Period Simulation - TEVA-SPOT uses both the hydraulic and water quality modeling portions of EPANET. In order to support the water quality modeling, the model must be an extended period simulation (EPS) that represents the system operation over a period of several days. Typically a model that uses rules to control operations (e.g., turn pump A on when the water level in tank B drops to a specified level) are more resilient and amenable to long duration runs than are those that use controls based solely on time clocks. Model output should be examined to ensure that tank water levels are not systematically increasing or decreasing over the course of the run since that will lead to unsustainable situations.

The required length of simulation depends on the size and operation of the specific water system. However, in general, the length of the simulation should reflect the longest travel times from a source to customer nodes. This can be calculated by running the EPANET model for water age and determining the higher water age areas. In determining the required simulation length, small dead-ends (especially those with zero demand nodes) can be ignored. Typically a run length of 7 to 10 days is required for TEVA-SPOT though shorter periods may suffice for smaller systems and longer run times required for larger or more complex systems.

Seasonal Models - In most cases, water security incidents can take place at any time of the day or any season of the year. As a result, sensor systems should be designed to operate during one or more representative periods in the water system. It should be noted that this differs significantly from the normal design criteria for a water system where pipes are sized to accommodate water usage during peak seasons or during unusual events such as fires. In many cases, the only available models are representative of these extreme cases and generally, modifications to such models should be made to reflect a broader time period prior to use with TEVA-SPOT. Specific guidance on selecting models is provided below:

- <u>Optimal situation</u>: the utility has multiple models representing average conditions throughout the year, typical higher demand case (e.g., average summer day) and typical lower demand case (e.g., average winter day).
- <u>Minimal situation</u>: the utility has a single model representing relatively average conditions throughout the year.
- <u>Situations to avoid</u>: the utility has a single model representing an extreme case (e.g., maximum day model).

- Exceptions: (1) If a sensor system is being designed to primarily monitor a water system during a specific event such as a major annual festival, then one of the models should reflect conditions during that event; and (2) If the water system experiences little variation in water demand and water system operation over the course of the year, then a single representative model would suffice.

Model Detail - A sufficient amount of detail should be represented in the model for use within TEVA-SPOT. This does not mean that an all-pipes model is required nor does it mean that a model that only represents transmission lines would suffice. At a minimum, all parts of the water system that are considered critical from a security standpoint should be included in the model, even if they are on the periphery of the system. The following guidance drawn from the Initial Distribution System Evaluation (IDSE) Guidance Manual of the Final Stage 2 Disinfectants and Disinfection Byproducts Rule provides a reasonable **lower limit** for the level of detail required for a TEVA-SPOT analysis (USEPA, 2006).

Most distribution system models do not include every pipe in a distribution system. Typically, small pipes near the periphery of the system and other pipes that affect relatively few customers are excluded to a greater or lesser extent depending on the intended use of the model. This process is called skeletonization. Models including only transmission networks (e.g. pipes larger than 12 inches in diameter only) are highly skeletonized while models including many smaller diameter distribution mains (e.g. 4 to 6 inches in diameter) are less skeletonized. In general, water moves quickly through larger transmission piping and slower through the smaller distribution mains. Therefore, the simulation of water age or water quality requires that the smaller mains be included in the model to fully capture the residence time and potential water quality degradation between the treatment plant and the customer. Minimum requirements for physical system modeling data for the IDSE process are listed below.

- At least 50 percent of total pipe length in the distribution system.
- At least 75 percent of the pipe volume in the distribution system.
- All 12-inch diameter and larger pipes.
- All 8-inch diameter and larger pipes that connect pressure zones, mixing zones from different sources, storage facilities, major demand areas, pumps, and control valves, or are known or expected to be significant conveyors of water.
- All 6-inch diameter and larger pipes that connect remote areas of a distribution system to the main portion of the system or are known or expected to be significant conveyors of water.
- All storage facilities, with controls or settings applied to govern the open/closed status of the facility that reflect standard operations.
- All active pump stations, with realistic controls or settings applied to govern their on/off status that reflect standard operations.
- All active control valves or other system features that could significantly affect the flow of water through the distribution system (e.g., interconnections with other systems, pressure reducing valves between pressure zones).

Model Demands - The movement of water through a distribution system is largely driven by water demands (consumption) throughout the system. During higher demand periods, flows and velocities generally increase and vice versa. Demands are usually represented within a model as average or typical demands at most nodes and then (a) global or regional demand multipliers are applied to all nodes to represent periods of higher or lower demand, and (b) temporal demand patterns are applied to define how the demands vary over the course of a day. In some models, demands within a large area have been aggregated and assigned to a central node. In building a model for use with TEVA-SPOT, rather than aggregating the demands and assigning them to only a few nodes, each demand should be assigned to the node that is nearest to the actual point of use. Both EPANET and most commercial software products allow the user to assign multiple demands to a node with different demands assigned to different diurnal patterns. For example, part of the demand at a node could represent residential demand and utilize a pattern representative of residential demand. Another portion of the demand at the same node may represent commercial usage and be assigned to a representative commercial diurnal water use pattern. TEVA-SPOT supports either a single demand or multiple demands assigned to nodes.

Model Calibration/Validation - Calibration is the process of adjusting model parameters so that predicted model outputs generally reflect the actual behavior of the system. Validation is the next step after calibration, in which the calibrated model is compared to independent data sets (i.e., data that was not used in the calibration phase) in order to ensure that the model is valid over wider range of conditions. There are no formal standards in the water industry concerning how closely the model results need to match field results nor is there formal guidance on the amount of field data that must be collected. Calibration methods that are frequently used include roughness (c-factor) tests, hydrant flow tests, tracer tests and matching model results over extended periods for pressure, flow and tank water levels to field data collected from SCADA systems or special purpose data collection efforts.

The IDSE Guidance Manual stipulates the following minimum criteria in order to demonstrate calibration. "The model must be calibrated in extended period simulation for at least a 24-hour period. Because storage facilities have such a significant impact upon water age and reliability of water age predictions throughout the distribution system, you must compare and evaluate the model predictions versus the actual water levels of all storage facilities in the system to meet calibration requirements." For TEVA-SPOT application, the water utility should calibrate the model to a level that they are confident that the model adequately reflects the actual behavior of the water system being represented by the model. Some general guidelines for calibration/validation are shown below:

- If the model has been in operation actively and for several years and has been applied successfully in a variety of extended period simulation situations, then further substantial calibration may not be necessary. However, even in this case, it is prudent to demonstrate the validity of the model by comparing the model results to field measurements such as time-varying tank water levels and/or field pressure measurements.
- If the model has been used primarily for steady state applications, then further calibration/validation emphasizing extended period simulation is needed.
- If the model has been recently developed and not undergone significant application, then a formal calibration/validation process is needed.

Model Tanks - Tank mixing models: Most water distribution system models use a "complete mix" tank representation that assumes that tanks are completely and instantaneously mixed. EPANET (and most commercial modeling software models) allow for alternative mixing models such as last in-first out (LIFO), first in-first out (FIFO), and compartment models. If a utility has not previously performed water quality modeling, they may not have determined the most appropriate tank mixing model for each tank. Since the tank mixing model can affect contaminant modeling and thus the sensor placement decisions, tank mixing models should be specified in the EPANET model input files.

Model Testing - The final step in preparing the model for use in TEVA-SPOT is to put the model through a series of candidate tests. Following is a list of potential tests that should be considered.

1. If the model was developed and applied using a software package other than EPANET, then following its conversion to EPANET, the original model and the new EPANET model should be run in parallel under EPS and the results compared. The models should give virtually the same results or very similar results. Comparisons should include tank water levels and flows in major pipes, pumps and valves over the entire time period of the simulation. If there are significant differences between the two models, then the EPANET model should be modified to better reflect the original model or differences should be explained and justified.
2. The EPANET model should be run over an extended period (typically 1 to 2 weeks) to test for sustainability. In a sustainable model, tank water levels cycle over a reasonable range and do not display any systematic drops or increases. Thus, the range of calculated minimum and maximum water levels in all tanks should be approximately the same in the last few days of the simulation as they were in the first few days. Typically, a sustainable model will display results that are in dynamic equilibrium in which temporal tank water level and flow patterns will repeat themselves on a daily (or other periodic) basis.
3. If the water system has multiple sources, then the source tracing feature in EPANET should be used to test the movement of water from each source. In most multiple source systems, operators generally have a good idea as to how far the water from each source travels. The model results should be shown to the knowledgeable operators to ensure that the model is operating in a manner that is compatible with their understanding of the system.
4. The model should be run for a lengthy period (1 to 2 weeks) using the water age option in EPANET in order to determine travel times. Since the water age in tanks is not usually known before modeling, a best guess (not zero hours) should be used to set an initial water age for each tank. Then after the long run of the model, a graph of calculated water age should be examined for each tank to ensure that it has reached a dynamic equilibrium and is still not increasing or decreasing. If the water age is still systematically increasing or decreasing, then the plot of age for each tank should be visually extrapolated to estimate an approximate final age and that value should be reinserted in the model as an initial age, and the model rerun for the extended period. The model output of water age should then be investigated for reasonableness, e.g., are there areas where water age seems unreasonably high? This exercise will also help to define a reasonable upper limit for the duration of the model run to be used in the TEVA-SPOT application.

Following these test runs, any identified modifications should be made in the model to ensure that the model will operate properly under TEVA-SPOT. Many utilities will not be able to make all of the above modifications to their network model. In that case, TEVA-SPOT can still be applied; however the overall accuracy of the results will be questionable and should only be considered applicable to the system as described by the model.

Sensor Characteristics

The TEVA-SPOT analysis requires some assumptions about the detection characteristics of the sensors. In particular, the sensor type, detection limit, and accuracy need to be specified. For example, the analysis can specify a contaminant-specific detection limit that reflects the ability of the water quality sensors to detect the contaminant. Alternatively, the analysis can assume perfect sensors that are capable of detecting all non-zero concentrations of contaminants with 100% reliability. The latter assumption, though not realistic, provides an upper bound on realistic sensor performance. If the utility has some idea as to the type of sensor that they are planning on using and its likely detection performance, then that information should be provided in a sensor data file. If that information is not available, then some typical default values will be used in the TEVA-SPOT analysis.

In order to quantify detection limits for water quality sensors, the utility must indicate the type of water quality sensor being used, as well as the disinfection method used in the system. Generally, water quality sensors are more sensitive to contaminant introduction with chlorine disinfection than with chloramine. As a result, contaminant detection limits may need to be increased in the design of a sensor network for a chloraminated system.

Ongoing pilot studies for EPA's Water Security Initiative use a platform of water quality sensors, including free chlorine residual, total organic carbon (TOC), pH, conductivity, oxidation reduction potential (ORP), and turbidity (USEPA, 2005b). The correlation between contaminant concentration and the change in these water quality parameters can be estimated from experimental data, such as pipe loop studies (Hall et al., 2007; USEPA, 2005c). Of these parameters, chlorine residual and TOC seem to be most likely to detect a wide range of contaminants.

Detection limits for water quality sensors can be defined in terms of the concentration that would change one or more water quality parameters enough that the change would be detected by an event detection system (for example, Cook et al., 2005; McKenna, Wilson and Klise, 2006) or a water utility operator. A utility operator may be able to recognize a possible contamination incident if a change in water quality is significant and rapid. For example, if the chlorine residual decreased by 1 mg/L, the conductivity increased by 150 µSm/cm, or TOC increased by 1 mg/L.

A sensor data file is a text file that can be created with any text editor. TEVA-SPOT requires two types of sensor files depending on the application. One type of sensor file is used in the ***Sensor Placement*** module under ***Location*** Categories. This sensor file is described in Table 3. The second type of sensor file is used under the command ***HIA Sensors-Import HIA Sensor Data.*** This type of sensor file is described in Table 4. Each line of the sensor file for loading HIA sensors into TEVA-SPOT consists of nine text fields separated by one or more spaces or tabs. The contents of the fields are defined in Table 4. The ***HIA Sensors*** feature is used to load a single sensor network design into TEVA-SPOT in order to produce a complete set of maps, charts, and tables delineating the reduced impacts given the sensor network design. Each sensor file can be named as the user chooses, with a *txt* extension.

Table 3: Sensor File for Use in Sensor Placement Module

Field	Description
`#Name`	Literal string.
`<Keyword>`	*feasible, infeasible, fixed, and unfixed*
<*NodeID*>	The name of a node in the water network.

For example, the sensor placement file should appear as follows (***notice there no spaces in the title name***):

#Name: Demo_2_sensors_fixed_location_design
infeasible ALL
fixed Junction-100 Junction-101

Note that after the keywords "*infeasible* and *fixed*" there is a space or tab. Similarly, there is a space or tab between node identifiers. Each line of the must begin with a keyword.

Table 4: Fields of Sensor Data Files for Loading Sensors into Health Impacts Assessment (HIA) Sensors

Field	Description
`SAMPLELOC`	Literal string.
<*NodeID*>	The name of a node in the water network.
<*SensorType*>	A string defining the type of the sensor located at the node given by <*NodeID*>. Valid values for <*SensorType*> are given below.
<*SampleType*>	A string defining the type of the sampling performed by the sensor located at the node given by <*NodeID*>. Valid values for <*SampleType*> are given below.
<*DetectionLimit*>	The minimum concentration detectable by the sensor.
<*SampleVolume*>	The volume, in liters, sampled by the sensor (ignored for sensors having <*SampleType*> = `REALTIME`).
<*SampleFrequency*>	The sensor's sampling frequency in hours.
<*SampleStartTime*>	The elapsed time, in hours, from the start of the simulation at which the sensor takes its first sample.
<*SampleDelay*>	The sensor's lag time, in hours, from detection to reporting. This is the same as Response Time Delay.

Valid values for the <*SensorType*> are as follows:

`EXISTING`, which indicates that a sensor (not placed by the Sensor Placement Algorithm) already exists at the node given by <*NodeID*>;

`SELECTED`, which indicates that the Sensor Placement Algorithm considered the node given by <*NodeID*> and, in fact, recommended placing a sensor there;

`POTENTIAL`, which indicates that the Sensor Placement Algorithm considered the node given by <*NodeID*> but did not recommend placing a sensor there; and

`IGNORED`, which indicates that the Sensor Placement Algorithm did not consider the node given by <*NodeID*>.

Valid values for the <*SampleType*> are as follows:

REALTIME, which indicates that the sampling performed at the node given by <*NodeID*> is sampled instantaneously (i.e., in real time). There is no linkage to the volume of water that passes the node of the sensor location when the sample type is REALTIME (i.e., the <*SampleVolume*> is ignored).

COMPOSITE, which indicates that the sampling performed at the node given by <*NodeID*> is a collection of samples (i.e., composite sample). The volume of composited water that passes the node of the sensor location is specified by the <*SampleVolume*>. This sample type is useful for detecting biological organisms that may only exist in very small concentrations.

FILTERED, which indicates that the sampling performed at the node given by <*NodeID*> is a set of filtered samples. The volume of filtered water that passes the node of the sensor location is specified by the <*SampleVolume*>. This sample type is useful for detecting biological organisms that may only exist in very small concentrations.

The sensor file for loading into ***HIA Sensors*** must be a text file with each sensor location (*nodeID*) and its associated identifiers specified on a single line in the text file. For example, the text file should appear as follows (with the keywords replaced as appropriate):

SAMPLELOC *<NodeID>* *<SensorType>* *<SampleType>* 0 *<SampleVolume>* 24 1 24

Design Basis Threat

A design basis threat identifies the type of threat that a water utility seeks to protect against when designing a CWS. In general, a CWS is designed to protect against contamination threats; however, there are a large number of potentially harmful contaminants and a myriad of ways in which a contaminant can be introduced into a distribution system. Some utilities may wish to design a system that can detect not only high impact incidents, but also low impact incidents that may be caused by accidental backflow or cross-connections. It is critical for a water utility to agree upon the most appropriate design basis threat before completing the sensor network design.

Contamination incidents are specified by the type of contaminant(s), the quantity of contaminant, the location(s) at which the contaminant is introduced into the water distribution system, the time of day of the introduction, and the duration of the contaminant introduction. Given that it is difficult to predict the behavior of adversaries, it is unlikely that a water utility will know, with any reasonable level of certainty, the specific contamination threats that they may face. The TEVA-SPOT approach assumes that most of these parameter values cannot be known precisely prior to an incident; therefore, the modeling process must take this uncertainty into account.

As an example, probabilities are assigned to each location in a distribution system indicating the likelihood that the contaminant would be introduced at that location. The default assumption is that each location is equally likely to be selected by an adversary (each has the same probability assigned to it). A large number of contamination incidents (an ensemble of incidents) are then simulated and sensor network designs are selected based on how well they perform for the entire set of incidents. Based on their completed vulnerability assessment and other security related studies, a utility may have some knowledge or preconceived ideas that will assist in refining these assumptions. Some specific questions to consider are listed below:

- Are there certain locations that should be assigned higher probabilities? Should all nodes be considered as possible introduction sites or only nodes with consumer demand?
- Should utility infrastructure sites, such as storage tanks, be considered as potential contamination entry locations?
- Are there specific contaminants of concern to this utility?

Performance Measures

The TEVA-SPOT software utilizes an optimization model that selects the best sensor design in order to meet a specific set of performance measures. These measures are also sometimes referred to as objectives or metrics. There are several performance measures that are currently supported by TEVA-SPOT including:

- the number of individuals exposed to a contaminant
- the percentage of incidents detected
- the time of detection
- the length of pipe contaminated
- the contaminated mass consumed
- the contaminated volume consumed

With each of these performance measures, several statistics can be used to design the sensor network. The following statistics are currently supported by TEVA-SPOT:

- the minimum impact over all contamination events
- the mean impact over all contamination events
- the worst impact over all contamination events
- the lower quartile: 25% of contamination incidents have an impact value less than this quartile
- the median: 50% of contamination incidents have an impact value less than this quartile
- the upper quartile: 75% of contamination incidents have an impact value less than this quartile
- the value at risk (VaR): 100*beta% of contamination incidents have an impact value less than this value, where beta is a user-defined parameter
- the tailed-conditioned expectation (TCE): the mean value of the impacts that are greater than or equal to VaR

Although it requires more time and input from the user, TEVA-SPOT can also consider multiple objectives in its analysis. If the water utility has any preferences in the area of performance measures, they should specify which of the above measures should be used and the relative importance (weight) to be assigned to each measure. If there are other quantitative measures that they wish to be considered, these should be specified.

Utility Response

The TEVA-SPOT analysis uses the concept of "response times" in the analysis of the effectiveness of a sensor system. Response time is an aggregate measure of the total time between the indication of a contamination incident (e.g., detection of an unusual event by a sensor system) and full implementation of an effective response action such that there are no more consequences. The following response activities are likely following sensor detection (USEPA, 2004; Bristow and Brumbelow, 2006):

- Credibility determination: integrating data to improve confidence in detection; for example, by looking for additional sensor detections or detection by a different monitoring strategy, and checking sensor maintenance records.
- Verification of contaminant presence: collection of water samples in the field, field tests and/or laboratory analysis to screen for potential contaminants.
- Public warning: communication of public health notices to prevent further exposure to contaminated water.
- Utility mitigation: implementing appropriate utility actions to reduce likelihood of further exposure, such as isolation of contaminated water in the distribution system or other hydraulic control options.
- Medical mitigation: public health actions to reduce the impacts of exposure, such as providing medical treatment and/or vaccination.

Past analyses have shown that the benefits of a contaminant warning system (CWS) are very dependent on a rapid response time. Typically, the TEVA-SPOT analysis assesses a range of response times between 0 and 24 hours. A zero hour response time is obviously infeasible but is usually analyzed in TEVA-SPOT as the best-case scenario and thus the maximum benefits that can be associated with a CWS. Water utilities should assess their own emergency response procedures and their acceptable risk tolerance in terms of false negative and false positive responses in order to define a range of response times to be used in the TEVA-SPOT analysis.

Potential Sensor Locations

TEVA-SPOT searches potential sensor locations to determine those set of locations (nodes) that will result in the optimal performance measure for a particular number of sensors. Utilities can choose to consider all nodes as potential sensor locations or to limit the search to a subset of specified nodes.

The primary physical requirements for locating sensors at a particular location are accessibility, electricity, physical security, data transmission capability, sewage drains, and temperatures within the manufacturer specified range for the instrumentation (ASCE, 2004). Accessibility is required for installation and maintenance of the sensor stations. Electricity is necessary to power sensors, automated sampling devices, and computerized equipment. Physical security protects the sensors from natural elements and vandalism or theft. Data transmission is needed to transmit sensor signals back to a centralized SCADA database, and can be accomplished through a variety of solutions including digital cellular, private radio, land-line, or fiber-optic cable. Sewage drains are required to dispose of water and reagents from some sensors. Temperature controls may be needed to avoid freezing or heat damage.

Most drinking water utilities can identify many locations satisfying the above requirements, such as pumping stations, tanks, valve stations, or other utility-owned infrastructure. Many additional locations may meet the above requirements for sensor locations or could be easily and inexpensively adapted. Other utility services, such as sewage systems, own sites that likely meet most of the requirements for sensor locations (e.g., collection stations, wastewater treatment facilities, etc.). In addition, many publicly-owned sites could be easily adapted, such as fire and police stations, schools, city and/or county buildings, etc. Finally, many consumer service connections would also meet many of the requirements for sensor placement, although there may be difficulties in securing access to private homes or businesses. Nevertheless, the benefit of using these locations may be worth the added cost. Compliance monitoring locations may also be feasible sites.

The longer the list of potential sensor sites, the more likely one is to design a high-performing CWS. Typically, the TEVA-SPOT analysis will consider two or three subsets of nodes. For example, the set of all nodes in the model, the set of all publicly-owned facilities, and the set of all water utility owned facilities. The utility should develop a list of the (EPANET) node numbers associated with the facilities that they would like to have considered as potential sensor locations. Multiple lists indicating different subsets (such as water utility owned, publicly owned, etc.) may also be specified.

The user can designate sensors as being either eligible for placement by the algorithm, ineligible for placement, or required to be placed; the latter category signifies sensors that already exist. A location categories file is a text file that can be created with any text editor. The file can be named as the user chooses; TEVA does not require the filename to have a particular extension.

Each line of the file consists of a keyword followed either by the literal `ALL` or by a blank-separated list of ids of nodes in the water network. If `ALL` is specified, the keyword applies to all nodes in the network; otherwise it applies only to the nodes whose ids are given. The `ALL` keyword must be in upper case, as shown, otherwise it is taken as the id of a specific node. There are four keywords (`feasible`, `infeasible`, `fixed`, and `unfixed`). At all times during the reading and processing of a location categories file, each node of the network has a feasibility property (specified by the `feasible` or `infeasible` keyword) and a forceability property (specified by the `fixed` or `unfixed` keyword). The meaning of the keywords is given in Table 5.

Table 5: Meaning of the Keywords in Location Categories Files

Property	Keyword	Meaning
Feasibility	`feasible`	Node is *permitted* to have a sensor
	`infeasible`	Node is *not permitted* to have a sensor
Forceability	`fixed`	Node is *required* to have a sensor
	`unfixed`	Node is *not required* to have a sensor

Initially, all nodes have the properties `feasible` and `unfixed`. The lines of the file are processed sequentially. Each line causes the specified nodes (or all nodes, if `ALL` is specified) to acquire values for *both* properties, as shown in Table 6. The table also shows how the SP algorithm treats the specified nodes if the values of their properties are not subsequently changed.

Table 6: Effect of Keyword in LC File, and Treatment of Nodes by SP Algorithm

<table>
<tr><th rowspan="3">Specified Keyword</th><th colspan="4">Values Conferred on Specified Nodes</th><th rowspan="3">Eligibility for Sensor Placement When Values Are Final</th></tr>
<tr><th colspan="2">Feasibility Property</th><th colspan="2">Forceability Property</th></tr>
<tr><th><code>feasible</code></th><th><code>infeasible</code></th><th><code>fixed</code></th><th><code>unfixed</code></th></tr>
<tr><td><code>feasible</code></td><td rowspan="2">✓</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">✓</td><td rowspan="2">Eligible</td></tr>
<tr><td><code>unfixed</code></td></tr>
<tr><td><code>infeasible</code></td><td></td><td>✓</td><td></td><td>✓</td><td>Ineligible</td></tr>
<tr><td><code>fixed</code></td><td>✓</td><td></td><td>✓</td><td></td><td>Forced</td></tr>
</table>

Population

In TEVA-SPOT analyses, the most commonly used performance measure for sensor placement is the number of persons made ill following exposure to contaminated drinking water. In order to estimate health impacts, information is needed on the population at each node. There are a variety of methods that can be used to estimate nodal population.

- The simplest method is to assume a constant relationship between demand assigned to a node and the population for that node. This method is most appropriate for a homogeneous, largely residential area. If a water demand-based population method is to be used, the total population calculated by the model using a per capita water usage rate needs to be verified with the population served considering billing records.
- Alternatively, if the number of service connections and types of service connections (i.e. residential, commercial, industrial, etc.) are known for each node, then this information can be used to estimate population.
- A third alternative involves independent determination of population based on census data. If the use of a census-based population is desired, the population associated with each non-zero demand node of the model needs to be determined using the census data and GIS software. The resulting total population needs to be verified with the population served by the water system.

If the second or third method is used to estimate nodal population, a population data file needs to be created with any text editor. The file can be named as the user chooses; TEVA-SPOT does not require the filename to have a particular extension. Each line of the file consists of two text fields separated by one or more blanks. The contents of the fields are defined in Table 7 below.

Table 7: Fields of Population Data Files

Field	Description
<NodeID>	The name of a node in the water network; the node should be a junction, tank, or reservoir (i.e., a point-like component of the network).
<Population>	The population at the node given by *<NodeID>*.

Note: Be sure there are no additional hard returns at the beginning or end of the text file. ***Also, be sure the file name does not have any spaces in it.***

For more information about applying the TEVA-SPOT methodology, see Murray et al. (2007) or visit the EPA website http://www.epa.gov/nhsrc/water/teva.html.

APPENDIX B: EXAMPLE MSX FILE

```
[TITLE]
Hypothetical biological contaminant with a 3-component broth Model

[OPTIONS]
AREA_UNITS M2
RATE_UNITS SEC
SOLVER ROS2
COMPILER VC ; alternative is none
TIMESTEP 60
ATOL 0.0010
RTOL 0.0010

[SPECIES]
BULK BC MG
BULK CL MG
BULK T1 MG
BULK T2 MG
BULK T3 MG

[COEFFICIENTS]
CONSTANT k1 300
CONSTANT k2 20
CONSTANT k3 0.01
CONSTANT r1 0.05
CONSTANT r2 0.01
CONSTANT r3 0.01
CONSTANT r4 1000.0
CONSTANT k4 86E-6

[PIPES]
RATE BC -k4*r4*BC*CL
RATE CL -k1*T1*CL-k2*T2*CL-k3*T3*CL-k4*BC*CL
RATE T1 -k1*r1*T1*CL
RATE T2 -k2*r2*T2*CL
RATE T3 -k3*r3*T3*CL

[SOURCES]
SETPOINT { SPECIFY NODE FOR Cl- BOOSTER} CL 1.0
SETPOINT { SPECIFY NODE FOR Cl- BOOSTER} CL 1.0
SETPOINT { SPECIFY NODE FOR Cl- BOOSTER} CL 1.0

[QUALITY]
GLOBAL CL 1.0

[REPORT]
NODES ALL
SPECIES BC YES 5
SPECIES CL YES 5
SPECIES T1 YES 5
SPECIES T2 YES 5
SPECIES T3 YES 5
PAGESIZE 0
```

Additional Reading

American Society of Civil Engineers (ASCE), 2004. Interim Voluntary Guidelines for Designing an Online Contaminant Monitoring System.

Berry, J. et al, 2005. Sensor Placement in Municipal Water Networks. *Jour. Wat. Res. Plan. Manag.* 131 (3): 237-243.

Berry, J. et al, 2006. Sensor Placement in Municipal Networks with Temporal Integer Programming Models. *Jour. Wat. Res. Plan. Manag.* 132(4): 218-224.

Bristow, E. and Brumbelow, K., 2006. Delay between sensing and response in water contamination events. *Jour. Infrastructure Systems*, p. 87-95.

Cook, J. et al, 2005. Decision Support System for Water Distribution System Monitoring for Homeland Security. Proceedings of the AWWA Water Security Congress, Oklahoma City.

Davis, M. J., and Janke, R. (2007a). "Development of a Probabilistic Timing Model for the Ingestion of Tap Water," J. Water Resour. Planning Manage., 135(5), 397-405.

Davis, M. J., and Janke, R. (2008). "Importance of exposure model in estimating impacts when a water distribution system is contaminated." J. Water Resour. Planning Manage., 134(5), 449-456.

Davis, M. J., and Janke, R. (2010a). "Patterns in potential impacts associated with contamination events in water distribution systems." J. Water Resour. Planning Manage., (16 March 2010), 10.1061/(ASCE)WR.1943-5452.0000084.

Davis, M. J., and Janke, R. (2010b). "Assessing Potential Impacts Associated with Contamination Events in Water Distribution Systems: A Sensitivity Analysis," United States Environmental Protection Agency, draft report, EPA/600/R-10/061. DRAFT NOT YET CITABLE.

Hall, J. et al, 2007. On-line Water Quality Parameters as Indicators of Distribution System Contamination. *Jour. AWWA*, 99:1:66-77.

McKenna, S. A., Wilson, M., and Klise, K. A. (2008). "Detecting changes in water quality data." *Journal American Water Works Association*, 100(1), 74–85.

Murray, R., Janke, R., Hart, W. E., Berry, J. W., Taxon, T., and Uber, J. (2008b). “Sensor network design of contamination warning systems: a decision framework.” *Journal American Water Works Association*, 100(11), 97–109.

Murray, R., Haxton, T., Janke, R., Hart, W. E., Berry, J. W., and Phillips, C. A. (2010). Sensor Network Design for Contamination Warning Systems: A Compendium of Research Results and Case Studies Using the TEVA-SPOT Software. U. S. Environmental Protection Agency, Office of Research and Development, National Homeland Security Research Center, Cincinnati OH. EPA/600/R-09/141.

Skadsen, J., Janke, R., Grayman, W., Samuels, W., Tenbroek, M, Steglitz, B., and Bahl, S. 2008. “Distribution system on-line monitoring for detecting contamination and water quality changes.” *Jour. AWWA,* 100:7:81-94.

U. S. Environmental Protection Agency, 2004. Response Protocol Toolbox: Planning for and Responding to Drinking Water Contamination Threats and Incidents. http://www.epa.gov/safewater/watersecurity/pubs/rptb_response_guidelines.pdf

U. S. Environmental Protection Agency, 2005a. Review of State-of-the-Art Early Warning Systems for Drinking Water.

U. S. Environmental Protection Agency, 2005b. WaterSentinel System Architecture. http://epa.gov/watersecurity/pubs/watersentinel_system_architecture.pdf

U. S. Environmental Protection Agency, 2005c. WaterSentinel Online Water Quality Monitoring as an Indicator of Contamination. http://epa.gov/watersecurity/pubs/watersentinel_wq_monitoring.pdf

U. S. Environmental Protection Agency, 2006. Initial Distribution System Evaluation Guidance Manual for the Final Stage 2 Disinfectants and Disinfection Byproducts Rule. EPA 815-B-06-002. http://www.epa.gov/safewater/disinfection/stage2/pdfs/guide_idse_full.pdf