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

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

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Definitions

Collection – Describes a group of applications or ensembles within TEVA-SPOT-GUI (graphical user interface version of TEVA-SPOT).

Contamination Scenario – Describes a contaminant’s injection or release at a location in the network (node ID), the contaminant’s transport and fate in the network, and the exposure of individuals by the ingestion of tap water obtained from the network.

C-Values – Consequence Values. Consequences can be estimated, for example, as public health consequences or extent of contamination, such as number of pipe feet contaminated.

Dose Level – A measure of public health consequences defined as the size of the population receiving an ingestion dose above some level.

Ensemble – Defines a group of unique contamination scenarios that are to be simulated within TEVA-SPOT-GUI. Also, describes a user defined application of TEVA-SPOT-GUI.

EPANET-MSX – EPANET’s water quality component is limited to tracking the transport and fate of a single chemical species, such as chloride used in a tracer study or free chlorine used in a disinfectant decay study. EPANET-MSX provides an extension to EPANET that allows the user to model any system of multiple, interacting chemical species. This capability has been incorporated into both a stand-alone executable program as well as a toolkit library of functions that programmers can use to build custom applications. This set of software tools is referred to as EPANET-MSX, where MSX stands for Multi-Species Extension.

GRASP heuristic - GRASP heuristic algorithm performs sensor placement optimization without explicitly creating a MIP formulation. GRASP uses much less memory than PICO and usually runs much faster in comparison to PICO. Although the GRASP does not guarantee that a globally optimal solution is found, it has proven effective at finding optimal solutions to a variety of large-scale applications.

Injection Definition - Describes the contaminant release or injection that will be simulated in TEVA-SPOT-GUI, including contaminant name, contaminant’s mass injection rate (mg/min), and the start and stop times for the contaminant release or injection.

Node Set Definition – Defines a set of network locations (node IDs) where the contaminant will be release or injected.

Node Injections – Represents the addition of a contaminant’s “Injection Definition” with a “Node Set Definition” to create a set of “Node Injections.”

Population Dosed – Number of people who receive a dose greater than a given dose level.

Sensor Placement Optimization Statistic - The statistical measure used to optimize the placement of sensor monitoring stations given the distribution of consequences that are defined by the ensemble of contamination scenarios. The mean statistic is the *expected* consequence given a set of contamination scenarios. Worst case is the maximum consequence obtained with a design for some specified conditions.

Scenario Set – Represents one or more “Node Injections” to create a folder of contamination simulations. One or more scenario sets specify a unique set of contamination scenarios.

TSO-2-Impact – Precursor file for sensor placement optimization.

GUI/UI – Graphical User Interface (GUI) or simply user interface (UI).

Acronyms

ATUS – American time use survey

CWS – Contamination warning system

DL – Dose level

ec – Extent of contamination (feet of pipe)

ERD – EPANET results database

GPD – Gallons per person per day

GRASP - Greedy randomized adaptive search procedure

GUI – Graphical user interface

HIA – Health impacts analysis

ID – Infectious dose

INP – EPANET file format, extension to text file (e.g., Test.inp)

IIA – Infrastructure impacts analysis

kg – Kilograms

LD – Lethal dose

MIP – Mixed integer program

MSX – Text file with the .msx extension. It is loaded into TEVA-SPOT-GUI for multi-species analyses

NHSRC – National Homeland Security Research Center

NZD – Non-zero demand

PICO - Parallel integer and combinatorial optimizer

pd – Population dosed

pe – Population exposed

pk – Population killed

RAM – Random access memory

SP – Sensor placement

SRS - Surveillance and response system

TEVA-SPOT – Threat ensemble vulnerability assessment, sensor placement optimization tool

TSO – Threat simulator output. In an earlier version of TEVA-SPOT, the acronym “tso” was used to describe the output from EPANET, i.e., contaminant concentration values at each receptor node and time step given a contaminant injection at an injection node. The tso formalism has since been replaced by “ERD” (EPANET Results Database).

txt – File extension for TEVA-SPOT-GUI results in TEVA-SPOT-Database/ENSEMBLE folder that can be viewed with a text editor.

USGS – United States Geological Survey

Vc – Volume consumed

WDS – Water distribution system

WQ – Water quality

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Portions of TEVA-SPOT-GUI 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-GUI 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*

Questions or Problems

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Executive Summary

This report provides a User's Manual for the Threat Ensemble Vulnerability Assessment – Sensor Placement Optimization Tool (TEVA-SPOT), graphical user interface (GUI) software program. The TEVA-SPOT-GUI software tool was developed by the U.S. EPA, National Homeland Security Research Center (NHSRC) to evaluate contaminant threats to drinking water distribution systems and use the quantified consequence data to help design sensor monitoring networks for drinking water distribution systems. The TEVA-SPOT software tool quantifies consequences from an array of contaminant-release scenarios. Contaminant threats can be either intentional or unintentional releases of contaminants.

TEVA-SPOT-GUI which provides an easy to use graphical user interface for inputting the necessary parameters and for outputting and viewing results from TEVA-SPOT. TEVA-SPOT-GUI uses EPANET 2.00.12 as its hydraulic and water quality modeling engine.

This manual is based on using the TEVA-SPOT-GUI version dated 20160921.

TEVA-SPOT-GUI is available for download at: <http://www.epa.gov/nhsrc/index.html>, see “Models, Tools, and Applications for Homeland Security Research” and then click “Water Distribution System Tools.”

1. Introduction

Threat Ensemble Vulnerability Assessment – Sensor Placement Optimization Tool (TEVA-SPOT) is a software tool developed by the U.S. EPA, National Homeland Security Research Center (NHSRC) to evaluate contaminant threats to drinking water distribution systems. Contaminant threats are posed by both intentional and unintentional releases of contaminants. The TEVA-SPOT software tool quantifies consequences from an array of contaminant-release scenarios. The emergency planner's ability to prioritize enhancements to drinking water distribution system monitoring, surveillance, and response capabilities through deployment of a contamination warning system, hinges on effective consequence analysis. The quantification of consequences is needed to support the design of an effective contamination warning system (CWS) and response capabilities. One key component of a CWS is the sensor monitoring network, which enables timely detection of water quality anomalies indicative of a contaminant release. Quantified consequences of contaminant releases - of various contaminants, in various amounts and from various locations - are required for the design and evaluation of a robust sensor monitoring network and for prioritization of security enhancements at utility facilities located in the distribution system. The TEVA-SPOT software tool fulfills pivotal roles in the development of an effective contamination warning system for the protection of drinking water distribution systems.

TEVA-SPOT uses EPANET 2.00.12 as its hydraulic and water quality modeling engine [1, 18]. This report provides a User's Manual for the TEVA-SPOT graphical user interface (GUI) version, which provides an easy to use graphical user interface for inputting the necessary parameters and for outputting and viewing results. This manual is based on using the TEVA-SPOT-GUI version. TEVA-SPOT-GUI is available for download at: <http://www.epa.gov/nhsrc/index.html>, see "Models, Tools, and Applications for Homeland Security Research" [2].

TEVA-SPOT-GUI incorporates the multi-species extension to EPANET (EPANET-MSX), which provides the ability to simulate and model more sophisticated contaminant interactions and the influence of those interactions on estimating public health and infrastructure damages. The use of the EPANET-MSX capabilities requires the specification of the necessary kinetic reactions that describe the interactions of the contaminant in the water distribution system. [EPANET-MSX](http://www.epa.gov/nhsrc/index.html) is available from the same link as TEVA-SPOT-GUI: <http://www.epa.gov/nhsrc/index.html>, see "EPANET Extensions" [3].

1.1 Supporting Documents

A solid foundation in water distribution system modeling, hydraulics, and water quality is the best preparation for using TEVA-SPOT-GUI. A strong understanding and experience using EPANET is a prerequisite for using TEVA-SPOT-GUI. Numerous journal articles and reports have been published on water distribution system modeling, including contaminant fate and transport modeling, exposure, and consequence assessment of contaminants released into water distribution systems, as well as on the design of sensor monitoring networks to support contamination warning systems. Appendix C contains a list of some publications and reports that provide supplemental information supporting the use of TEVA-SPOT-GUI. These supporting documents are organized in Appendix C according to three areas: (1) modeling and general information, (2) exposure, dose, and consequence assessment, and (3) sensor network design.

1.2 Data Structure Concepts

The TEVA-SPOT-GUI user will begin by creating an ensemble of contaminant release locations in a water distribution system network, simulate contaminant release(s), perform 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. TEVA-SPOT-GUI's principal data structures are hierarchically organized as shown in Figure 1.1.

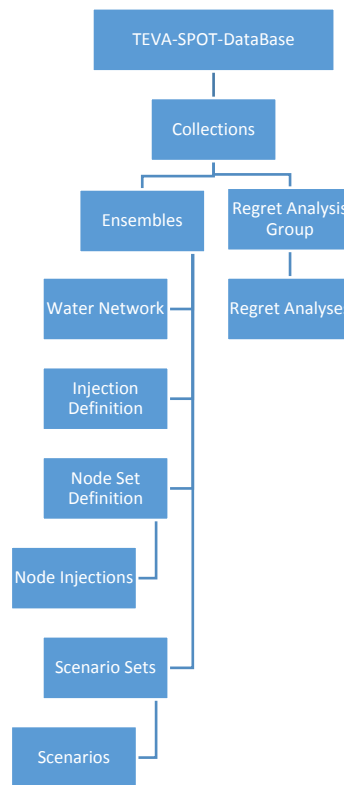


Figure 1.1 Data Flow of TEVA-SPOT-GUI

Two modes of operation exist for TEVA-SPOT-GUI: (1) ensemble analysis mode and (2) regret analysis mode. The user is presented with the “Ensemble Analysis” mode when starting TEVA-SPOT-GUI. Ensemble analysis mode is where contaminant consequence analyses and sensor network designs are performed. Regret analysis mode is where sensor network designs can be further evaluated.

Ensemble analysis consists of four modules: (1) population setup, (2) EPANET simulations, (3) impacts analysis, and (4) sensor placement. Consequences or impacts are determined and used to develop optimized sensor network designs.

Regret analysis is a trade-off analysis that determines how well a particular sensor network design meets

an objective(s) other than the one they were designed to achieve. Regret analysis uses the impact files and sensor designs generated by TEVA-SPOT-GUI and designated by the user in order to create or edit regret analysis parameters.

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. Figure 1.2 provides a flow chart illustrating the process to define a contamination event, identify contamination injection locations, and define a unique set of contamination scenarios. The figure also describes relationship between an “Ensemble” and a “Collection.”

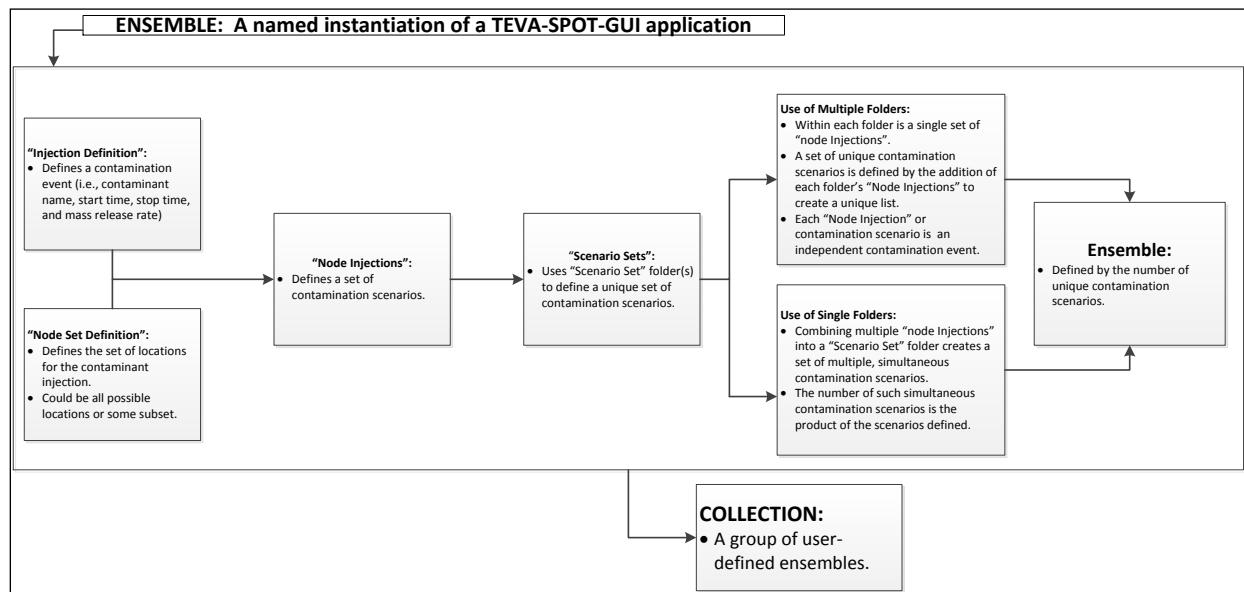


Figure 1.2 Process for Defining Contamination Scenarios

1.3 Installation

The distribution executable (.exe file) contains the TEVA-SPOT-GUI program and User’s Manual. The prerequisite software can be obtained by searching for the required items below. Prerequisite software includes the Java Development Kit (JDK) (e.g., Version 1.6 update 20) and the Python Scripting Language (version 2.7 or later). The JDK and Python products need to be installed prior to the installation of TEVA-SPOT-GUI. 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-GUI has been tested on Windows XP and Windows 7, as well as Windows 10 and Windows Server 2012. JDK and Python installers need to be correlated with computer hardware and operating system (i.e., 32 bit versus 64 bit hardware/software) in which TEVA-SPOT-GUI will be installed. The latest versions should be installed.

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

- Go to START Programs/TEVA-SPOT and choose STOP TEVA-SPOT Services from START Programs/TEVA-SPOT (i.e., for Microsoft® Windows XP and 7).
- If you have previously setup a contaminants file, move the “contaminants.xml file” from the “client” folder under Program Files/TEVA-SPOT/client to a 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.
- Go to START Programs/TEVA-SPOT and 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 loss of older ensemble or regret data residing in the TEVA-SPOT-Database folder.

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

Each TEVA-SPOT-GUI installation (.exe) file is tagged with a date of release, e.g., TEVA-SPOTInstaller-2.3.2-MSX Beta -20170110.exe, signifying a release date of January 10, 2017 (last eight digits in the file name). The initial two numbers in the filename describe the version number, i.e., 2.3, refers to the major release number (2) and the minor release number (3). The final number in the file name that describes the version number, i.e., 2, designates a sub-minor release which is specific to TEVA-SPOT-GUI. After installation, the release version can be determined by clicking on the main menu’s “ABOUT” drop down menu and then the “About” button. Figure 1.3 provides a screen shot of the “About” screen.

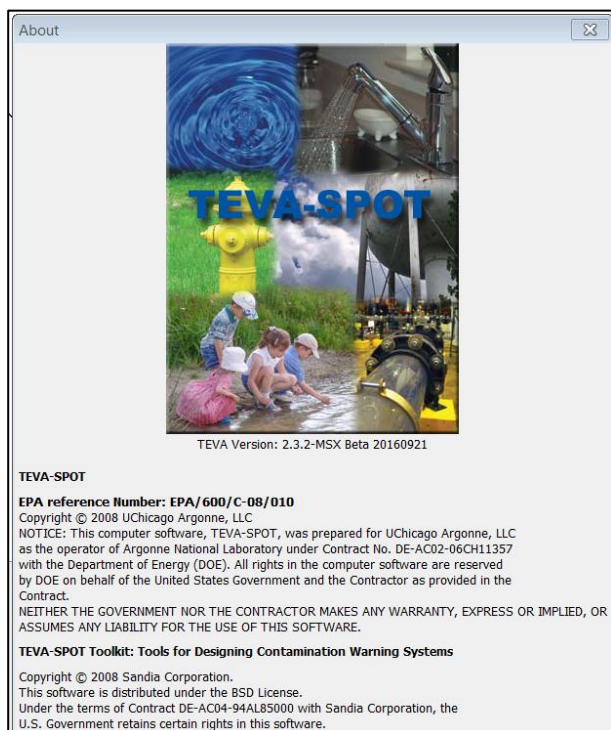


Figure 1.3. About Screen

1.4 Document Organization

After the introduction, the organization of this User's Manual is by section, namely Sections [2](#) through [19](#) (References) and then Appendices A and B. A user of TEVA-SPOT-GUI might be best supported by reading and implementing Sections [2](#) (Getting Started with TEVA-SPOT-GUI), [3](#) (Creating Collections and Ensembles), and [4](#) (Importing EPANET Network Model) first. Next, the TEVA-SPOT-GUI user should read and implement Section [6](#) (EPANET Network Model Setup). The TEVA-SPOT-GUI user should go to Section [8](#) (Input Generation) next to read and implement the tasks associated with data input and generation. Next, the user should read and implement the remaining sections in the order of [18](#), [7](#), [9](#), [10](#), [11](#), [12](#), [13](#), [14](#), [15](#), [16](#), and [17](#) as needed. Reading and examining Section [18](#) early might seem a bit out of place but is important from a quality assurance and quality control perspective. Appendices [A](#) and [B](#) should be consulted as needed.

2. Getting Started with TEVA-SPOT-GUI

Upon opening TEVA-SPOT-GUI from the Microsoft Windows™ START MENU, the user will see two screens: (1) the user interface screen (Figure 2.1) and (2) an associated Disc Operating System (DOS) command line screen (Figure 2.2). The DOS screen is self-generated and is used for internal execution and monitoring capabilities. The DOS screen cannot be used to input data or retrieve results. DO NOT CLOSE THE DOS SCREEN. *Closing the DOS screen will close the TEVA-SPOT-GUI user interface.*

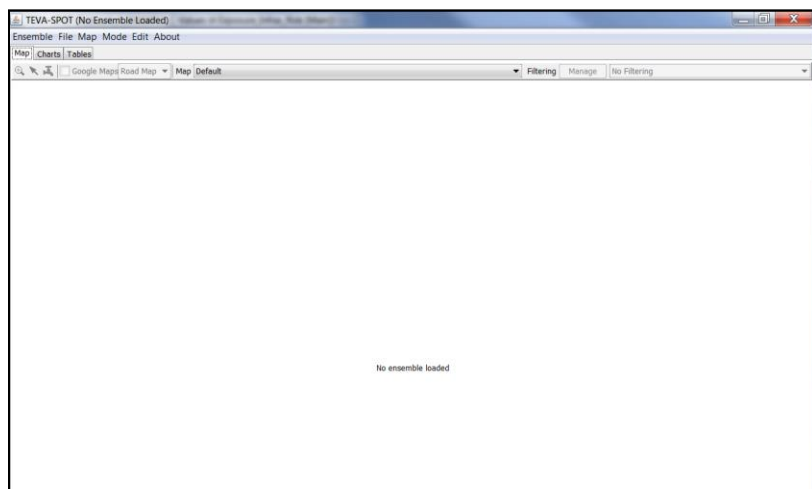


Figure 2.1 User Interface Screen

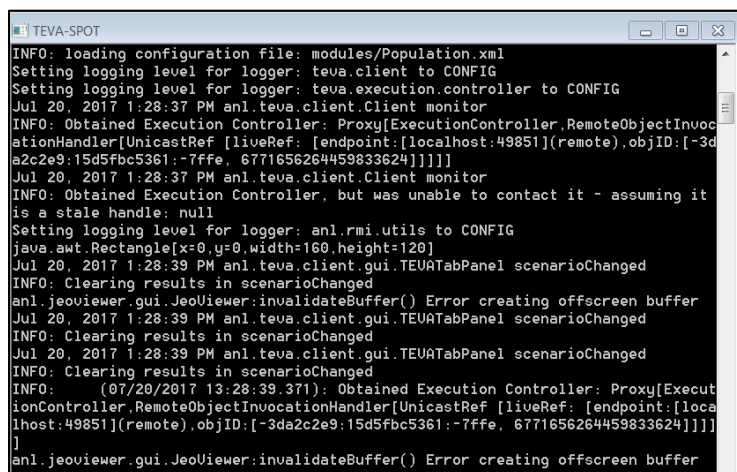


Figure 2.2 DOS Screen

Execution is implemented from the “Execution Control” panel. Once an Ensemble or Regret Analysis is loaded, the “Execution Control” panel can be opened by clicking the keys Control (Ctrl)-Letter E together or choosing “Execution Control” from the main “ENSEMBLE” menu. This is illustrated in Figure 2.3.

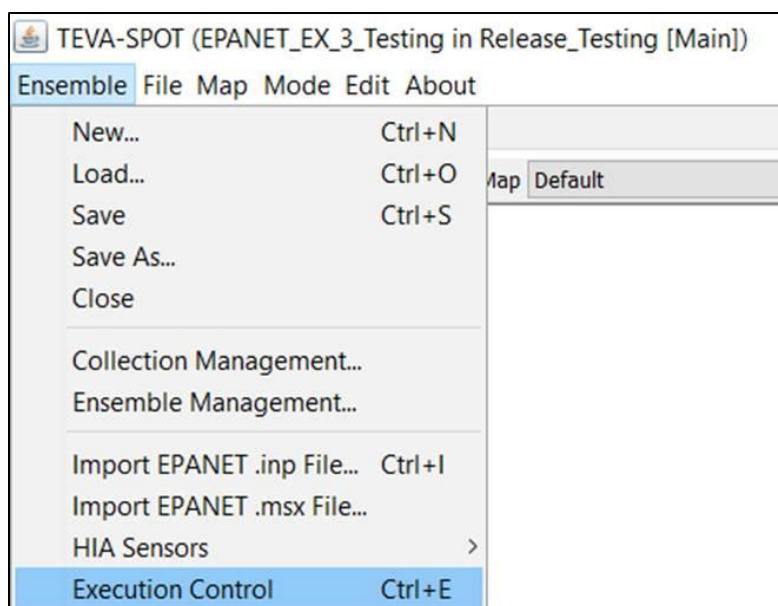


Figure 2.3. Opening Execution Control Panel

After an Ensemble is loaded or created, but not yet executed, each TEVA-SPOT-GUI module will show a red exclamation mark next to it, as shown in Figure 2.4.

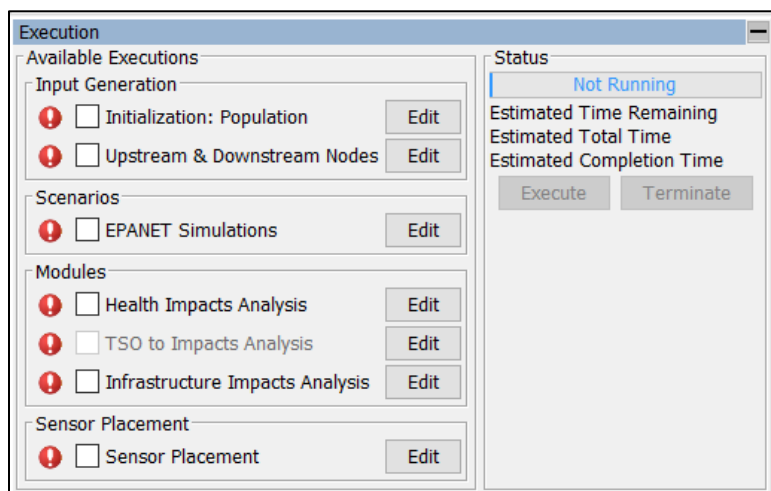


Figure 2.4. Execution Control Panel – Prior to Execution

Once the TEVA-SPOT-GUI modules have been selected (check mark placed in box next to the module) and the “Execute” button clicked and the runs of the modules have completed, the user will see the status of completion which now shows green check marks in the box associated with each executed module (shown in Figure 2.5).¹

¹ Note that the module “TSO to Impacts Analysis” was not executed.

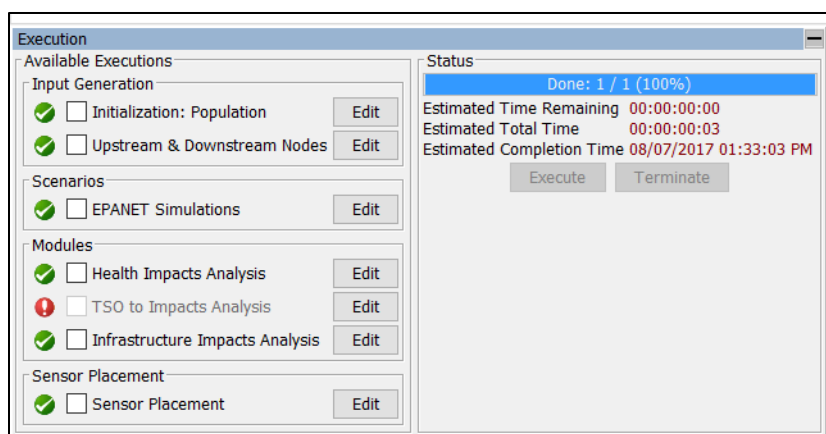


Figure 2.5. Execution Control Panel – After Execution is Completed

It is important to understand that running TEVA-SPOT-GUI initiates TEVA-SPOT services that work independently of the graphical user interface (GUI) client. In other words, closing TEVA-SPOT-GUI 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 could take some time to complete depending on the EPANET model and the module 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-GUI 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-GUI 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 Some Items to Be Careful About...

FLOW UNITS...

All flow units within an EPANET input (inp) file are converted to gallons per minute (gpm) in TEVA-SPOT-GUI. For example, cubic meters per hour flow rate units are converted in TEVA-SPOT-GUI to gpm. The volume consumed (vc) impact measure is in units of gallons and since there are approximately 264 gallons in a cubic meter, the 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, many nodes will receive very small concentrations which turn into very small doses. These 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 the “Concentration Zero Threshold mg/L” box of “Injection Definition” a value that is 1E-6 or greater.

USING THE “ZERO CONCENTRATION THRESHOLD” IN INJECTION DEFINITION...

The “Concentration Zero Threshold” is the contaminant concentration below which concentrations are not reported or recorded. 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, then all other WQ concentrations in the other steps, within the reporting interval, would be 0 since they would be below the threshold.

VISUAL C COMPILER 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. The abbreviation “VC” is specified in the .MSX file for COMPILER. “VC” here, which is all caps should not be confused with “vc” in small caps, which stands for volume consumed, a sensor network optimization objective.

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.

3. Creating Collections and Ensembles

A TEVA-SPOT-GUI analysis application begins with setting up a “Collection” and creating an “Ensemble.” A “Collection” is a folder that contains one or more “Ensembles.” An “Ensemble” represents a user-defined application of TEVA-SPOT-GUI. A contamination scenario is described by the injection or release of a contaminant at a location in the network (node ID), the contaminant’s transport and fate in the network, and the exposure of individuals by the ingestion of tap water or exposure to contaminated tap water from inhalation during showering or from humidifier use. An “Ensemble” defines a unique set of contamination scenarios that are simulated in TEVA-SPOT-GUI. For example, an “Ensemble of Utility Facilities” could describe a contaminant injection at all the nodes in the distribution system model representing valves, tanks, or pumps or the “Ensemble” could describe a contaminant injection at all possible locations in the model (all nodes).

Collections and Ensembles are available from the “Ensemble” drop down menu from the opening user interface screen. Figure 3.1 provides a screen shot of TEVA-SPOT-GUI’s dialogue box for creating a “COLLECTION.” Click NEW, enter name of “COLLECTION” and click “OK.” Similarly, Figure 3.2 provides a screen shot of TEVA-SPOT-GUI’s dialogue box for creating an “ENSEMBLE.” Click “NEW,” select the appropriate “COLLECTION” from the drop down menu and then enter name of “ENSEMBLE” and click “OK.”

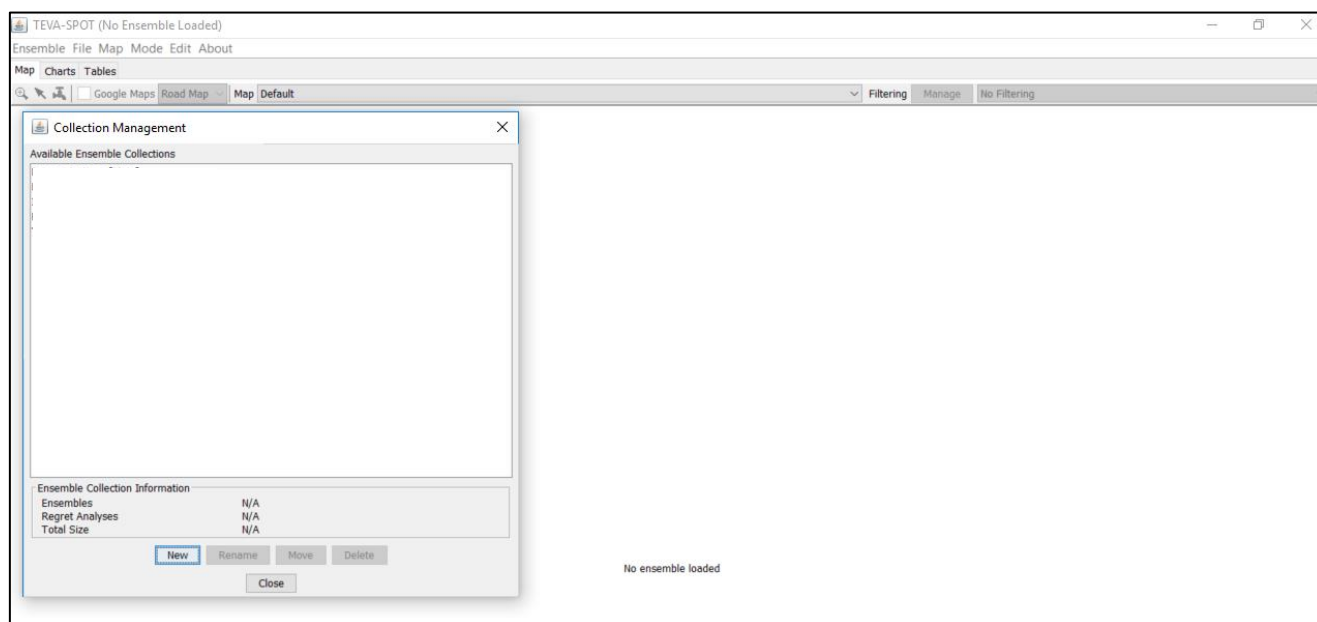


Figure 3.1. Collection Management

“Collections” can be renamed, moved, or deleted using the “COLLECTION MANAGEMENT” interface panel. Please note that if a “Collection” is in use, you will not be able to rename, move, or delete it. It is best to first close the GUI interface, choose “Restart TEVA-SPOT Services,” and then proceed to open the “COLLECTION MANAGEMENT” interface before trying to rename, move or, delete a “Collection.”

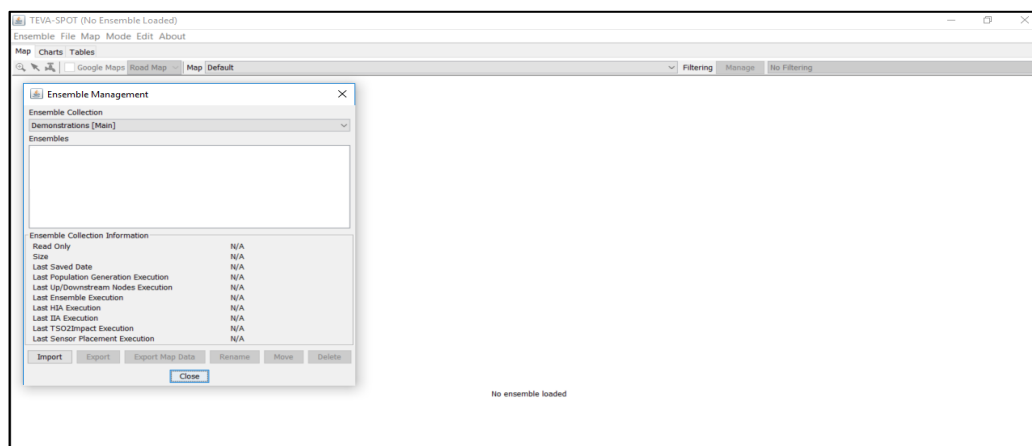


Figure 3.2. Creating an Ensemble

“Ensembles” can also be renamed, moved, or deleted using the “ENSEMBLE MANAGEMENT” interface panel. Please note that if an “Ensemble” is in use, you will not be able to rename, move or, delete it. It is best to first close the GUI interface, choose “Restart TEVA-SPOT Services,” and then proceed to open the “ENSEMBLE MANAGEMENT” interface before trying to rename, move or, delete an “Ensemble.”

“ENSEMBLE MANAGEMENT” has the additional features of “IMPORT,” “EXPORT,” and “EXPORT MAP DATA.”

The “IMPORT” button allows the user to *Import* an “Ensemble.” The “SELECT” button allows the user to browse to the Windows folder location to identify and import the Ensemble. Figure 3.3 provides a screen shot of the interface. Please note that the user must first be in the COLLECTION where the imported ensemble is to be imported.

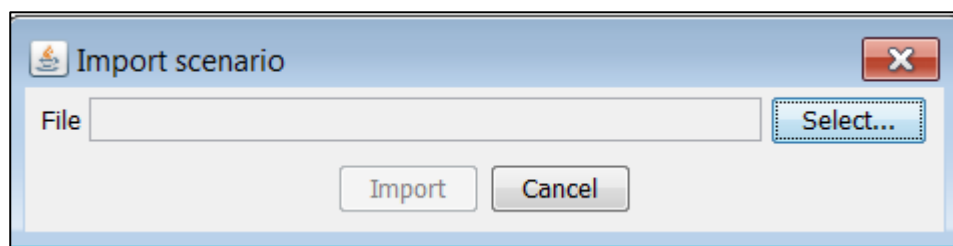


Figure 3.3. Import scenario

The “EXPORT” button allows the user to Export an “Ensemble.” Figure 3.4 provides a screen shot of the Export interface panel. The interface provides the user with a number of ensemble choices to “Export.” A user clicks to “SELECT” to choose the desired ensemble to export. Only choices that have been run and completed will be available to “Export” and will, therefore, be highlighted. The “SELECT” button allows the user to navigate to an appropriate Windows folder to “Export” the “Ensemble.” All exports are in the form of a .ZIP file.

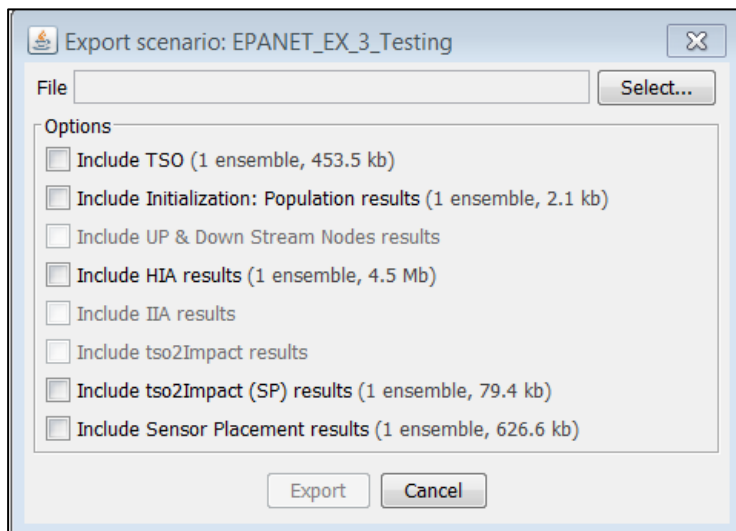


Figure 3.4. Export Scenario

The “EXPORT MAP DATA” button allows the user to “Export” map data (attributes and coordinates) for the network model and results (both consequence and sensor network designs) in order to help facilitate geographical information system (GIS) analysis. Figure 3.5 provides a screen shot of the Export Map Data interface. The “SELECT” button allows the user to navigate to the Windows folder desired for the map data. The default location is C:\Program Files\TEVA-SPOT\Client. The user is able to *select* by clicking in the boxes associated with “Health Impacts Maps” and/or “Sensor Placement” results. The map data is exported as dBase IV files combined into a .ZIP file. A future option is to be able to Export Map Data as an ESRI Shapefile but this functionality is yet available, hence it is grayed out.

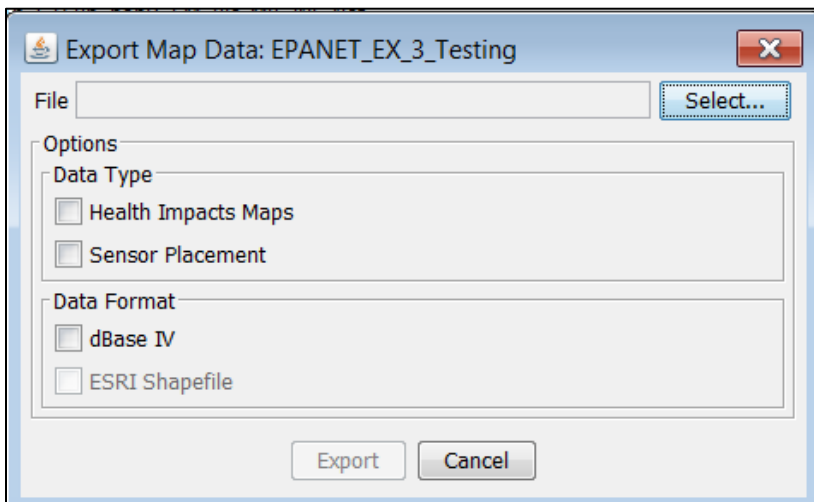


Figure 3.5. Export Map Data: Ensemble Name

4.Importing EPANET Network Model

In the “ENSEMBLE” Menu, choose Import *EPANET.inp* File. Please note that Import *EPANET.inp* File is only available as an option when an ensemble is loaded. EPANET .net file extensions are not supported by TEVA-SPOT. An Open dialogue box appears to allow the user to browse and select the EPANET input file. The imported EPANET .inp file should have QUALITY set to CHEMICAL and all SOURCES removed [18]. If SOURCES are present, TEVA-SPOT will remove them with a notification to the user. Figure 4.1 displays a screen shot from the user interface screen of TEVA-SPOT-GUI for importing an EPANET based network model.

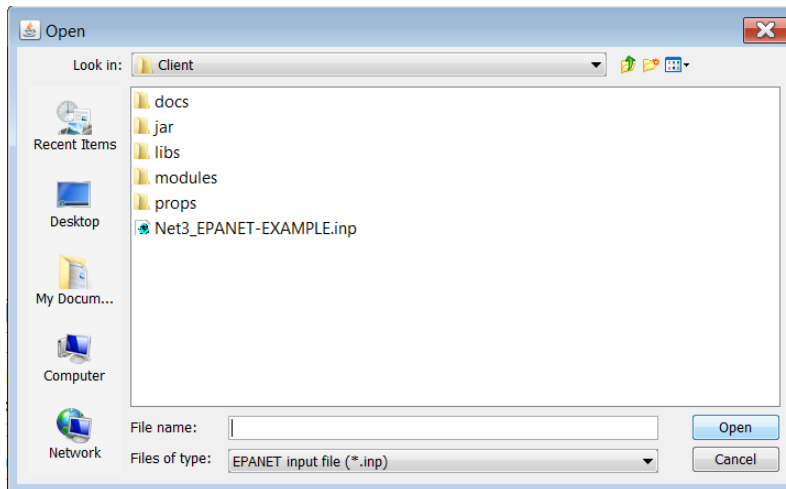


Figure 4.1. Dialogue box for importing EPANET network model

Browse to the directory where your network model is located (where the EPANET input file is located). Notice in Figure 4.1 that the default directory is the location of the “Client” folder within the TEVA-SPOT-GUI Program Files folder: C:\Program Files\TEVA-SPOT\Client. Click the icon for your network (note that no EPANET network model files (.inp) appear in Figure 4.1). Choosing the *.inp file places the name of the file into File name: text box. Click the “OPEN” button to import your network.

5.Using EPANET-MSX Capabilities

TEVA-SPOT-GUI includes EPANET-MSX capabilities. Please refer to the EPANET-MSX User's Manual for more details on software functionality and use. To run EPANET-MSX capabilities within TEVA-SPOT-GUI, 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, and 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.

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 Microsoft® 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.

It is highly recommended that any EPANET-MSX-based modeling be first conducted in the stand-alone EPANET-MSX software. Then, once the application is working properly, apply TEVA-SPOT-GUI to the application.

6. EPANET Network Model Setup

The EPANET simulation parameters are generally specified in the Menu item “EDIT” and then by selecting “ENSEMBLE OPTIONS.” Figure 6.1 provides a screen shot of the user interface display for the “ENSEMBLE OPTIONS.”

The ensemble option parameters within the “ENSEMBLE OPTIONS” are representative of the EPANET example network 3 model provided to users when they download EPANET. The screen shot shown in Figure 6.1 represents a very simple network with very short water residence times. For TEVA-SPOT-GUI analyses, the simulation length (hrs. or min) should be sufficiently long for consequences to stabilize. This is generally a week (168 hours) or longer.

The screenshot displays the "Ensemble Options" dialog box, which is organized into several sections for configuring simulation parameters:

- Description:** A large text area at the top for user input.
- Time Parameters:** Includes fields for Duration (24 hours), Quality Timestep (1 minutes), Hydraulic Timestep (1 hours), and Reporting Interval (1 hours). The status is "OK".
- Water Quality Parameters:** Features checkboxes for "Average concentration over reporting interval" and "Store Link Quality" (both checked). It also includes a "WQ Tolerance Value" of 0.01, a "Transport Method" set to "Original", and a "Tank Mixing model" set to "Use Scenario".
- Hydraulic Parameters:** Contains fields for Maximum Trials (40), CHECKFREQ (2), MAXCHECK (10), DAMPLIMIT (0.0), Unbalanced Condition (Continue w/trials), and Additional Trials (10).
- Simulation Parameters:** Includes a checked box for "Use all servers (Uncheck for extremely large networks)" and a dropdown for "Number of simultaneous SP executions" set to "Max".
- Decay Parameters:** Shows "Decay Name" as "Biological" and "Reaction Order" dropdowns for Bulk, Wall, and Tank, all set to 1.
- Reaction Coefficients:** Includes fields for Bulk and Wall coefficients, both set to 0.0.
- QA Parameters:** Features a checked box for "Perform Mass Balance Analysis" and an unchecked box for "Include Mass Losses". There is also a "Select" button for "Injection Location Exclusions (0)".

At the bottom of the dialog are "OK" and "Cancel" buttons.

Figure 6.1. Screen Shot of Ensemble Options

The “Ensemble Options” dialogue box is composed of seven parameter modules. Starting in the upper left hand corner of Figure 6.1, the seven parameter modules consist of (1) Time Parameters, (2) Water Quality Parameters, (3) Hydraulic Parameters, (4) Simulation Parameters, (5) Decay Parameters, (6) Reaction Coefficients, and (7) QA Parameters.

The “Time Parameters” specify the simulation parameters for EPANET. These are the same as those described in an EPANET INP file under “Time Options.” “Duration” is total simulation duration. “Quality Timestep” is the time step for the water quality simulation. “Hydraulic Timestep” is the time

step for the hydraulic simulation. “Reporting Interval” is the time interval between which computed results are reported. EPANET’s default reporting interval is 1 hour.

The water quality time step should be as short as reasonably achievable given computational resources and available time. Generally, a 1-minute water quality time step preferred, but no greater than 5 minutes. If injection duration shorter than 1 minute is needed, a shorter water quality time step might be needed. An error message is given when the user tries to define a contaminant injection shorter than the water quality time step. The error message instructs the user as to how the injection mass rate should be adjusted to accommodate the longer water quality time step.

Shorter water quality time steps will increase computation time and hardware (computer) resources (memory requirements). Shorter hydraulic time steps will increase computation time. The hydraulic time step must be less than or equal to the reporting time step or TEVA-SPOT-GUI displays an error message in the “ENSEMBLE OPTIONS” under the “EDIT” menu item. Similarly, the hydraulic time step must also be less than or equal to the pattern time step or TEVA-SPOT-GUI will display an error message. The error message will appear in the “Ensemble Options” which is under the “EDIT” menu item. Additionally, as part of the error message indicating that the hydraulic time step is not less than or equal to the pattern time step, TEVA-SPOT-GUI will report what the pattern time step currently is in parentheses.

Generally, a reporting time step of 1 hour is used. A warning will be given if the hydraulic/reporting interval parameters generate an exceedingly large number of time steps. Proceeding without change can result in long computation time and/or exhaustion of computer resources, including processing capabilities, available memory, and storage (hard drive) space.

Within the “Ensemble Options” box is a “Water Quality Parameters” section. Here the box “Average concentration over reporting interval” should be checked. Un-checking would result in the contamination concentration occurring at the end of the time step being reported. The “WQ Tolerance Value” refers to the water quality tolerance, specified in EPANET. This parameter specifies the smallest change in water quality that will result in a new parcel of water being created in a pipe. The default setting in EPANET is 0.01 mg/L for chemicals [1, 18]. The water quality tolerance determines whether the quality of one parcel of water is the same as that of another parcel. In EPANET, water flow is discretized into finite volumes of water. The volume of water in a parcel is assumed to be homogeneous. The water quality tolerance specifies the acceptable tolerance of each parcel. For a chemical contaminant, the value could be the detection limit of the analytical method used to measure the chemical contaminant, adjusted by a suitable safety factor [1, 18]. Generally, lowering the water quality tolerance will provide increased accuracy of the water quality modeling results, but will also increase computation time. It is recommended that a value of 0.01 mg/L be used. Finally, within the “Water Quality Parameters” section the user can globally set the mixing model for the system’s tanks. The default is “Use Scenario,” which corresponds to using what is specified in the INP file for the water distribution system.

The EPANET 2.00.12 hydraulic adjustment parameters are specified within the “Ensemble Options” box. These parameters can be adjusted as advised in EPANET 2.00.12 to decrease simulation time and/or help eliminate hydraulic errors and warnings [1, 18]. EPANET’s reaction and decay parameters are also specified in the “Ensemble Options” box.

The water quality tolerance can also be specified in the “Injection Definition” (see Section 7.0).

Inserting a water quality (WQ) tolerance value in the “Injection Definition” will override the water quality tolerance specified in the “Ensemble Options” box.

Tolerance (mg/L) value here will override the WQ Tolerance specified in the EDIT/ Ensemble Options box; however no value need be specified with the “Injection Definition.”

Also, while in the default map, different network attributes can be highlighted. Within any map network, users can zoom to features. Zooming out can be accomplished by right clicking the mouse on the map and then choosing the appropriate zoom out level.

EPANET multi-species (EPANET-MSX) reaction parameters are specified in an MSX file, which is uploaded into TEVA-SPOT-GUI immediately after loading of the network INP file [2], [3], and [12].

The “Water Quality Parameters” module is enlarged in Figure 6.2 above. The first check box, “Average concentration over reporting interval,” if unchecked provides the user with the ability to mirror results from those obtained using the EPANET User Interface program (EPANET version 2.00.12). If the box is checked, TEVA-SPOT-GUI averages water quality concentrations over the reporting interval. For example, if the water quality time step is 1 minute and the reporting interval is 1 hour, then 60 water quality concentration values will be averaged each hour of the simulation. The check box “Store Link Quality” is selected if the user wants to examine pipe concentrations during animation.

The “WQ Tolerance Value” provides the user with the ability to modify the water quality tolerance value for the EPANET simulation. This will override the water quality tolerance value specified in the EPANET network model that was imported when the TEVA-SPOT-GUI ensemble was created.

The check box for “Use injection mass scaling” allows the user to scale the injection mass injected by a user specified amount. Selecting this check box will open a window for inputting an injection mass scaling integer value.

Water Quality Parameters

☒ Average concentration over reporting interval

☒ Store Link Quality

WQ Tolerance Value

☐ Use injection mass scaling

Transport Method:

☐ Combine non-zero concentration only

Tank Mixing model:

☐ Override if set

Use Scenario
Completely Mixed (MIXED)
2-compartment (2COMP)
Plug Flow (FIFO)
Stacked PLug Flow (LIFO)

Figure 6.2. Ensemble Options – Water Quality Parameters

The “Transport Method” selection menu allows the user to use EPANET’s original water quality algorithm (time-based algorithm) or choose the preliminary “Flow based” water quality algorithm.

The check box “Combine non-zero concentration only” provides the user with the ability to combine non-zero water quality concentration results obtained during the simulation.

The “Tank Mixing model” selection menu allows the user to override what is specified in the EPANET network model imported when the ensemble was created. This is a global tank mixing model meaning that the selection will change the mixing model for all of the tanks in the network model. The option “Use Scenario” is the default and it will use what is specified in the network model. If a selection other than “Use Scenario” is chosen, the “Override if set” box will be enabled. If this box is selected, the user will override what is in the network model INP file that was imported if it is different than that selected.

Figure 6.3 provides an enlarged view of the “Simulation Parameters” module within the “Ensemble Options” box. This module provides two features: (1) check box indicating whether all servers will be used and (2) drop down box for selecting the number of simultaneous sensor network designs that will be executed within the Sensor Placement module. The “Use all servers” check box should generally always be checked. For the “Number of simultaneous SP executions” option, some thought is warranted depending on the size of the model (number of nodes), number of injection scenarios evaluated, and number of feasible sensor locations being used. Generally, if the number of injection scenarios is 12,000 or less and the number of feasible nodes for sensor placement (i.e., nodes in the model) is also 12,000 or less, then the default of “MAX” should suffice. This means that TEVA-SPOT-GUI has allocated 2 GB of computer memory for each sensor placement. If, for example, one of these two numbers is double, then a smaller number of simultaneous SP executions should possibly be chosen.

Specifically, the user should select a number that corresponds to allocating approximately 10 GB of computer memory per sensor network design.

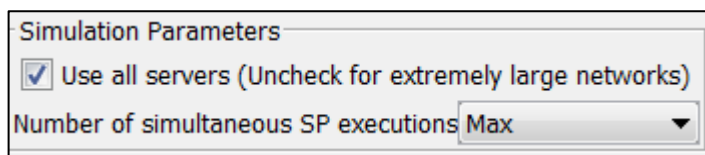


Figure 6.3. Ensemble Options – Simulation Parameters

Figure 6.4 provides an enlarged screen shot of the “Decay Parameters,” which is composed of “Reaction Order” and “Reaction Coefficients” along with other contaminant parameter options. The configuration shown will result in zero decay or loss during the simulation, since the bulk and wall reaction coefficients are zero with a first order decay rate. To simulate decay, the user enters a negative number (including decimal if needed) in the appropriate box for either bulk or wall decay. The user should refer to the EPANET User Manual for more information.

Decay Parameters

Decay Name: Biological

Reaction Order

Bulk: 1

Wall: 1

Tank: 1

Reaction Coefficients

Bulk: 0.0

Wall: 0.0

Limiting Concentration: 0.0

Wall Coeff. Correlation: 0.0

Figure 6.4. Ensemble Options – Decay Parameters

Figure 6.5 provides an enlarged screen shot of the “QA Parameters” module within the “Ensemble Options” box. This dialogue box allows the user to perform a mass balance analysis.

QA Parameters

☒ Perform Mass Balance Analysis

☐ Include Mass Losses

Injection Location Exclusions (0) Select

Figure 6.5. Ensemble Options – QA Parameters

Also under the “QA Parameters” is the option to select or upload a list of node ID(s) representing nodes that will be eliminated from the particular “Node Set Definition” and, therefore, eliminated from being simulated or evaluated. These parameters are discussed in Quality Assurance, Section [18](#).

Clicking the “Faucet Icon” (see Figure 6.6 below) while in the “MAP” tab will bring up the majority of the INP file in a side panel on the right of the screen (see Figure 6.7). The “faucet” functionality can be used to explore the EPANET INP file or water system model. Under “Data Type”, choose “Options”.

Within the “Options” panel, the user sees what is contained in the .INP file. Some of these parameters can be modified by changing and clicking “Apply”. Changes will then be reflected in the .INP file that is saved to the TEVA-SPOT-Database/ENSEMBLE_NAME/BaseEnsemble.

The *start time* specified in the .INP file (see Figure 6.7) specifies the start of the simulation. TEVA-SPOT-GUI recognizes the *start time* as local time. For many network models, the start time specified is 12:00 AM. If a contaminant is to be injected at 6:00 AM, then the user would need to specify within the *injection definition* the *start time* for the injection, which in this case would be 6 hours, i.e., NOT zero hours. Similarly, an injection occurring at 6 PM local time would be simulated by defining the *start time* for the injection to be 18 hours, i.e., 12 hours later than the 6 AM injection. The user should be careful that if the *start time* for the injection is much later than the start time of the model the total

simulation length might need to be increased to be sure that consequences still stabilize. There is not a minimum recommended time between the simulation start time and the injection start time.

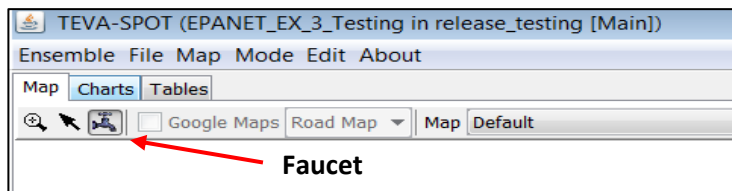


Figure 6.6. Map Tab – Faucet: Access INP File

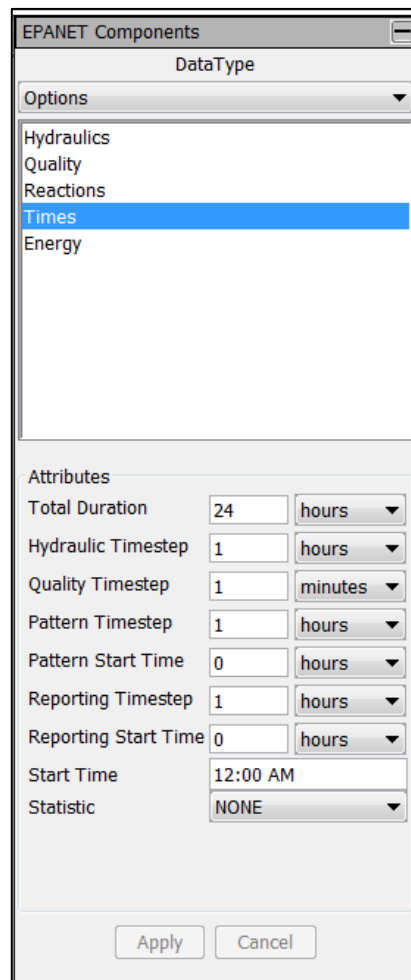


Figure 6.7. Faucet – EPANET Components – Options - Times

7. EPANET Simulations

This section describes how to setup contamination injection scenarios and an ensemble of contamination scenarios. In addition, this section describes the parameter inputs and various options available to the TEVA-SPOT-GUI user for running EPANET simulations. Most of the EPANET simulation parameters for TEVA-SPOT-GUI can be specified in the network model (INP file) that is imported. Defining contaminant injections and setting up EPANET simulations are specified in the “EPANET Simulations” dialogue box.² Figure 7.1 provides a screen shot of the “Execution” panel which shows, with a green arrow, the “EPANET Simulations” EDIT button.

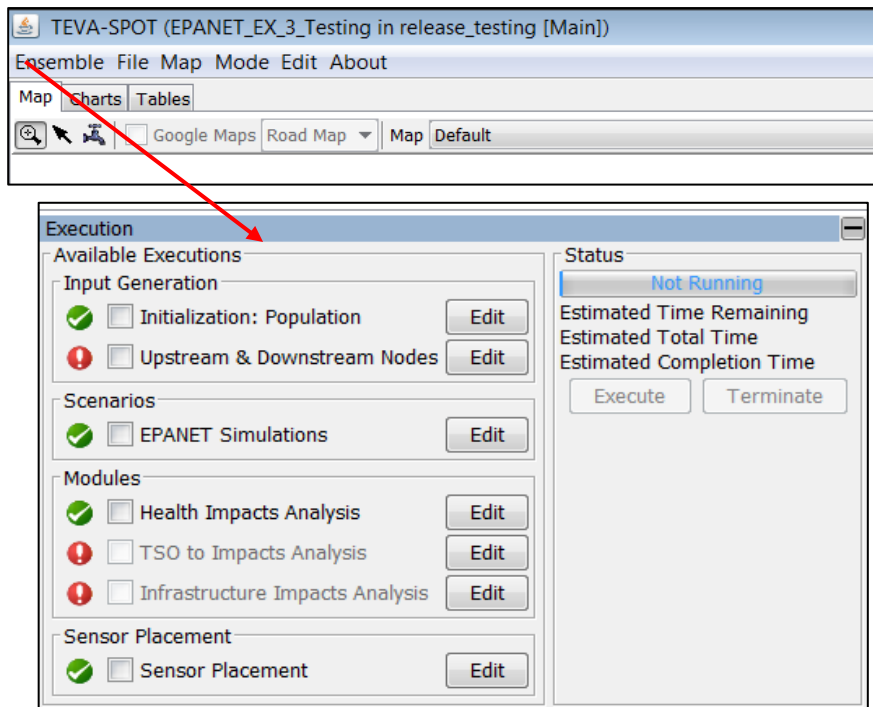


Figure 7.1. Screen shot of Execution Panel

In the following sub-sections, EPANET contamination scenarios are described. These sub-sections are taken from the EPA Report titled, “Application of TEVA-SPOT for Prioritizing Security Enhancements at Utility Facilities and for Protection of Critical Facilities” [21].

7.1 Contamination Scenario

Contamination scenarios and an ensemble of contamination scenarios are defined and created in the “Scenarios” module of the “Execution” panel. Contamination of a water distribution system could occur through the dumping of toxic chemicals, pesticides, biological organisms, toxins, or radioactivity into a water tank or through the inadvertent or purposeful injection of contaminants. Contaminants can be injected into a water distribution system from a service connection by reversing the flow of water for the connection using water pressure greater than that in the network. The factors that define a

² EPANET simulation parameters can be specified in the “Ensemble Options” dialogue box, which is under the “EDIT” main menu.

contamination scenario are (1) the contaminant and its behavior in a water distribution system, (2) the quantity of contaminant released, (3) the start time of the contaminant injection, and (4) the duration of the contaminant injection. For the first factor, the TEVA-SPOT-GUI user decides whether to consider contaminant loss (e.g., using a first order decay/loss rate coefficient or analyzing multi-species interactions by using the EPANET-MSX capability within TEVA-SPOT-GUI). For factors (2) through (4), the TEVA-SPOT-GUI user specifies the contamination scenario parameters of the mass injection rate and the start time and stop time of the contaminant injection. Simple contaminant loss/decay can be set in TEVA-SPOT-GUI under the Edit menu bar and then select Ensemble Options and specify the appropriate rate coefficient under bulk or wall rate coefficients boxes. For more information on determining and entering the most appropriate rate coefficients refer to the EPANET User's Manual [1] and [9]. For using the EPANET-MSX capability in TEVA-SPOT-GUI, the user must first load the MSX file after importing the EPANET (INP file) model. Please refer to the EPANET-MSX User Manual for more information [3].

Clicking the “Edit” box next to the “EPANET Simulations” module on the “Execution” window (Figure 7.1) opens the “Edit BaseEnsemble Parameters.” A contamination scenario together with the possible locations within the water distribution system where the contaminant could be injected describes a contamination threat scenario. Figure 7.2 provides a screen shot of both the “Edit BaseEnsemble Parameters” dialogue box and the “Injection Definition” dialogue box.

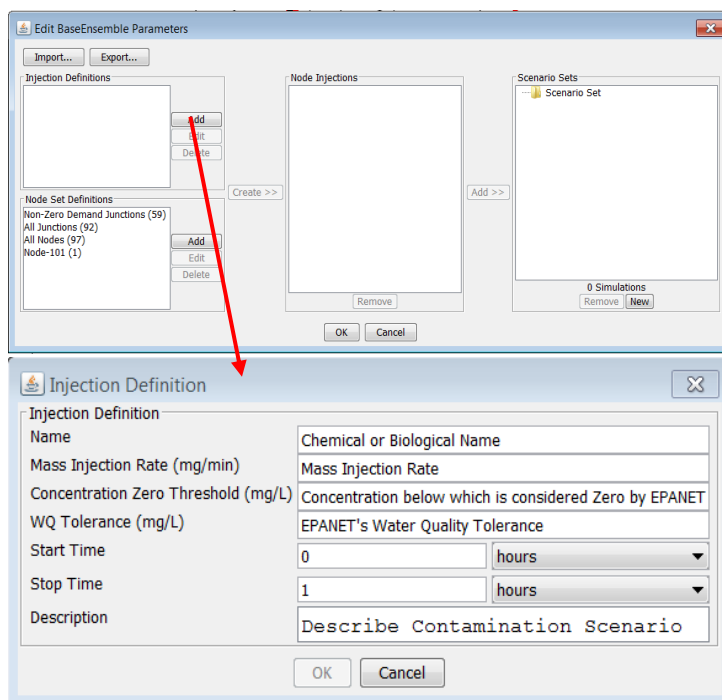


Figure 7.2. Screen shots of Edit BaseEnsemble Parameters and Injection Definition.

Within the “Edit BaseEnsemble Parameters” dialogue box are four screens: (1) Injection Definitions, (2) Node Set Definitions, (3) Node Injections, and (4) Scenario Sets. The contaminant and its injection parameters are specified in the “Injection Definition” panel by selecting “Add,” as shown in the TEVA-SPOT-GUI screen shot of Figure 7.2 (top). Multiple injection definitions can be defined. Separately, included in the screen shot of Figure 7.2 (bottom) is a brief description of the parameter and text

descriptions.

“Node Set Definition” defines the locations where the contaminant will be injected. “Node Injections” is then added using “Add” to a folder called a “Scenario Set.” “Node Injections” represent the summation of the injection definition with the set of injection locations. Each “Scenario Set” represents a set of contamination scenarios. Multiple “Scenario Set[s]” can be created with each set containing “Node Injections.”

Figure 7.3 shows the adding of “Injection Definitions” with “Node Set Definitions” to create two folders of scenario sets containing “Node Injections”: (1) 59 “Node Injections” for biological contaminant and (2) 59 “Node Injections” for chemical contaminant which results in the creation of 118 total simulations³. “Node Injections” or contaminant scenarios that are created in separate “Scenario Set” folders will result in the summation of the contaminant scenarios in each folder to create a unique set of scenarios. Combining multiple “Node Injections” within a “Scenario Set” folder will result in the product of the number of scenarios described by each “Node Injections” definition to result in the unique set of simultaneous contamination scenario simulations. Combining multiple “Node Injections” within a “Scenario Set” folder will result in a number of combinations of simultaneous contamination scenarios. For example, a “Scenario Set” containing the two cases of the “Node Injections” for biological and chemical contaminants will result in combinations of two simultaneous contamination scenarios. This will result in 3,481 (59 x 59) total scenarios and 1770 unique contaminant scenarios (Figure 7.4).

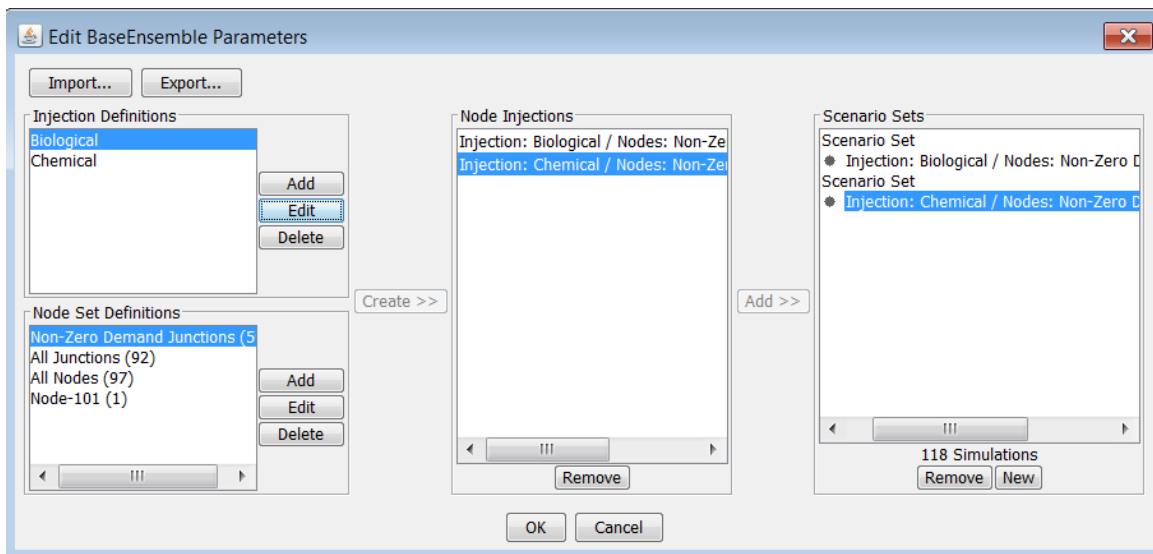


Figure 7.3. Combining injection definitions and node set definitions to build scenario sets

³ Although not visible in the figure, please note that the non-zero demand junctions equal 59 nodes or locations for network model.

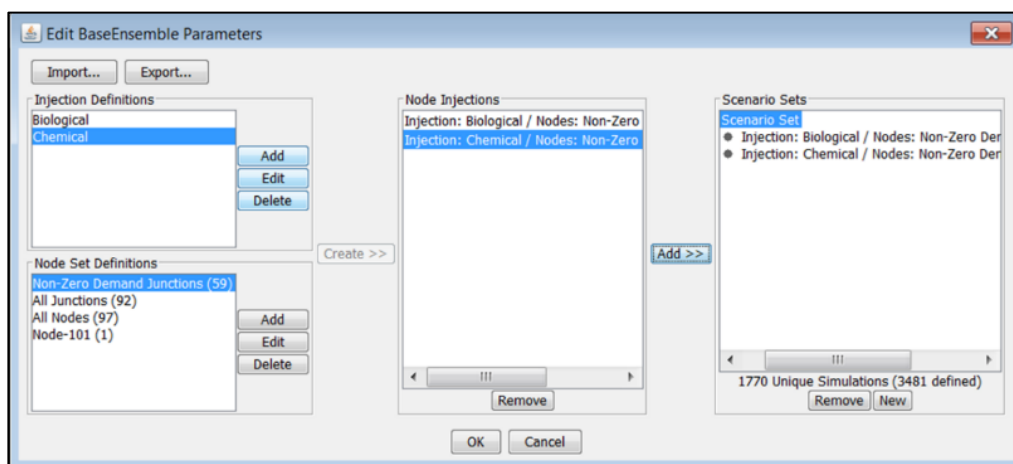


Figure 7.4. Creation of ensemble of two simultaneous contaminant scenarios

The screen shot shown in Figure 7.4 shows that the number of contaminant scenarios created will be unique and, therefore, not duplicated (see lower right corner of figure, 1770 *unique* simulations versus 3481).

Once an ensemble of contamination scenarios is created using the “Edit” box associated with “EPANET Simulations,” the “EPANET Simulations” are available to “Execute” (i.e., not grayed out). Once “Execution” of the EPANET simulations is complete, a green check mark will appear (Figure 7.1).

Users of TEVA-SPOT-GUI should determine the relevant threat or threats for their application (e.g., prioritizing resources and efforts to support facility hardening or designing a sensor monitoring network). Unfortunately, the interpretation of threat information is imperfect, and there is no single definition of a threat to the water sector. Thus, judgment and consideration of local circumstances must be considered when deciding on the threat. For example, a utility concerned primarily with local or insider threats might consider contaminants that could be stolen or purchased in large quantities from local sources. On the other hand, utilities concerned about international terrorism threats might consider exotic contaminants that are more difficult to acquire, but would produce more severe consequences. Resources are available to help in this decision-making process. The WaterISAC tracks and reports potential threats to the water sector through their secure portal. Clark and Hakim [14] provide some supporting information, including an overview of research related to understanding and characterizing intentional threats to water systems.

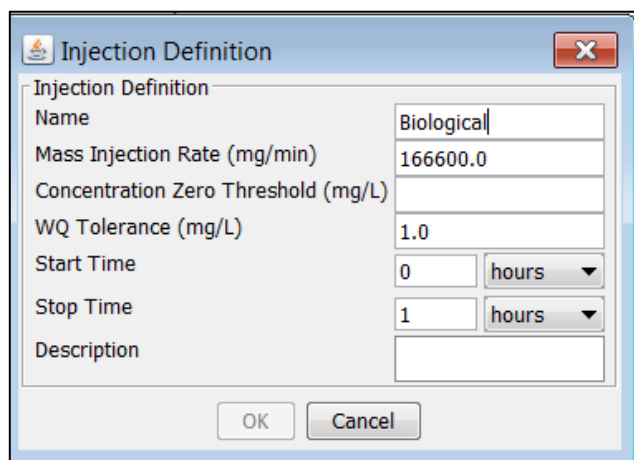
EPANET simulates the pressurized backflow of a contaminant at a junction or node in the water distribution system network model. A node in a network model generally represents multiple service connections. The pressurized backflow of contaminants will contaminate water used at the injection node and also any water flowing downstream from the node. EPANET, and therefore TEVA-SPOT-GUI, models pressurized backflow or contaminant injection as a mass injected per unit time (mg/min). EPANET does not have the ability to model volume additions to pressurized pipe flow. As a result, the assumption is that any volume changes are insignificant.

In Sections 7.2 through 7.5, information is provided related to each of the factors that define a contamination scenario. This information is provided to help users design a contamination scenario for use in TEVA-SPOT-GUI to meet their needs in the most computationally efficient manner. In Section 7.6, a table is provided with four example contamination scenarios for possible use in TEVA-SPOT-

GUI. Some supporting information is also provided about how TEVA-SPOT-GUI simulates contaminant releases into tanks and pressurized backflow of contaminants at nodes.

7.2 Contaminant

The contaminant is named and described in the “Injection Definition” box within the “Edit BaseEnsemble Parameters” box of the “EPANET Simulations” module. Figure 7.5 provides a screen shot of the “Injection Definition” box. In this screen shot, the contaminant name is “Biological.”



Injection Definition	
Name	Biological
Mass Injection Rate (mg/min)	166600.0
Concentration Zero Threshold (mg/L)	
WQ Tolerance (mg/L)	1.0
Start Time	0 hours
Stop Time	1 hours
Description	

Figure 7.5. Injection Definition - Example

The potential for adverse public health consequences increases as contaminant toxicity increases. Potential public health consequences for contaminants can vary substantially between networks [7], [8], [9]. For contaminants with high toxicities, public health consequences increase with network population, particularly for scenarios with injection locations that produce consequences near the upper end of the distribution [7], [8]. For less toxic contaminants, potential public health consequences have been shown to not be particularly sensitive to network population, even across networks that vary by more than a factor of 100 in population size [7], [8]. This is because low toxicity contaminants tend to produce consequences that are localized, and which are limited by the mass of the contaminant available rather than by the population served by a utility. Davis et al. [10] showed that sensor monitoring networks should be designed for the most toxic contaminant likely to be of concern.

Contaminant decay can have a significant influence on the magnitude of estimated consequences resulting from a contamination event [9]. Davis et al. [9] provide a table (Table III) listing various potential water contaminants, along with literature values of first-order decay or loss coefficients, K. The contaminants, decay mechanisms, and environmental conditions in the reference were selected to illustrate a range of K values for a range of possible water contaminants [9]. Simple contaminant decay parameters are entered in “Decay Parameters” module within the “Ensemble Options” box (Figure 7.2). Research has shown that sensor monitoring networks that are designed assuming no contaminant decay or loss will likely perform better (i.e., better able to reduce public health consequences) than if decay or loss is assumed to occur [10]. Therefore, it is recommended that no decay or loss of contaminant be considered for most applications. The use of a simple decay/loss approach in TEVA-SPOT-GUI does not increase computational times. However, the use of the EPANET-MSX functionality can increase computational time significantly.

Davis et al. defined adverse public health consequences (impacts) as the size of the population receiving an ingestion dose of contaminant above some level [9]. Such an approach avoids any reference to a specific contaminant, but provides results that can be related to specific contaminants if desired [9]. Use of this approach in TEVA-SPOT-GUI is simple and provides the ability to examine a wide-range of potential contaminants at the same time and in a single ensemble. Estimated impacts have less uncertainty than estimated number of fatalities or illnesses [9]. The approach is more flexible than use of a particular contaminant since a range of contaminants is considered. Overall, the approach provides a convenient and computationally efficient means for estimating and comparing potential adverse public health consequences of a wide range of contamination events in water distribution systems.

7.3 Contaminant Quantity

The quantity of contaminant mass that is injected is specified in the “Injection Definition” under the “Edit BaseEnsemble Parameters” panel (Figure 7.5).

Adverse public health consequences can be widespread given a sufficiently large mass injection [7], [8]. Consequences can be expected to be localized for a small injection mass [7], [8]. For chemicals and toxins, the injection mass in TEVA-SPOT-GUI is specified in units of milligrams. For biological contaminants, the injection quantity must be based on the number of organisms injected instead of the mass of the contaminant used for chemicals or toxins. In Davis et al. [9], the authors showed how to convert a range of dose levels developed for a chemical or toxin to a comparable range for biological contaminants. Solubility and organoleptic properties of a particular contaminant (taste, odor, and color) should be considered in determining the injection mass that should be used. An evaluation of the actual availability of the contaminant being considered for injection should also be performed.

The total mass of a contaminant that can be reasonably obtained depends on the specific contaminant, and is also related to the threat information discussed in section 7.2. Generally speaking, toxic chemicals might be available in quantities of several thousand kilograms (kg), while more exotic, yet highly toxic, contaminants will generally only be available in much smaller quantities (e.g., less than 10 kg for tightly controlled materials).

In Davis et al. [9], the authors outlined a process for determining a simple contaminant mass bound on adverse consequences. The equations in Davis et al. [9] can be used to help determine a suitable, lower limit on mass injection rate for a particular contaminant. The mass of contaminant ingested can be related to the mass of contaminant injected as shown in Equation (1):

$$MI = q \cdot M / Q \quad (1)$$

Where MI is the mass of contaminant ingested, q is a constant per capita water ingestion rate, M is the mass of contaminant injected, and Q is a constant per capita water usage rate. U. S. EPA provides an estimate of the per capita water ingestion rate (1 liter per person per day (L/d)) for the United States [15]. In 2000, the United States Geological Survey (U.S.G.S) provided an estimate of water use (677.6 L/d) in the United States [16]. The maximum number of people (N) who can receive an ingested dose d equals the mass ingested divided by the dose, shown in Equation (2):

$$N = q \cdot M / Qd \quad (2)$$

N should be set to the population served as represented by the water distribution system model. The dose d is the dose resulting from the tap water ingestion of the target contaminant. An individual's target dose for a particular contaminant can be determined from available dose response data for the contaminant along with the individual's body mass. For instance, the LD dose is the dose at which 50% of the population who receives such a dose dies. This defines the LD50 for a contaminant. LD50 values for chemicals and toxins are usually expressed in units of mg of contaminant per kg of body mass. Using contaminant-specific LD50 information and an average body mass for the population (N), a target dose for a contaminant can be determined as shown in Equation (3):

$$\text{Target Dose for Contaminant} = \text{LD50 (mg/kg)} * \text{Body Mass (kg)} \quad (3)$$

Equation (2) can be solved for M to give:

$$M = (d * N * Q) / q \quad (4)$$

As an example, consider a scenario in which the target contaminant's LD50 is 0.001 mg/kg, the population served by the water system is 1,000,000, the average body mass of the population served is 70 kg, the usage rate, Q, is 677.6 L/d, and the ingestion rate, q, is 1 L/d. This scenario results in a target contaminant injection mass of 47 kg. The estimate of 47 kg would be the minimum injection quantity needed since it assumes:

- Injection of the contaminant is at a location (node in the model) with at least the given number of people downstream of the injection location. In other words, assumes the injection location is a very high consequence injection location.
- Everyone ingests tap water with the same concentration of contaminant.
- No contaminant losses (e.g., no decay) are present in the system.

This approach would be expected to work best for less toxic contaminants, in which high consequence injection locations are likely easiest to find and, generally, consequences are small.

7.4 Contaminant Injection Start and Stop Times

The "Start" and "Stop" time of the contaminant mass injection is specified in the "Injection Definition" under the "Edit BaseEnsemble Parameters" panel (Figure 7.10). "Start" times must be integer values. "Start" and "Stop" times can be specified in hours, minutes, or seconds. The "Start" time is correlated to the start time specified in the network model. If the network model is specified to "Start" at time 0 (local time) or 12:00 AM and the "Start" for the contaminant injection is specified as "0," the start time for the injection of the contaminant will be 12:00 AM.

7.5 Contaminant Injection Duration and Mass Release Rate

Contaminant injection duration is defined by the difference between “Start” and “Stop” times specified (Figures 7.2 and 7.5). Once the injection duration, D, is determined, the target contaminant mass derived in Section 7.3 can be used to determine a corresponding mass release rate, MR (mg/min), which is used by TEVA-SPOT-GUI. The mass release rate is shown in Equation (5):

$$MR = (M \text{ (kg)} * 1 \times 10^6 \text{ mg/kg}) / (60 \text{ min/hr} * D \text{ (min)}) \quad (5)$$

7.6 Example Contamination Scenarios

Table 1 below provides four example contamination scenarios [\[21\]](#).

Table 1. Example Contamination Scenarios

Contaminant & Behavior	Mass or Quantity	Mass or Quantity Release Rate	Time of Injection	Duration of Injection
Example toxin used in this manual (assumed no decay or loss)	300 g	625 mg/min	12:00 AM local time	8 h
Example less toxic chemical (assume no decay or loss)	>47Kg	32,939 mg/min	6:00 AM local time	24 h
Very toxic chemical or toxin (assume no decay or loss)	=> 500 g	=> 8330 mg/min	6:00 AM local time	1 h
Very toxic biological (assume no decay or loss)	=> 10^{14} organisms	4.2×10^{12} organisms/min	6:00 AM local time	24 h

8. Input Generation

This section describes three critical data input steps for running TEVA-SPOT-GUI. From the “Execution Control” panel (see Figure 7.2), “Input Generation” is the first module that should be implemented following the import of the EPANET network model into TEVA-SPOT-GUI. This section is composed of three components or subsections: (1) Initialization: Population, (2) Upstream and Downstream Nodes, and (3) Visualizing Display in Google Maps™.

8.1 Initialization: Population

After the network model is imported and the simulation parameters are reviewed, the network population is initialized. By clicking the appropriate “Calc” button, TEVA-SPOT-GUI allows the user to specify the population distribution using either (1) a demand based method or (2) a census based method. Figure 8.1 shows a screen shot of the “Edit Population Parameters” dialogue box which is opened after clicking “Edit” next to “Initialization: Population” on the “Execution” panel. The demand-based method requires a user to input the number of gallons of water used per person per day (GPD). A default value often used is 200 GPD, which corresponds to the quantity of water used per person per day for all uses. For more information on drinking water consumption rates, the user should seek other sources for the most up-to-date and relevant information. Alternatively, the user could import a text file that details the number of people who reside at each non-zero demand node (node ID) in the model (i.e., a text file containing two columns of data). Non-zero demand nodes are used because exposure and ingestion of contaminated water can only occur at those locations where water is used.

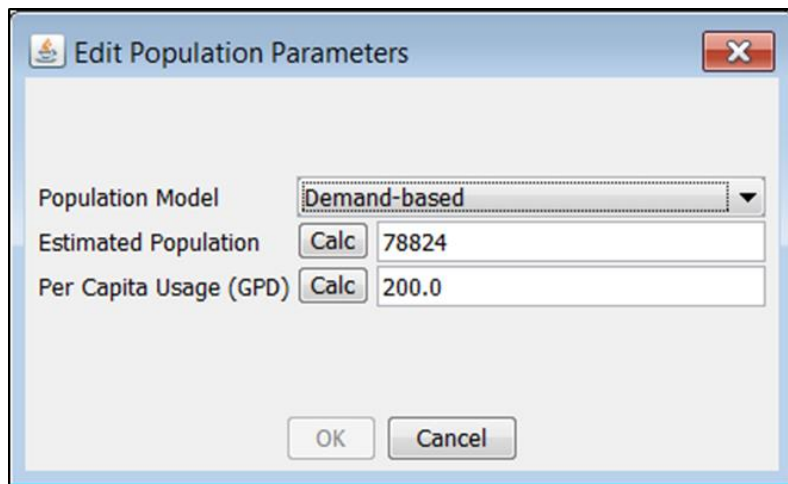


Figure 8.1. Edit Population Parameters

8.2 Upstream and Downstream Nodes

Within the “Execution Control” panel, “Input Generation” module is the “Upstream & Downstream Nodes” module (see Figure 7.1). The upstream and downstream nodes module determines the upstream and downstream nodes corresponding to a set of contaminant scenarios or injection locations. The number of upstream or downstream nodes associated with a particular injection location (node) is a function of the time step of the simulation. The default simulation duration for this module is the

simulation length specified in the “Ensemble Options” box. Most uses of this module would input the default simulation length and, therefore, would not require the user to input any data. This module is not necessarily required for running TEVA-SPOT-GUI’s other modules. It is required if contaminant backtracking capabilities are wanted or if the user would like to define a “Node Set Definition” (set of injection locations) based on *Critical Facilities* [21].

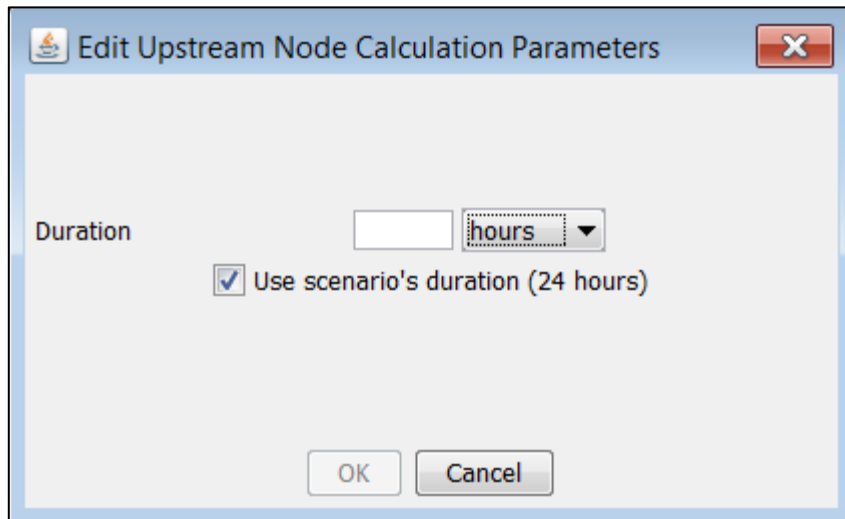


Figure 8.2. Edit Upstream Node Calculation Parameters

8.3 Visualizing Display in Google Maps™

TEVA-SPOT-GUI allows the user to view a distribution system network model within Google Maps™. The functionality within TEVA-SPOT-GUI to access Google Maps and view the distribution system model in various Google Maps backdrops is accomplished through the MAP Menu item (Figure 8.3). To properly view the network model in Google Maps, the user is required to input the necessary projection data by selecting the “Projection Data...” tab (Figure 8.4). Please see below for more information on the projection data.

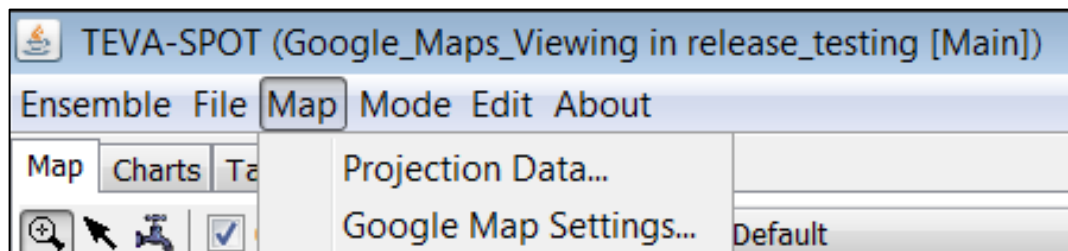


Figure 8.3. Selecting MAP Menu

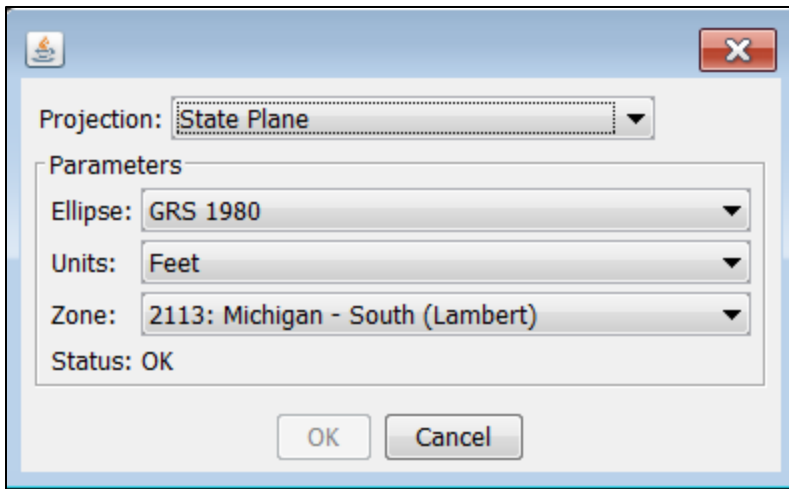


Figure 8.4. Screen shot of Projection Data Screen

Under the “Google Maps Settings...” the user can specify a Google API Key to access an unlimited number of Google Map tiles each day. Google Maps sets a limit on the number of times a user can access tiles from Google per day. This limit is 1,000 tiles. To overcome this limitation, the user may register for a Google API (application programmer’s interface) key (see Figure 8.5). Within the “Google Map Settings” feature of TEVA-SPOT-GUI is a link, “Get API Key”. A Google API key is not required and since retrieved tiles are cached locally, exceeding 1,000 tiles in a single day will likely not be a problem.

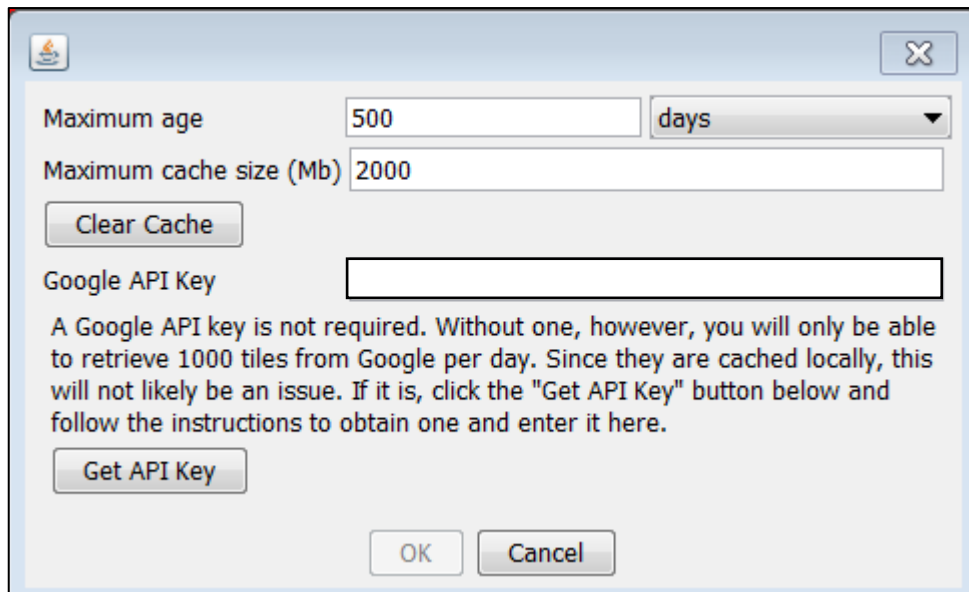


Figure 8.5. Screen Shot of Google Map Settings Screen

In order to properly display the distribution system network, network model projection information is needed. To properly plot a distribution system model within Google Maps, the data must be defined according to a particular coordinate system. The coordinate system allows the integration of the data (e.g., network model) with the geographical data of Google Maps. A coordinate system is a reference

system used to represent the locations of the water utility attributes (i.e., pipes, nodes, and facilities). Each coordinate system is defined by:

- A measurement system or framework that is often geographic, meaning that spherical coordinates are measured from the earth’s center.
- A unit of measurement that is often in feet or meters.
- Map projection definition for project coordinate systems.
- Other measurement system parameters (e.g., spheroid of reference, datum, and project parameters, such as central meridian).

Two common types of coordinate systems are geographic coordinate system and projected coordinate system. A geographic coordinate system can be specified as spherical and parameterized by latitude-longitude. A projected coordinate system is based on a map projection such as transverse Mercator. TEVA-SPOT-GUI recognizes three projected coordinate systems: (1) state planar, (2) universal transverse Mercator, and (3) transverse Mercator. Generally, projection information is available within the geographical information system (GIS) database for the model. Figure 8.6 provides projection information for a particular water system. Notice the bolded information in the figure. This information can be entered into TEVA-SPOT-GUI to project the water system model onto a user-selected Google Map backdrop.

Projection Information
PROJCS["NAD_1983_StatePlane_Florida_East_FIPS_0901_Feet",GEOGCS["GCS_North_American_1983",DATUM["D_North_American_1983",SPHEROID["GRS_1980",6378137.0,298.257222101]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]],PROJECTION[" Transverse_Mercator "],PARAMETER[" False_Easting ",656166.6666666665],PARAMETER[" False_Northing ",0.0],PARAMETER[" Central_Meridian ",81.0],PARAMETER[" Scale_Factor ",0.9999411764705882],PARAMETER[" Latitude_Of_Origin ",24.33333333333333],UNIT["Foot_US",0.3048006096012192]]
Note: For North America, the spheroid of choice is GRS 1980 , upon which the North American Datum 1983 (NAD83) is based.

Figure 8.6. Example Projection Information.

To demonstrate here, the user selects “State Plane,” “GRS 1980,” “Feet,” and “zone: 0901: Florida-East” within the panel of options shown in Figure 8.4 of TEVA-SPOT-GUI and clicks “OK.” Within TEVA-SPOT-GUI, the user can select one of four Google Map backdrops to display model attributes and output results. The four backdrops are: (1) road, (2) satellite, (3) terrain, and (4) hybrid. Figure 8.7 demonstrates the display of a small portion of a water distribution system model within Google Maps (road backdrop) using the projection data described in Figure 8.6.

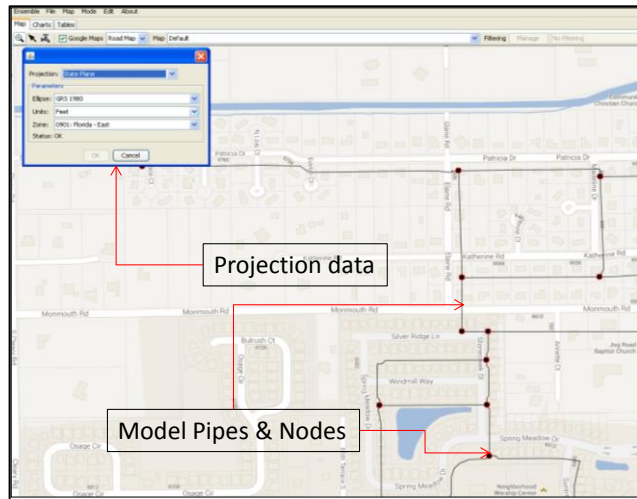


Figure 8.7. Example Distribution System Network Model Projection

To display a network model with a Google Maps backdrop in TEVA-SPOT-GUI, nothing is required from Google Maps. Provided the projection information is correct and access to the internet is available, TEVA-SPOT-GUI automatically communicates with Google Maps to display the map details requested by the user. Notice in the example (Figure 8.7) the projection of the pipe detail onto the Google Map road backdrop indicates that several pipes lie underneath houses or businesses. This is likely not the case and is probably a result of errors in the projection information or the coordinates associated with the pipes/nodes in the model. Figure 8.8 displays a small portion of another distribution system model on a satellite image backdrop. Notice here that the pipes are reasonably located along or adjacent to roads and the model's tank icon is aligned with the actual tank.

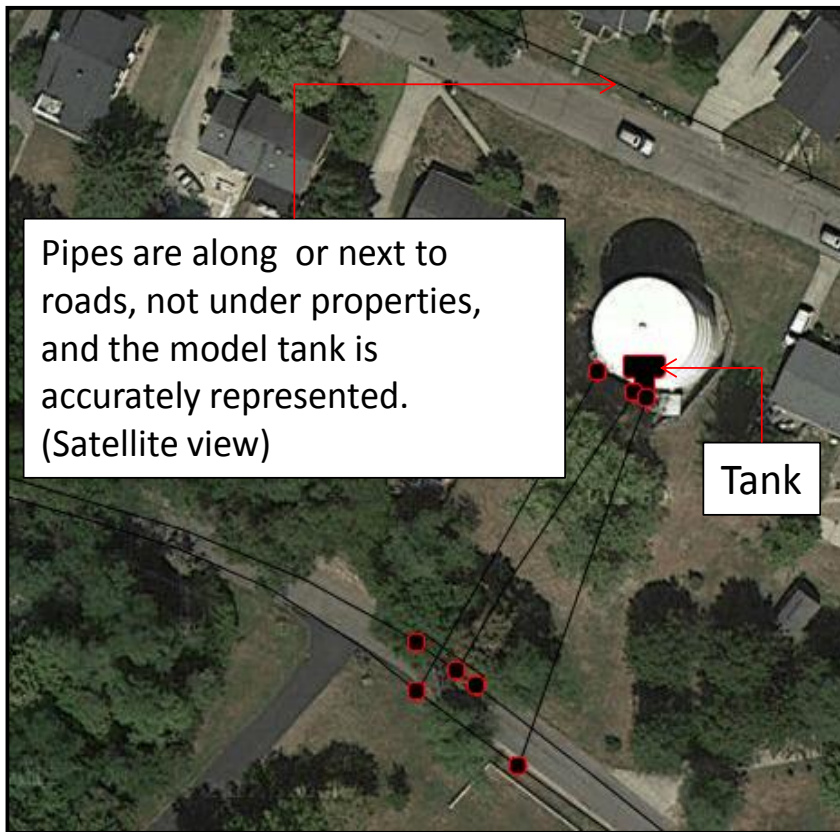


Figure 8.8. Example of a Properly Projected Distribution System Network Model

9. Health Impacts Analysis

The “Health Impacts Analysis” module is shown in Figure 9.1 and can be accessed by clicking the “Edit” button to the right of the name in the Execution window. TEVA-SPOT-GUI provides for examining and estimating the exposures, doses, and consequences from three contaminated tap water exposure pathways: (1) ingestion, (2) inhalation during showering, and (3) inhalation during humidifier use. For each exposure pathway, the user selects information to determine the extent of the analysis and enters data to determine doses and dose response.

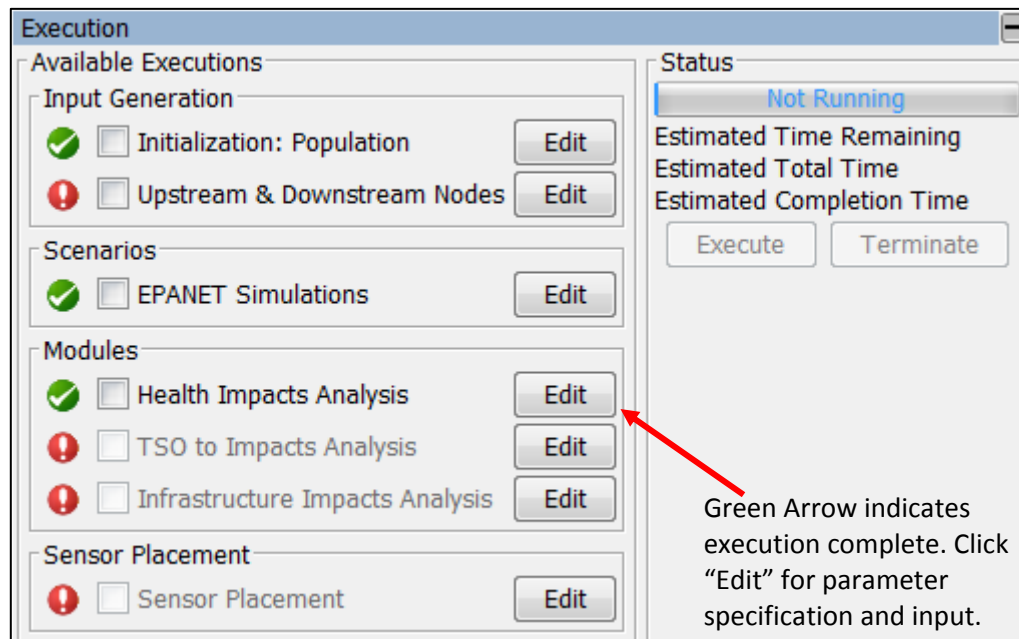


Figure 9.1. Opening Health Impacts Analysis Module from Execution Panel

Figure 9.2 provides a screen shot of the “Edit Health Impacts Analysis Parameters – Ingestion” tab. The design of the “Edit Health Impacts Analysis Parameters” screen is composed of a “Contaminant” module (top) and exposure pathways module (bottom). The “Contaminant” module (top) of Figure 9.2 specifies the contaminant name and contaminant type information along with receptor body weight. The exposure pathways module (bottom) of Figure 9.2 provides for the exposure, dose, and consequence analyses. Within each exposure pathway tab (i.e., “Ingestion,” “Inhalation – Showering,” and “Inhalation – Humidifier”) are check boxes for (1) “Calculate Ingestion” and (2) “Calculate Dose-Response.”

For each exposure pathway, the health impacts analysis module provides the capability to assess public health consequences in terms of exposure, dose received, or a health effects end point using contaminant-specific dose response information entered by the user. Each exposure pathway is consistent in terms of layout, but each pathway (i.e., panel) must be setup for multiple exposure pathways are to be evaluated. A check mark in the box “Calculate Dose-Response” will enable the dose response capabilities. To “Calculate Dose-Response,” the user first selects the type of contaminant (i.e., “Chemical/Toxin” or “Biological”). Next, the user selects the dose response model to be used. TEVA-SPOT-GUI provides two such models: (1) probit slope and (2) sigmoid, 4 parameter model. For “Chemical/Toxin” contaminants, health consequences are based on a lethal dose (LD) [4]. For “Biological” contaminants, health consequences are based on an infectious dose (ID). For

“Chemical/Toxin”, the user enters their contaminant-specific LD that would result in death to 50% of the population (LD50) given such a dose [4]. For “Biological,” the user enters their contaminant-specific ID dose that would result in 50% of the population becoming diseased or infected (ID50) after receiving such a dose. For “Chemical/Toxin” or “Biological,” the user is required to enter a contaminant-specific probit slope factor. For “Chemical/Toxin,” the user is also required to enter a body weight since LD50 values are specified in terms of mg of chemical or toxin per kilogram of body weight. Generally, each tab is comprised of six components: (1) Dose Calculation Parameters, (2) Thresholds, (3) Relative Contribution, (4) Dose Response Method, (5) Disease Progression Parameters, and (6) Worst-case Results.

Edit Health Impacts Analysis Parameters

Contaminant
 Name: CHEMICAL_VOL Type: Chemical/Toxin
 Select Defaults... Average Body Mass (kg): 70.0

Ingestion: Inhalation - Showering | Inhalation - Humidifier

☒ Calculate Ingestion

Dose Calculation Parameters
 Dose Calculation Method: [Dropdown]
 Ingestion Timing Model: 5 Fixed Times
 Ingestion Volume Model: Fixed Volume
 Mean Volume (liters/person/day): 1.0

Thresholds
 Dose: 1.0E-4,0.001,0.01,0.1,1.0,10.0,100.0 [Edit]
 Response: 0.001,0.01,0.1 [Edit]

Relative Contribution
☒ Include Relative Contribution Analysis
 Dose Thresholds: 0.1,0.25,0.5,0.75,0.95 [Edit]
 Bins: Num
 Relative Contribution: 10

☒ Calculate Dose-Response

Dose Response Method
 Dose-Response calculation method: Probit
 LD50 / ID50: 0.001
 Beta: 1000000.0

Disease Progression Parameters
 Latency Time (hrs): 1
 Fatality Time (hrs): 1
 Fatality Rate: 1.0

Worst-case Results
 Number of worst-case fatality scenarios to save: 1
 Number of worst-case dosage scenarios to save: 0

☐ Use one server per node

OK Cancel

Figure 9.2. Edit Health Impacts Analysis Parameters – Ingestion Tab

Since health consequences for biological contaminants are estimated as infections, the user is required to enter a “Fatality Rate” (fraction from 0 to 1) to predict fatalities. For “Chemical/Toxin,” the dose response model is predicting fatalities so a fatality rate is not needed. For both “Chemical/Toxin” and “Biological” contaminants, the user is also required to enter a “Latency Time” and “Fatality Time” in units of hours (integer only). The user can simplify the process for entering contaminant specific dose response information by using the “Select Defaults” box. The user prepares an XML formatted file (i.e., contaminants.xml) containing dose response data for a group of contaminants. The “contaminants.xml” file is then placed in the following folder: (C:\Program Files\TEVA-SPOT\Client).

If “Calculate Dose-Response” is disabled, the only public health consequence measure available will be “Dose Thresholds.” For the dose threshold-based approach, the user enters dose thresholds into the dose thresholds panel by clicking the associated EDIT button, entering a dose threshold value and then clicking ENTER after each value. Using dose thresholds, public health consequences are reported as the number of people who receive a dose greater than the indicated threshold. The “Dose Thresholds” method can be used with the “Calculate Dose-Response” method. The methodology for using dose thresholds is described in [6], [7], [8], [9], [10], and [11].

Finally, at the bottom of the “Edit Health Impacts Analysis Parameters” screen (for each of the exposure pathway tabs) is a check box to indicate whether only to “Use one server per node.” Here “node” is computer processor or core. This is a feature that should only be checked if the computational analyses to be simulated potentially exceeds the capabilities of the computer hardware.

9.1 Ingestion

Section 9 discussed the “Dose Response Method” and “Disease Progression Parameters.” This section will discuss items (1) Dose Calculation Parameters, (2) Thresholds, (3) Relative Contribution, and (6) Worst-case Results.

DOSE CALCULATION PARAMETERS:

Figure 9.3 provides a screen shot of the “Ingestion” tab, “Dose Calculation Parameters”. The “Dose Calculation Parameters” is composed of (1) Ingestion Timing Model, (2) Ingestion Volume Model, and (3) Mean Volume. Figure 9.4 provides a close-up view of the “Dose Calculation Parameters.” For the “Ingestion Timing Model,” four selections are available: (1) “5 Fixed Times,” (2) “Demand-based,” (3) “ATUS,” and (4) “User-defined Fixed Times” [5, 6]. Figure 9.4 provides a screen shot of these four options for modeling receptor behavior or timing for exposure and dose.

The screenshot shows the 'Ingestion' tab with three sub-tabs: 'Ingestion', 'Inhalation - Showering', and 'Inhalation - Humidifier'. The 'Calculate Ingestion' checkbox is checked. Below it, the 'Dose Calculation Parameters' section includes a 'Dose Calculation Method' dropdown set to '5 Fixed Times', an 'Ingestion Timing Model' dropdown set to 'Fixed Volume', and a 'Mean Volume (liters/person/day)' text box containing '1.0'.

Figure 9.3. Ingestion – Dose Calculation Parameters

This is a close-up of the 'Ingestion Timing Model' dropdown menu. The menu is open, displaying a list of options: '5 Fixed Times', 'Demand-based', 'ATUS', '5 Fixed Times', and 'User-defined Fixed Times'. The first '5 Fixed Times' option is highlighted in blue.

Figure 9.4. Ingestion Timing Models – Close up view

The “5 Fixed Times” receptor behavior model assumes that exposed individuals drink tap water at five fixed times during the day: 7:30 AM, 12:00 noon, 6:00 pm, and at midpoints between 7:30 am and noon (10:30 AM) and between noon and 6:00 pm (3:00 pm). All times are local times. The “Demand-based” model assumes the timing of drinking is proportional to demand. “ATUS” is the American Time-Use Survey model, which is a probabilistic assessment model of when people in the U.S. are most likely to drink water [6, 15]. The “User-defined Fixed Times” model allows the user to specify the times (decimal between 0 and 24) when receptors will drink tap and potentially receive a dose. The “Ingestion Volume Model” (Figure 9.4) allows the user to choose “Random” or “Fixed Volume”. The “Random” model is a probabilistic model [6].

THRESHOLDS:

Within the “Ingestion” tab and immediately below the “Dose Calculation Parameters” is the “Thresholds” component. “Thresholds” can be specified for either “Dose” or “Response.” “Dose Thresholds” are a measure of public health consequences defined as the size of the population receiving an ingestion dose above some level. “Dose Thresholds” are added by clicking “Edit” and entering the decimal number threshold one-by-one into the dialogue by hitting enter on the keyboard. “Response Thresholds” are similar, but can only be calculated if the “Calculate Dose-Response” box is checked. “Response Thresholds” are decimals between 0 and 1. Figure 9.5 shows an enlarged viewed of the “Thresholds” component.

Thresholds

Dose: 1.0E-4,0.001,0.01,0.1,1.0,10.0,100.0 [Edit]

Response: 0.1,0.25,0.5,0.75,0.95 [Edit]

Figure 9.5. Thresholds: Specifying dose and response thresholds

RELATIVE CONTRIBUTION:

The “Relative Contribution” analysis is optional but if run (box checked), a minimum of at least one “Dose Threshold” must be entered into the associated box and an integer number must be specified in the box next to “Bins Relative Contribution.”. Figure 9.6 shows an enlarged view of the “Relative Contribution” analysis capability.

Relative Contribution

☒ Include Relative Contribution Analysis

Dose Thresholds: 1.0E-4,0.001,0.01,0.1 [Edit]

Bins	Num
Relative Contribution	10

Figure 9.6. Relative Contribution Analysis

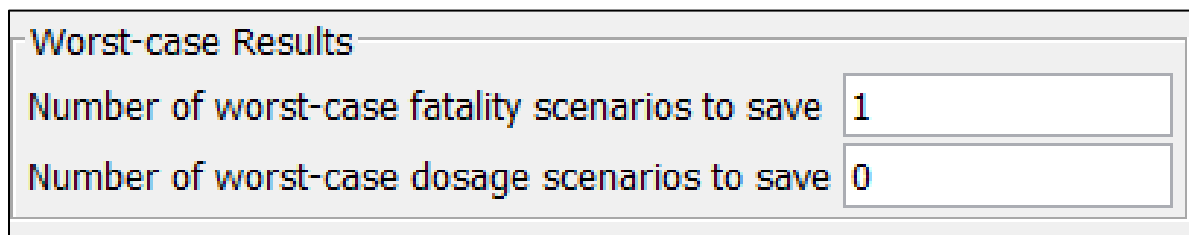
For some contaminants, the health effects resulting from exposure to the contaminant do not depend on the dose rate, but for other contaminants (e.g., cyanide) health effects depend on dose rate. For these type of contaminants, it is useful to understand whether the majority of the ingestion dose received was accumulated during a single ingestion exposure event. The “Relative Contribution” analysis provides this capability.

During the course of a simulation (e.g., a week simulation), individuals can be exposed and receive a contaminant dose at multiple times. The event of most importance for each individual ingesting contaminated tap water is the one with the largest water concentration of the contaminant at the time of ingestion. The relative contribution of this event is the dose estimated for the event divided by the total dose determined for the individual for the entire simulation. For each individual who ingests contaminated tap water and accumulates a dose greater than zero, the relative contribution of the major event is determined. Its value will always be less than or equal to one. These values are binned for all individuals for each scenario using 10 equally spaced bins extending from 0 to 1.0. The binned results are reported for the scenario and also combined to yield binned results for the entire ensemble.

Worst-case Results:

Figure 9.7 is a screen shot of the “Worst-case Results” module. This module is used to retrieve (TEVA-SPOT-Database/Ensemble Name/Health Impacts Folder) the time series concentration data for the

contamination scenarios that resulted in the most fatalities. Placing a number (integer only) in the boxes in the “Worst-case Results” (i.e., next to either “Number of worst-case fatality scenarios to save” or “Number of worst-case dosage scenarios to save”) will save the time series concentration results for the number of highest ranked scenarios indicated. The saved file(s) to the TEVA-SPOT-Database consist of contaminant concentration per time step of the simulation (fatality scenarios) and/or dosage data per time step of the simulation (dosage scenarios).



Worst-case Results	
Number of worst-case fatality scenarios to save	1
Number of worst-case dosage scenarios to save	0

Figure 9.7. Worst-case Results – Saves Time-Series Contaminant Concentration Data and Dosage Data

9.2 Inhalation – Showering

Sub-sections 9.2 and 9.3 address the use of the exposure pathways of inhalation during showering and inhalation from humidifier use. Prior to implementing these HIA modules, it is recommended that the user thoroughly review the report “Incorporating a Capability for Estimating Inhalation Doses in TEVASPOT” [22].

The “Inhalation -Showering” exposure pathway tab is shown in Figure 9.8. The inhalation during showering tab is comprised of seven components: (1) Dose Calculation Parameters, (2) CT Analysis Parameters, (3) Thresholds, (4) Relative Contribution, (5) Dose Response Method, (6) Disease Progression Parameters, and (7) Worst-case Results. Components (3), (4), (5), (6), and (7) are consistent with their corresponding parameters in the ingestion tab and, therefore, will not be discussed here, except to indicate that the inhalation exposure pathway requires contaminant information (e.g., dose response information) that is specific to the inhalation pathway. This section will briefly describe components (1) and (2). Additional information about the use and parameters associated with the inhalation during showering exposure pathway can be found in [17, 22].

Ingestion Inhalation - Showering Inhalation - Humidifier

☒ Calculate Inhalation - Showering

Dose Calculation Parameters

Method: **Transfer Efficiency** Timing Model: **Fixed** (all times are hour of day [0-24])

Breathing Rate (m^3/min) 0.012

Shower Volume (m^3) 2.0

Time in shower after off (min) 0.0

Average Transfer Efficiency (ratio 0.0-1.0) 0.8

Water Flow Rate (L/min) 9.0

Air Exchange Rate (1/min) 0.2

Probabilistic Iterations 1

Random Number Seed 1

One Shower Per Day: Time 1 6.5 Time 2 21.5

Two Showers Per Day: Time 1 6.5 Time 2 21.5

Duration Model: **Fixed** Duration (min) 7.7

Showering Frequencies

One/day 0.6

Two/day 0.18

None/day 0.22

Dose Response

☒ Calculate Dose-Response

Dose Response Method: **Probit**

Dose-Response calculation method: **Probit**

LD50 / ID50 0.001

Beta 1000000.0

Disease Progression Parameters

Latency Time (hrs) 1

Fatality Time (hrs) 1

Fatality Rate 1.0

Worst-case Results

Number of worst-case fatality scenarios to save 11

Number of worst-case dosage scenarios to save 0

CT Analysis Parameters

☒ Include CT Analysis

CT Thresholds 0.0,1.0E-4,0.001,0.01,0.1,1.0,10.0,100.0,1000.0 **Edit**

☒ Report Separate C and T Results

Bins Num Size

Shower Duration (min) 15 5.0

Air Concentration (mg/m^3) 15 1.0

Thresholds

Dose 1.0E-4,0.001,0.01,0.1,1.0,10.0,100.0,1000.0 **Edit**

Response **Edit**

Relative Contribution

☒ Include Relative Contribution Analysis

Dose Thresholds 0.0,0.1,1.0 **Edit**

Bins Num

Relative Contribution 10

☐ Use one server per node

Figure 9.8. Edit Health Impacts Analysis Parameters – Inhalation during Showering Tab

DOSE CALCULATION PARAMETERS:

The calculation of an inhalation dose during the activity of showering requires a model for describing the showering behavior of potential receptors and a model for estimating contaminant concentrations in the air during a showering event. Contaminants might be present in the air in a shower due to the release of volatile contaminants contained in the shower water or from the formation of aerosol particles by the shower head. In both cases, the air concentration in a shower will vary with time. Inhalation dose is determined by the air concentration of the contaminant in the shower, the length of time an individual remains in the shower while it is on, the length of time an individual remains in the shower after it is turned off, and the individual's breathing rate. Figure 9.9 shows an enlarged screen shot of the "Dose Calculation Parameters" component of the "Inhalation – Showering" tab. The left side of the "Dose Calculation Parameters" panel outlines the components of the exposure model that estimates the air concentration of a contaminant in the showering. The right side of the "Dose Calculation Parameters" panel outlines the components to describe the behavior of the receptor with respect to showering (i.e., timing and frequency of showering). The panel also has three drop down menus: (1) Method (left side of panel), (2) Timing Model (top right side of panel), and (3) Duration Model (bottom right side of panel).

☒ Calculate Inhalation - Showering

Dose Calculation Parameters

Method	Transfer Efficiency	Timing Model	Fixed
Breathing Rate (m ³ /min)	0.012	<i>(all times are hour of day [0-24])</i>	
Shower Volume (m ³)	2.0	One Shower Per Day:	
Time in shower after off (min)	0.0	Time 1	6.5 Time 2 21.5
Average Transfer Efficiency (ratio 0.0-1.0)	0.8	Probability 1	0.7 Probability 2 0.3
Water Flow Rate (L/min)	9.0	Two Showers Per Day:	
Air Exchange Rate (1/min)	0.2	Time 1	6.5 Time 2 21.5
Probabilistic Iterations	1	Duration Model	Fixed
Random Number Seed	1	Duration (min)	7.7
		Showering Frequencies	
		One/day	0.6
		Two/day	0.18
		None/day	0.22

Figure 9.9. Dose Calculation Parameters – Inhalation During Showering

The “Method” drop down menu provides the user with four options for estimating the concentration of volatile chemicals or aerosols in the air during and immediately after showering. Figure 9.10 provides a screen shot of the four methods for estimating the concentration of volatile chemicals or aerosols in the air during and immediately after showering. The four methods are: (1) Mass Balance, (2) Empirical, (3) Mass Transfer Coefficient, and (4) Transfer Efficiency. Depending on the “Method” option chosen a particular set of parameter inputs will appear. These four methods are described in [22]. The drop down menus for the “Timing Model” and the “Duration Model” offer the user two choices – FIXED and PROBABILISTIC. The bottom left side of the panel in Figure 9.10 provides the user with the ability to perform “Probabilistic Iterations” based on the probabilistic functions, if enable, in the “Timing Model” and “Duration Model” or the “Showering Frequencies.” The “Random Number Seed” provides the user with the ability to reproduce probabilistic results by establishing a random number seed.

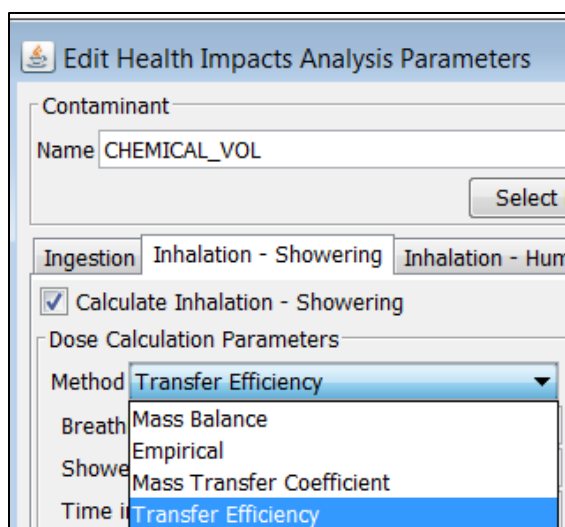


Figure 9.10. Four Methods for Estimating Contaminant Air Concentration During Showering

CT ANALYSIS PARAMETERS:

The “CT” (concentration multiplied by time) analysis is an optional analysis. Figure 9.11 provides a enlarged screen shot of the “CT Analysis Parameters” component of the “Inhalation – Showering” tab. The “CT Analysis Parameters” panel provides the user with the ability to examine receptor exposures in terms of exposure duration and contaminant air concentration of contaminant in addition to dose. The CT analysis can be used to evaluate the relative importance of the major exposure incident associated with showering. In order for TEVA-SPOT-GUI to perform the “CT Analysis,” the user must check the “Include CT Analysis” box and enter one or more “CT Thresholds” in the corresponding box after clicking the “Edit” button. The user is also able to specify whether they want additional CT results by clicking the check box “Report Separate C and T Results.” If the “Report Separate C and T Results” is checked, the user must also enter: (1) “Bins Num” (integer) and (2) “Size” (decimal) for both “Shower Duration (min)” and “Air Concentration (mg/m³).” The “Bins Num” determines how the results for concentration (C) and time (T) of the shower duration will be displayed.

Bins	Num	Size
Shower Duration (min)	15	5.0
Air Concentration (mg/m ³)	15	1.0

Figure 9.11. CT Analysis Parameters

9.3 Inhalation – Humidifier

The "Inhalation – Humidifier" exposure pathway tab is shown in Figure 9.13. TEVA-SPOT-GUI employs a similar approach for estimating inhalation doses associated with the use of an ultrasonic or cool-mist humidifier as that described in Section 9.2 for inhalation during showering. The inhalation during humidifier use parameter entry tab is comprised of seven components: (1) Dose Calculation Parameters, (2) CT Analysis Parameters, (3) Thresholds, (4) Relative Contribution, (5) Dose Response Method, (6) Disease Progression Parameters, and (7) Worst-case Results. Components (2), (3), (4), (5), (6), and (7) are consistent with their corresponding parameters in the ingestion and inhalation during showering tabs and, therefore, will not be discussed here. Again, consistent with estimating the dose associated with inhalation during showering, the inhalation exposure pathway resulting from humidifier use requires contaminant information (e.g., dose response information) that is specific to the inhalation pathway. This section will briefly describe the "Dose Calculation Parameters" component. Additional information about the use of this dose and consequence exposure pathway and the parameters associated with it can be found in [22].

The screenshot displays the 'Inhalation - Humidifier' tab in the TEVA-SPOT-GUI software. The interface is divided into several sections for parameter entry:

- Calculate Inhalation - Humidifier:** A checked checkbox.
- Dose Calculation Parameters:**
 - Dose Calculation Method:** A dropdown menu set to 'Empirical'.
 - Breathing Rate (m³/h):** A text input field with the value '0.3'.
 - Empirical Constant (L/m³):** A text input field with the value '0.2'.
 - Fraction of population using humidifiers:** A text input field with the value '1.0'.
 - Probabilistic Iterations:** A text input field with the value '1'.
 - Random Number Seed:** A text input field with the value '1'.
 - Fill Time Model:** A dropdown menu set to 'Fixed'.
 - Fill Time (hour of day):** A text input field with the value '22.0'.
 - Duration Model:** A dropdown menu set to 'Fixed'.
 - Duration (hours):** A text input field with the value '8.0'.
- CT Analysis Parameters:**
 - Include CT Analysis:** An unchecked checkbox.
 - CT Thresholds:** A text input field with an 'Edit' button next to it.
 - Report Separate C and T Results:** An unchecked checkbox.
 - Bins Table:**

Bins	Num	Size
Humidifier Use Duration (min)	15	60.0
Air Concentration (mg/m ³)	15	1.0
- Thresholds:**
 - Dose:** A text input field with the value '0.0,1.0E-9,1.0E-6,1.0E-4,0.001,0.01,0.1,1.0,10.0,100.0' and an 'Edit' button.
 - Response:** A text input field with an 'Edit' button.
- Relative Contribution:**
 - Include Relative Contribution Analysis:** An unchecked checkbox.
 - Dose Thresholds:** A text input field with an 'Edit' button.
 - Bins Table:**

Bins	Num
Relative Contribution	10
- Calculate Dose-Response:** A checked checkbox.
- Dose Response Method:** A dropdown menu set to 'Probit'.
- Dose-Response calculation method:** A dropdown menu set to 'Probit'.
- LD50 / ID50:** A text input field with the value '0.001'.
- Beta:** A text input field with the value '1000000.0'.
- Disease Progression Parameters:**
 - Latency Time (hrs):** A text input field with the value '1'.
 - Fatality Time (hrs):** A text input field with the value '1'.
 - Fatality Rate:** A text input field with the value '1.0'.
- Worst-case Results:**
 - Number of worst-case fatality scenarios to save:** A text input field with the value '1'.
 - Number of worst-case dosage scenarios to save:** A text input field with the value '0'.
- Use one server per node:** An unchecked checkbox.
- Buttons:** 'OK' and 'Cancel' buttons at the bottom.

Figure 9.12. Edit Health Impacts Analysis Parameters – Inhalation during Humidifier Use Tab

Figure 9.14 shows an enlarged screen shot of the "Dose Calculation Parameters" for the inhalation during humidifier use exposure pathway. The calculation of an inhalation dose while using a humidifier requires two models: (1) a behavioral model describing when potential receptors fill the humidifier using potentially contaminated tap water and describes how long the humidifier is operated and (2) a model for estimating contaminant concentrations in the air during humidifier use. The left side of the "Dose Calculation Parameters" panel outlines the components of the exposure model that estimates the air concentration of a contaminant associated with humidifier use. The right side of the "Dose Calculation Parameters" panel outlines the components to describe the behavior of the receptor with respect to humidifier use (i.e., timing for filling humidifier reservoir and duration of humidifier use). The panel also has three drop down menus: (1) Dose Calculation Method (left side of panel), (2) Fill Time Model

(top right side of panel), and (3) Duration Model (bottom right side of panel). The “Dose Calculation Method” offers two choices for the modeling the contaminant air concentration: (1) Mass Balance and (2) Empirical. Depending on the “Dose Calculation Method” option chosen a particular set of parameter inputs will appear. The two methods are described in [22]. Also associated with the “Dose Calculation Parameters” is the specification of the “Fraction of population using humidifiers,” which accepts decimal numbers.

The receptor exposure model for humidifier use is simpler than the corresponding model for receptor behavior during showering and, therefore, only requires the selection of “FIXED” or “PROBABILISTIC” for both the “Fill Time Model” and the “Duration Model” and an entry of the “Fill Time (hour of the day)” and “Duration (hours)” parameters. Both the “Fill Time (hour of day)” and “Duration (hours)” parameter entry screens accept decimal numbers. If one or both probabilistic options are chosen, the parameter entry screens appear for “Probabilistic Iterations” and “Random Number Seed” appear.

The screenshot shows a software dialog box titled "Calculate Inhalation - Humidifier". It contains a section for "Dose Calculation Parameters". The "Dose Calculation Method" is set to "Empirical". The "Fill Time Model" is set to "Fixed" with a value of 22.0 for "Fill Time (hour of day)". The "Duration Model" is set to "Fixed" with a value of 8.0 for "Duration (hours)". Other parameters include "Breathing Rate (m^3/h)" at 0.3, "Empirical Constant (L/m^3)" at 0.2, "Fraction of population using humidifiers" at 1.0, "Probabilistic Iterations" at 1, and "Random Number Seed" at 1.

Dose Calculation Parameters	
Dose Calculation Method	Empirical
Breathing Rate (m ³ /h)	0.3
Empirical Constant (L/m ³)	0.2
Fraction of population using humidifiers	1.0
Fill Time Model	Fixed
Fill Time (hour of day)	22.0
Duration Model	Fixed
Duration (hours)	8.0
Probabilistic Iterations	1
Random Number Seed	1

Figure 9.13. Dose Calculation Parameters – Inhalation During Humidifier Use

For the selection of “PROBABILISTIC” under either the “Fill Time Model” or the “Duration Model,” the user has the option to select either a “UNIFORM” or “TRIANGLE” distribution. For each “UNIFORM” probabilistic distribution model, the user is presented with the parameter entry screens: “Range start (hour of day)” and Range length (hours).” Both parameter entry screens accept decimal numbers. Figure 9.14 shows a screen shot of “UNIFORM” probabilistic distribution model for both the “Fill Time Model” and the “Duration Model.”

For each “TRIANGLE” probabilistic distribution model, the user is presented with the parameter entry screens: “Peak Fill Time (hour of day),” “Range start (hour of day),” and Range length (hours).” Figure 9.15 shows a screen shot of “TRIANGLE” probabilistic distribution model for both the “Fill Time Model” and the “Duration Model.” The “TRIANGLE” probabilistic distribution model requires the Range start (hour of day) and Range length (hours) as well as Peak Fill Time and Peak Duration parameters.

Dose Calculation Parameters			
Dose Calculation Method	Empirical	Fill Time Model	Probabilistic - Uniform
Breathing Rate (m^3/h)	0.3	Range start (hour of day)	
Empirical Constant (L/m^3)	0.2	Range length (hours)	
Fraction of population using humidifiers	1.0	Duration Model	Probabilistic - Uniform
Probabilistic Iterations	1	Range start (hours)	
Random Number Seed	1	Range length (hours)	

Figure 9.14. Probabilistic Uniform Distribution Parameter Entry.

Dose Calculation Parameters			
Dose Calculation Method	Empirical	Fill Time Model	Probabilistic - Triangle
Breathing Rate (m^3/h)	0.3	Peak Fill Time (hour of day)	
Empirical Constant (L/m^3)	0.2	Range start (hour of day)	
Fraction of population using humidifiers	1.0	Range length (hours)	
Probabilistic Iterations	1	Duration Model	Probabilistic - Triangle
Random Number Seed	1	Peak Duration (hours)	
		Range start (hours)	
		Range length (hours)	

Figure 9.15. Probabilistic Triangle Distribution Parameter Entry

10. Infrastructure Impacts Analysis

TEVA-SPOT-GUI provides for the analysis of infrastructure consequences as determined by the length of pipe (feet) that witnesses contaminant concentrations above a user specified concentration threshold. A more complicated infrastructure impacts analysis could be implemented using the built in EPANET-MSX functionality, but will not be discussed here.

Figure 10.1 provides a screen shot of the “Execution” control panel where the user can access and configure the parameters associated with the “Infrastructure Impacts Analysis” module.

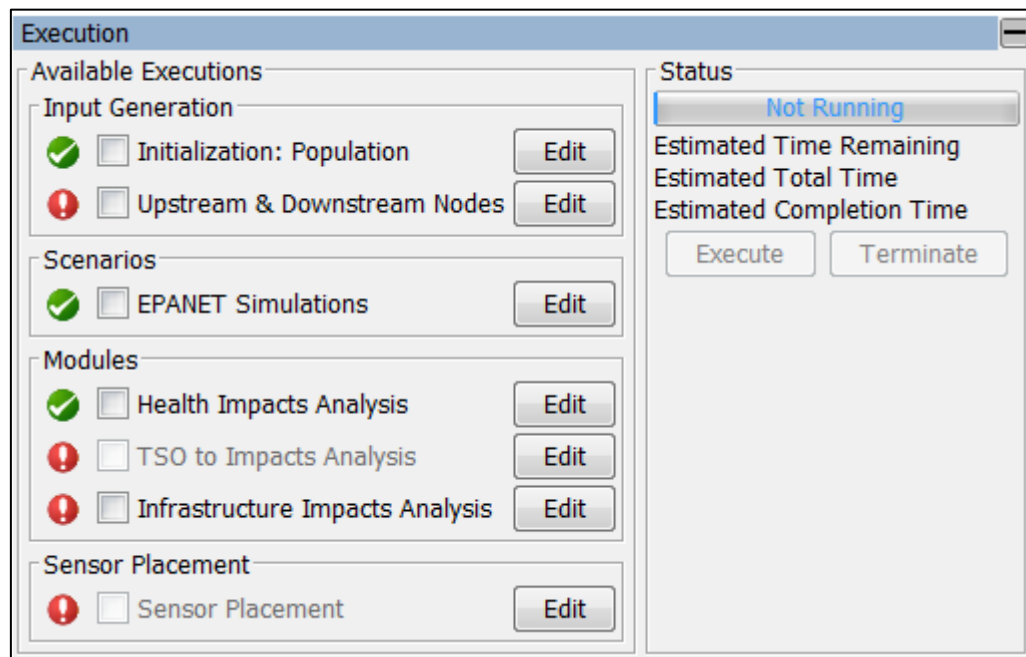


Figure 10.1. Execution Control Panel – Infrastructure Impacts Analysis Module

Figure 10.2 provides a screen shot of the “Infrastructure Impacts Analysis” module, after the user clicks the “Edit” button. Contaminant concentration thresholds are entered individually (click “Ok” after each entry) and results are returned in the user interface and within the directory: C:\TEVA-SPOT-Database\COLLECTION_NAME\ENSEMBLE_NAME\Infrastructure Impacts Analysis. Results are provided by contamination scenario (node location) in terms of pipe feet that witnessed a contamination level above the specified threshold. Results are organized by pipe diameter.

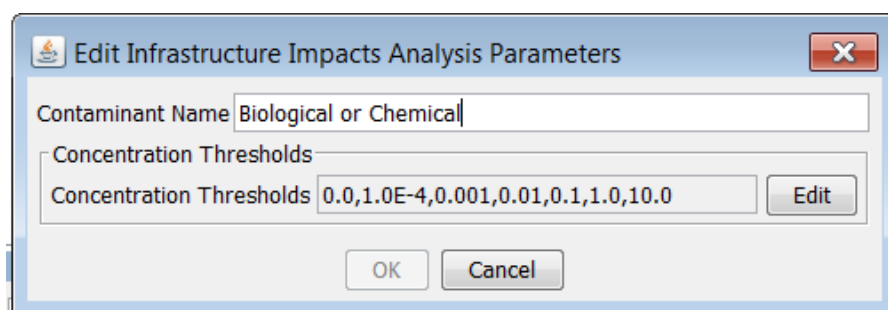


Figure 10.2. Edit Infrastructure Impacts Analysis Parameters

11. TSO to Impacts Analysis

A screen shot of the “Execution” control panel illustrating access to the “Threat-Simulator-Output (TSO) to Impacts Analysis” module is shown in Figure 11.1. The “TSO-to-Impact Analysis” (TSO-2-Impacts) module is between the “Health Impacts Analysis” and “Infrastructure Analysis” modules. The “TSO-to-Impacts Analysis” module is for users who want to use the distributed capabilities of TEVA-SPOT-GUI to create large and or complicated impact files for subsequent sensor placement optimization using separate software. It is grayed out in Figure 11.1, because it has not been enabled. It can be enabled or setup by clicking the “Edit” and entering the required information.

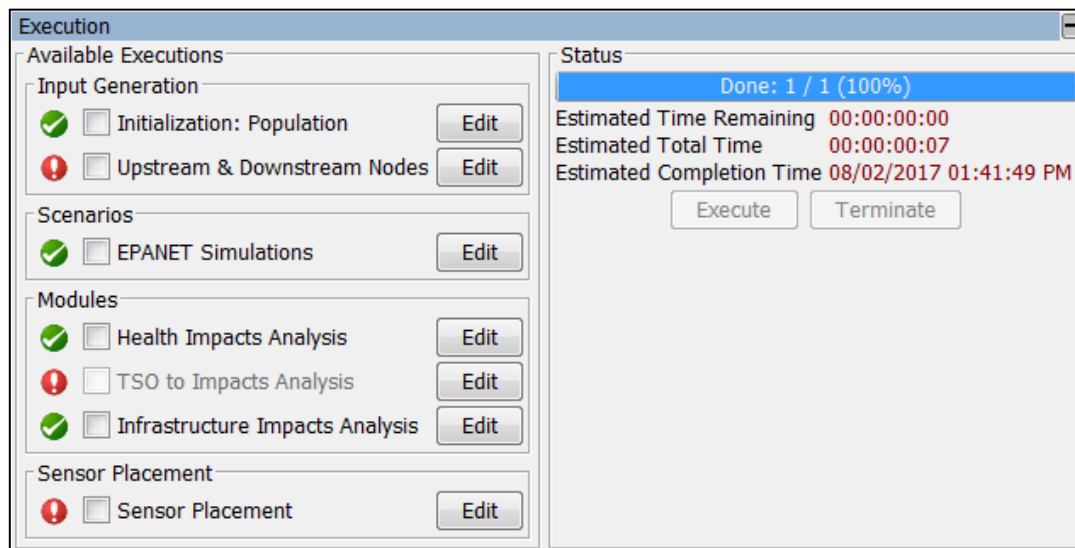


Figure 11.1. Execution Control Panel Showing TSO to Impacts Analysis

The generation of TSO-2-Impact files is the first step in the sensor placement optimization process. Once TSO-2-Impacts are generated, sensor placement algorithms can be used to perform the sensor placement optimization. TSO-2-Impact files are generated for each combination of consequence measure, response time, and detection limit. The impact file is what the sensor placement algorithm uses to optimally locate sensor monitoring stations to minimize a chosen objective. An impact file stores the results of the consequence assessment. Specifically, for each contamination scenario, the impact file contains a list of the locations in the network where a sensor could detect contamination. Locations (nodes) that do not detect the contaminant are not included in the impact file for that particular contamination scenario. For each location (node) that detects the contaminant, the impact file contains the detection time and the total consequence given a sensor at that location is the first to detect contamination from that scenario. For more information on the generation of impact files and sensor placement optimization, please refer to the User Manual for Water Security Toolkit [23]. For more information on sensor network design using TEVA-SPOT-GUI, please refer to Section 12.

Please Note This Module Is Currently Not Functioning.

12. Sensor Placement

A screen shot of the “Execution” control panel showing access to the “Sensor Placement” module is shown in Figure 12.1. The “Sensor Placement” module can be access by clicking the “Edit” button.

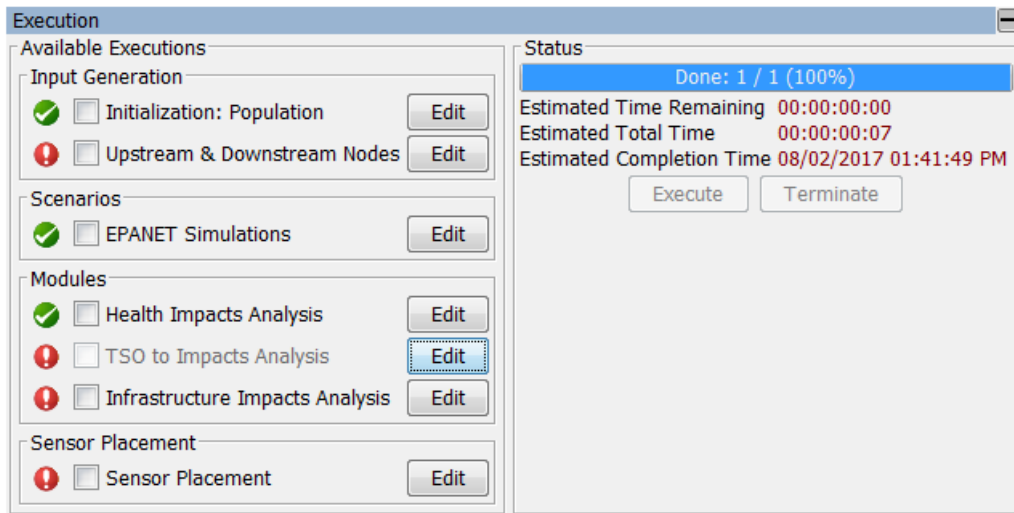


Figure 12.1. Execution Control Panel Showing Sensor Placement

The “Sensor Placement” module contains a heuristic algorithm capable of solving large and complicated WDS optimization problems. The algorithm tries to find a solution to the problem of placing a given number of sensors in the WDS network to optimize a stated objective, usually subject to several constraints. Figure 12.2 below highlights the main input screen for the “Sensor Placement” module within TEVA-SPOT-GUI. For more detailed description of these features, please refer to the Water Security Toolkit [23]. This section will briefly discuss each of the sensor design parameters.

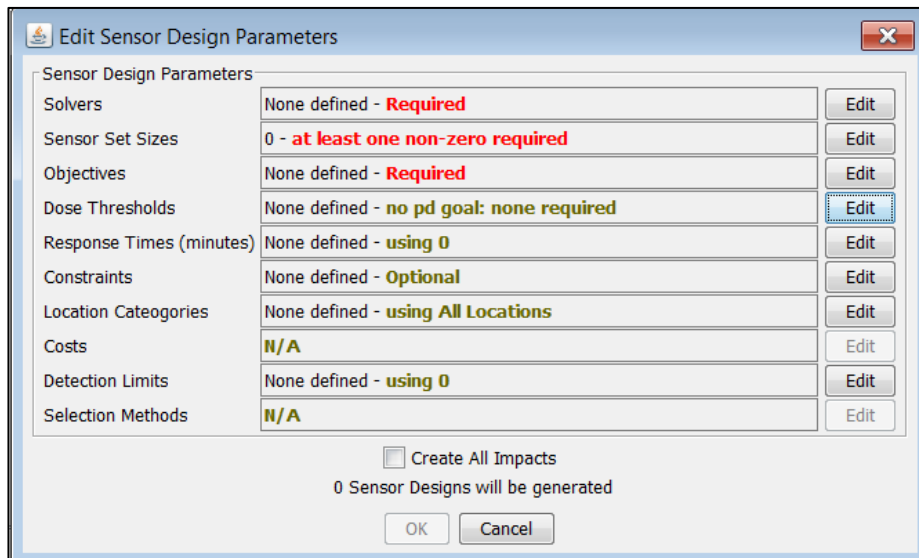


Figure 12.2. Edit Sensor Design Parameters

SOVLERS:

TEVA-SPOT-GUI offers the user one sensor placement optimization solver, called GRASP, which is a heuristic algorithm. To choose the GRASP algorithm, the user clicks the “Edit” button next to the “Solvers” option on the “Sensor Placement” module as shown in Figure 12.2. Once on the Solvers option (see Figure 12.3), the user clicks “Add Solver,” selects the “Grasp (heuristic),” and then clicks “OK.” Figure 12.3 shows the “Grasp (heuristic)” already selected.

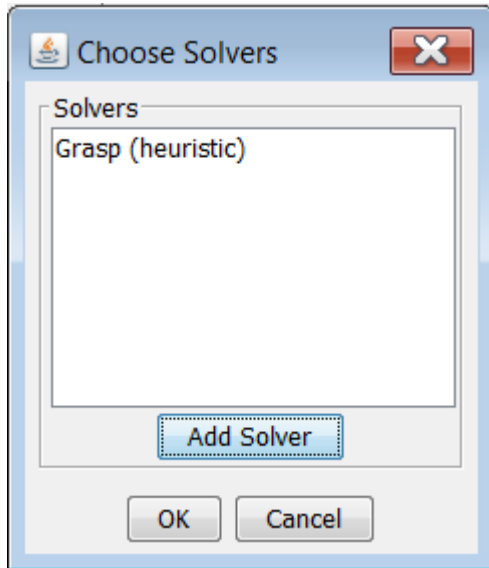


Figure 12.3. Choose Solvers

SENSOR SET SIZES:

Figure 12.4 provides a screen shot of the interface for configuring the number of unique sensor placement designs that are to be developed in TEVA-SPOT-GUI. The base case of zero sensors is the default and cannot be removed. The user enters a sensor set size and clicks “Enter” to register the number in the panel. Many sensor set sizes can be entered. The user decides the sensor set size (i.e., number of monitoring locations that are to be created and evaluated). A user might not know ultimately how many sensor monitoring stations will be needed, so they can use TEVA-SPOT-GUI to create and evaluate a range of potential sensor network monitoring designs (number of monitoring locations). For example, a user knows that anywhere from 10-20 sensor monitoring stations will be needed, but is not certain and, therefore, decides to have TEVA-SPOT-GUI generate sensor network designs to comfortably bracket this range by identifying 5, 10, 15, 20, and 25 sensor set sizes.

OBJECTIVES:

Figure 12.5 shows a screen shot of the “Objectives” panel for selecting one or more objectives for sensor placement. The “Edit Objectives” panel allows the user to select objectives from the drop down menu and add to the objectives panel above. After each objective selection, the user clicks “Add.” All desired objectives must appear in the “Objectives” panel. In choosing an “Objective,” the user also decides on an associated “Statistic.” Four statistics are available from the drop down menu: “Mean,” “Tail-Conditioned-Expectation or approximation,” “Value-at-Risk,” and “Worst.”

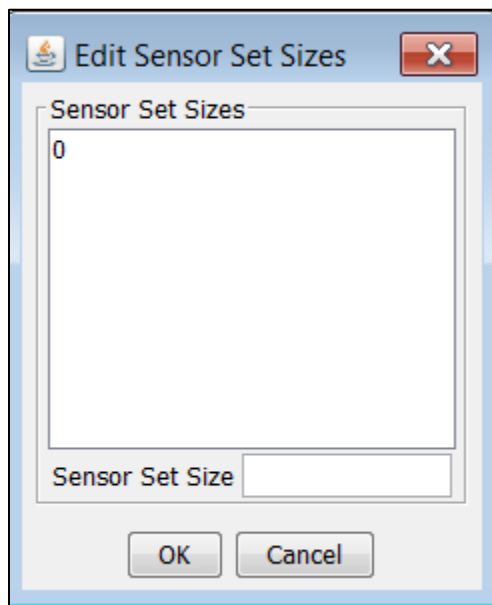


Figure 12.4. Edit Sensor Set Sizes

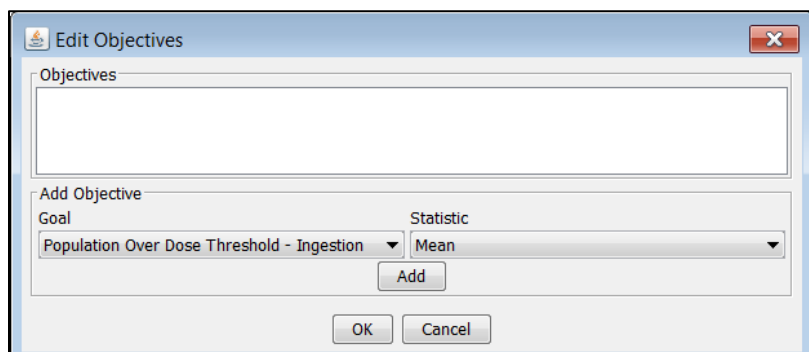


Figure 12.5. Edit Objectives

DOSE THRESHOLDS:

“Dose Thresholds” are specified if the objective of “Population Dosed” (pd) is selected. The screen for entering “Dose Thresholds” is analogous to the screen for entering sensor set sizes. After each “Dose Threshold” is typed into the screen, the user must click “Enter” for the dose threshold to appear. “Dose Thresholds” are decimal values.

RESPONSE TIMES:

“Response Times (minutes)” specifies the delay in time required to confirm the detection of contamination and stop further exposure and consequences, either through public notification and/or cessation of drinking water service. The “Response Times (minutes)” input screen is analogous to that of the “Dose Thresholds,” but only accepts integer values. Units of response time are minutes. Multiple response times can be entered.

CONSTRAINTS:

“Constraints” allows the user to define a side constraint on the objectives chosen. For example, population killed (pk) objective could be constrained to minimize the extent of contamination (ec) objective subject to an upper bound on ec. Figure 12.5 shows a screen shot of the “Edit Constraints” user interface panel. To add a constraint or set of constraints the user clicks “New Constraint Set,” and a new user interface panel opens (Figure 12.6) titled, “Edit Constraint Set.” The user selects the appropriate “Goal,” “Statistic,” and enters an “Upper bound” limit on the constraint (decimal value) chosen and then clicks “Add.” Multiple constraints can be designed and added. Each constraint will be paired with each objective previously chosen. If it is desired to also have one or more objectives used in sensor network designs without any constraints, then the button “Add Unconstrained Set” must also be selected and appear in the “Edit Constraints” window (Figure 12.5). The input decimal values for the upper bound should be consistent with the constraint chosen (e.g., the constraint of extent of contamination should have an upper bound that is reasonable and in units of pipe feet).

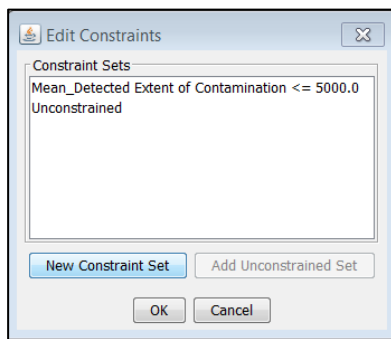


Figure 12.6. Edit Constraints

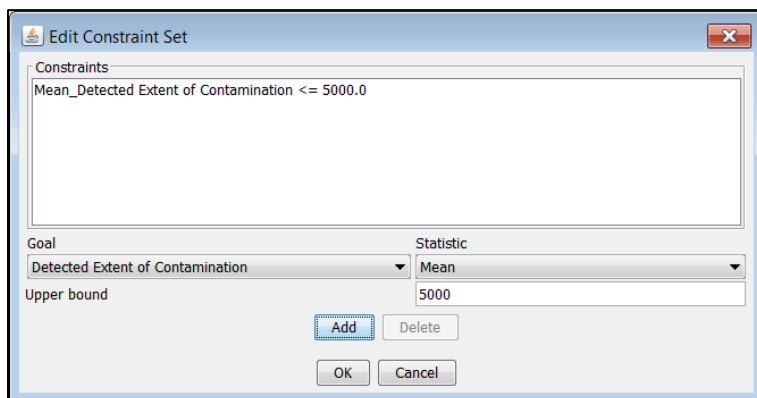


Figure 12.7. Edit Constraint Set

For more information, the user should refer to the Water Security Toolkit User’s Manual [\[23\]](#).

LOCATION CATEGORIES:

Location categories represent groups of network model nodes that can be used by the sensor placement optimization algorithm for optimizing the placement of sensor monitoring stations. Generally, location categories refers to the various categories of feasible, infeasible, and fixed locations that TEVA-SPOT-GUI will consider in the determination of the optimal placement of sensors. TEVA-SPOT-GUI provides the user with six options for choosing network model locations for sensor placement. Each of these six options represent a set of feasible or possible locations. Below is a list of the six options available. To identify the feasible locations, click “Edit” next to “Location Categories” on the “Sensor Placement” module as shown in Figure 12.2. Figure 12.8 provides a screen shot of the “Edit Locations Categories” user interface panel after opening it and then clicking “New.”

- All Locations
- Non-Zero Demand Nodes
- All Junctions
- Enumerated (user picks from list)
- Pipe Diameter
- SP Format (imported text file of node list)

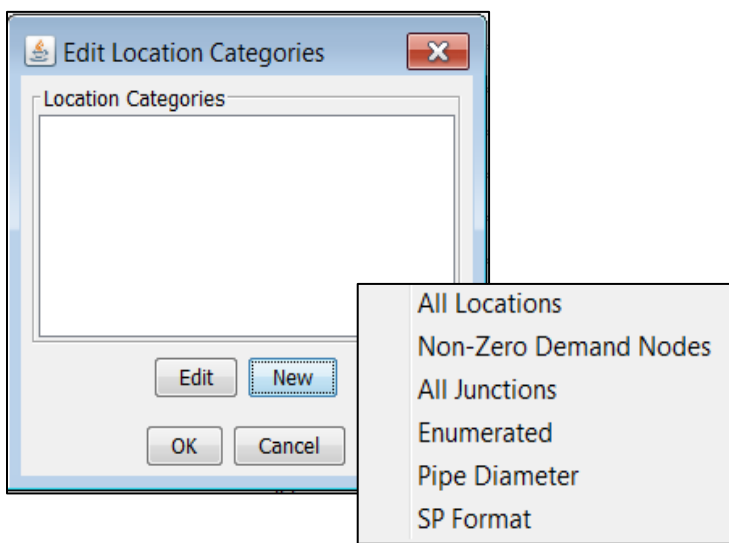


Figure 12.8. Edit Location Categories – Available Categories

The default location category” is “All Locations,” which indicates that all nodes in the network model will be evaluated as potential sensor monitoring locations. Choosing “All Locations” will result in the best overall performance (i.e., selection of sensor locations which best reduce the chosen consequence impact(s)) across the contamination scenarios ensemble.⁴

The “Non-Zero Demand Nodes” category only considers network nodes with non-zero demand (or demands greater than zero) as possible sensor monitoring locations.

⁴ Choosing “All Locations” may substantially increase computation time and computer memory requirements to complete.

The “All Junctions” location category includes only network model junctions. EPANET considers “All Junctions” to be just network model nodes (i.e., zero and non-zero demand nodes) and not tanks or reservoirs.

The location category “Enumerated” provides the user with the capability to create a list of feasible sensor placement locations from the list of network model nodes. Figure 12.8 provides a screen shot of the “Enumerated” location category user interface panel after clicking “Enumerated.” The user selects one or more network model nodes, clicks “Add,” and inserts a name for the enumerated node set, and then clicks “OK.” Alternatively, the user may also click “Add From File” which will open a Microsoft Windows Explorer window in order to navigate to a enumerated sensor locations file. To “Add From File,” the user must create a text file (.txt) that follows the format described below and shown, as an example, in Figure 12.9.

The format of the contents of the text file and the key words: “#name:,” “feasible ALL,” and “fixed [Node ID],” and “infeasible [Node ID]” are important. The keyword “infeasible” specifies those node ID(s) that cannot be considered in sensor placement. The “All” in “feasible All” or “infeasible All” can be replaced with node IDs. Word separations are SPACE or TAB delineated. TEVA-SPOT-GUI will use either the “#name:” value or the filename (if the “#name:” is not specified in the file) as the location category name that is appended to the output results.

For the key words “feasible ALL,” TEVA-SPOT-GUI identifies all nodes in the network model as being feasible for the placement of sensors. For the key words “infeasible [node ID],” TEVA-SPOT-GUI identifies the identified nodes in the network model as being infeasible for the placement of sensors. TEVA-SPOT-GUI executes the key word “fixed” and the associated location(s) that are to be fixed in each sensor network design. Multiple node IDs can be placed on the same line and/or multiple rows can be used. For each row, the keyword (e.g., “fixed” must precede the node ID(s)). Notice that capitalization is important: TEVA-SPOT-GUI will not recognize a fixed location if the node “Junction-0” is NOT capitalized exactly as it is in the model.

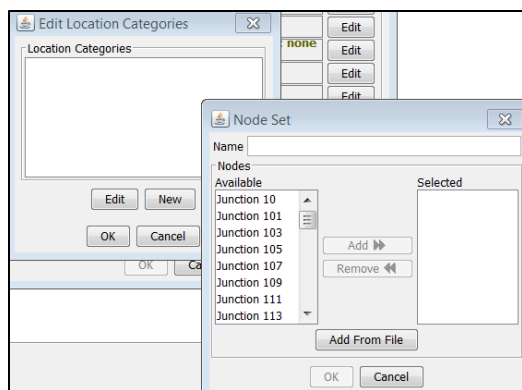


Figure 12.9. Edit Location Categories - Enumerated

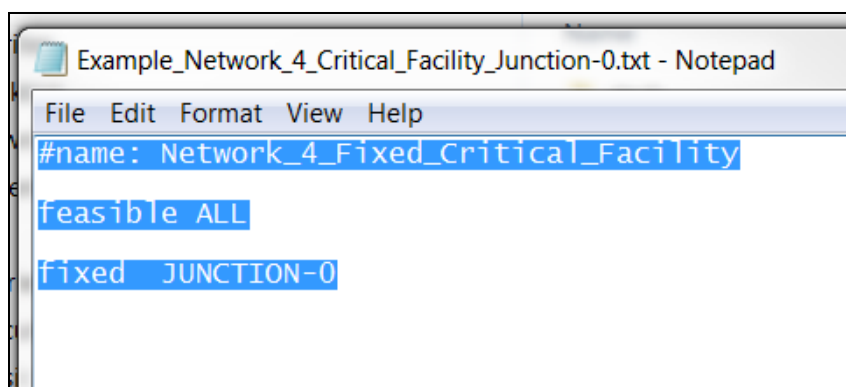


Figure 12.10. Example Text File for Feasible and Fixed Sensor Placement Node List⁵

COSTS:

The ability to optimize sensor placement based on costs has not yet been implemented. Thus, the “Edit” button next to the “Costs” option on the “Sensor Placement” module is grayed out (Figure 12.2).

DETECTION LIMITS:

Specifying a detection limit will create a sensor network design(s) that require a minimum contaminant concentration in the WDS (e.g., mg/L or organisms/L) for sensor detection for each particular sensor monitoring location. The user interface for specifying “Detection Limits” is shown in Figure 12.10 after clicking “Edit” next to “Detection Limits” on the “Sensor Placement” module as shown in Figure 12.2. Multiple detection limits can be specified. After entering each detection limit (decimal values), the user must click “Enter” for the detection limit to appear in the user interface panel. In Figure 12.10, the user has already entered 0.001 and is getting ready (after clicking “Enter” on the keyboard) to enter 0.01. Notice that TEVA-SPOT-GUI accepts scientific notation.

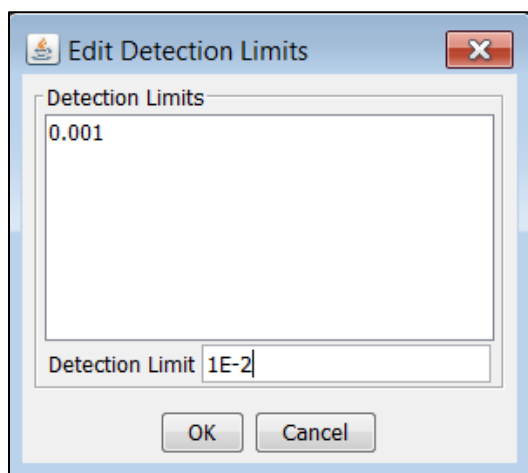


Figure 12.11. Edit Detection Limits

⁵ This screen shot was taken from EPA Report EPA/600/R-14/433.

SELECTION METHODS:

The “Selection Methods” functionality has not yet been implemented. Thus, the “Edit” button next to the “Selection Methods” option on the “Sensor Placement” module is grayed out (Figure 12.2).

13. Ensemble or Regret Execution

Execution for both the “Ensemble” and the “Regret” modes are implemented from the “Execution Control” panel. Once an Ensemble or Regret is loaded, the “Execution Control” panel can be opened by clicking the keys Control (Ctrl)-Letter E together or choosing “Execution Control” from the main “ENSEMBLE” menu. This is illustrated in Figure 13.1.

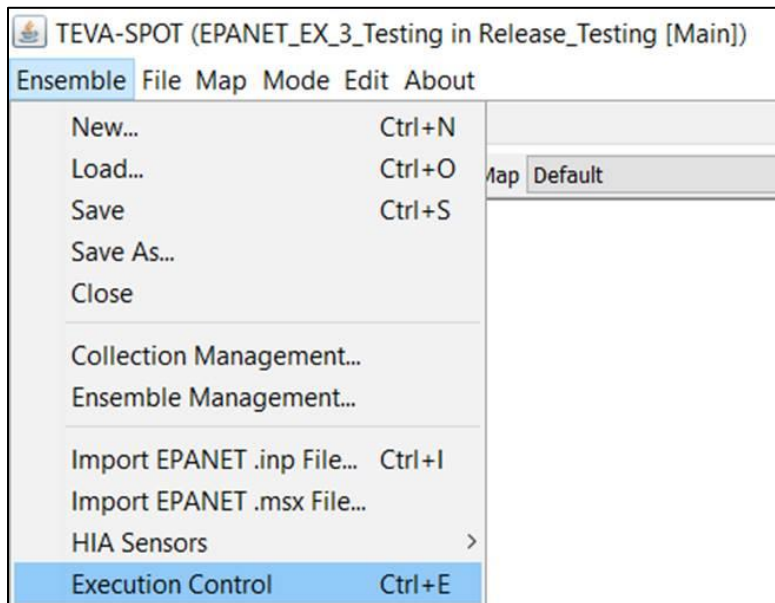


Figure 13.1. Opening Execution Control Panel

After an Ensemble is loaded or created, but not yet executed, each TEVA-SPOT-GUI module will show a red exclamation mark next to it, as shown in Figure 13.2.

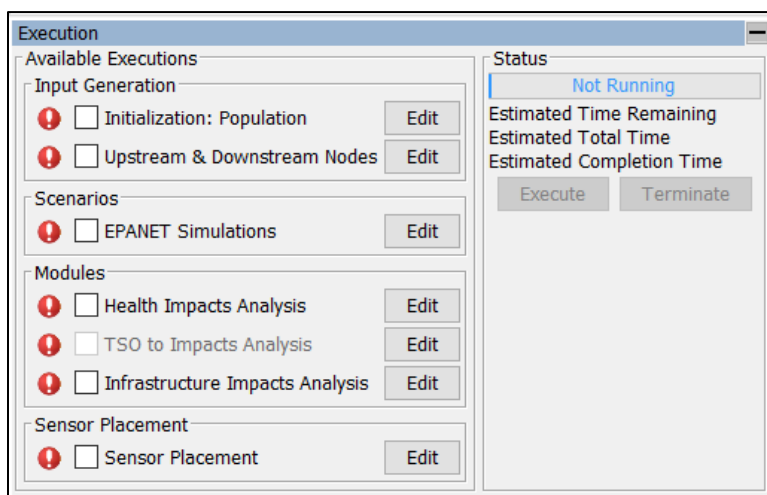


Figure 13.2. Execution Control Panel – Prior to Execution

Once the TEVA-SPOT-GUI modules have been selected (check mark placed in box next to the module), the “Execute” button has been selected, and the runs of the modules have completed, the user will see the status of completion which now shows green check marks in the box associated with each executed module (shown in Figure 13.3).⁶

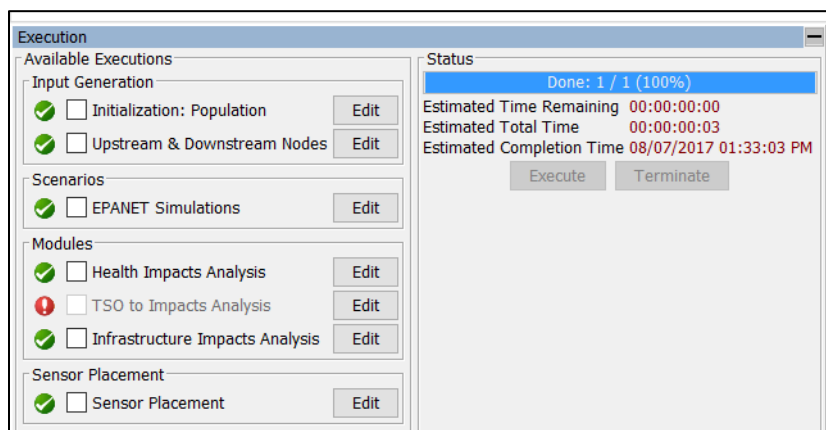


Figure 13.3. Execution Control Panel – After Execution is Completed

⁶ Note that the module “TSO to Impacts Analysis” was not executed.

14. Regret Analysis Mode

Regret analysis provides a means to select the best sensor design among many. For a particular WDS, a user can create multiple ensembles (e.g., different contaminants, release times, mass release rates, response delays, detection limits) and with each of these ensembles various sensor network designs are created. Without the “Regret Analysis,” a user might struggle with how to choose the best sensor network design among a group of designs.

In the “Regret Analysis Mode,” a user selects the impact files and sensor network designs by loading them into the Regret Analysis and the function “Evaluate Sensor” or “EVAL SENSOR” (see Water Security Toolkit) is used to compute the matrix of impacts. Every sensor network 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. No parameters need to be entered for this analysis, unlike 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 Mode” 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), different response times, and different detection limits. A single set of sensors should be selected (e.g., 10 sensors) in performing a regret analysis. Using regret analysis to determine a preferred sensor network design among different objectives should be done with caution.

The “Regret Analysis” mode is chosen from the main menu of TEVA-SPOT-GUI under the heading “Mode,” and clicking on “Switch to Regret Analysis,” as shown in Figure 14.1.

After switching to “Regret Analysis” mode, the user is presented with the screen shown in Figure 14.2.

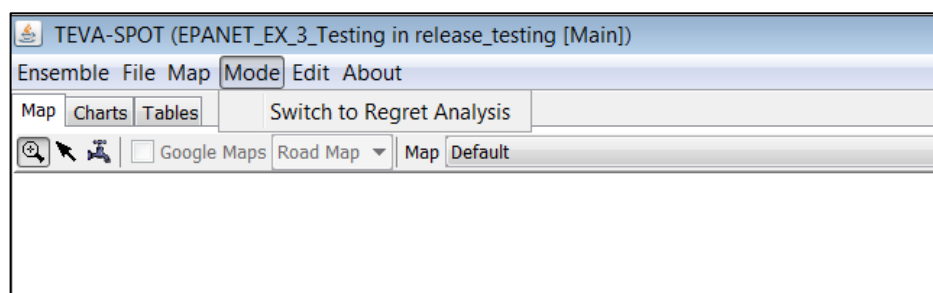


Figure 14.1. “Switch to Regret Analysis” Mode

Notice that “No Regret Analysis Loaded” is displayed on top bar, above menu headings. Since no regret analysis is loaded, the user must first click “New,” “Load,” or “Save As” to establish a regret analysis. Selecting “New” or “Save As” are essentially the same. If the user selects “New” or “Save As,” a user interface box appears which allows the user to choose a particular COLLECTION from the drop down menu and then type in a “Regret Analysis Name.” Regret analyses are contained in ENSEMBLE COLLECTIONS. Figure 14.3 provides a screen shot from TEVA-SPOT-GUI after choosing “New.” After the “Regret Analysis Name” is entered and the user clicks “OK,” the name of the “Regret Analysis” will appear in the top bar of the user interface (see Figure 14.4).

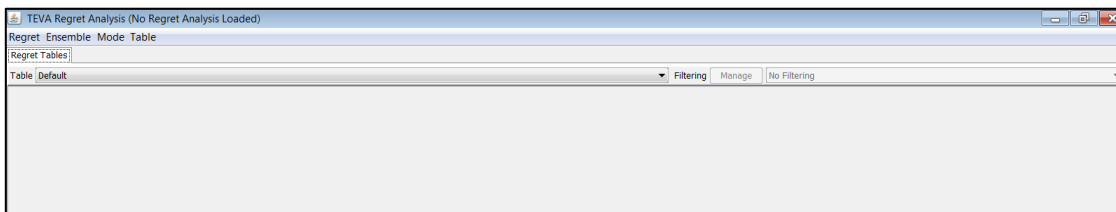


Figure 14.2. TEVA Regret Analysis (No Regret Analysis Loaded)

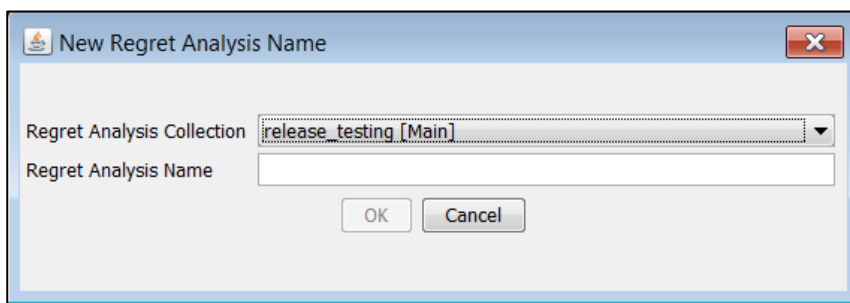


Figure 14.3. New Regret Analysis Name

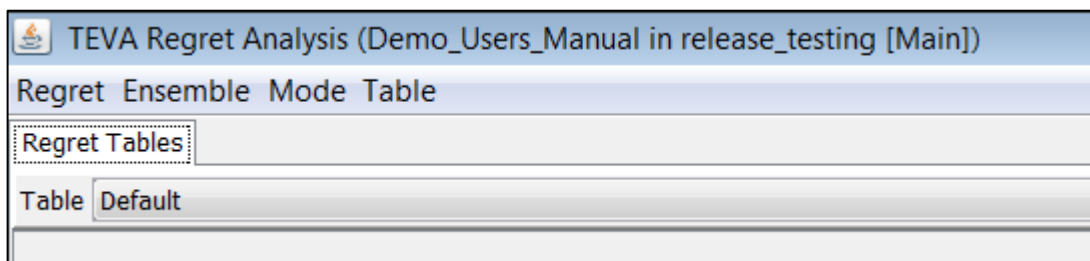


Figure 14.4. TEVA Regret Analysis – New or Loaded

Once a “Regret Analysis” is created or loaded, the user will next click “Load Ensembles” from the “ENSEMBLE” menu (see Figure 14.5). The user then loads all the ensembles that contain sensor network designs for a particular WDS network model. Different network models cannot be used. Once one or more ensembles are loaded, the user then opens the “Execution Control” panel (see Figure 14.6) from the “REGRET” menu.

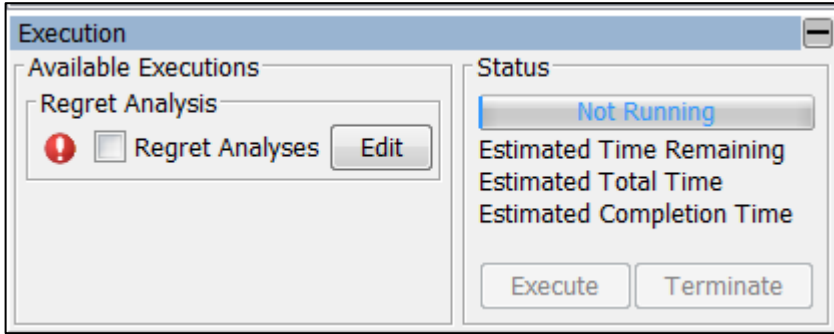


Figure 14.5. Regret Execution

In the “Regret Execution” control panel (Figure 14.6), the user clicks “Edit” to design the desired regret analyses. Figure 14.7 provides a screen shot of the “Regret Analysis Management” user interface. Next, the user clicks the “Add” button to open the “Regret Analysis Parameters” interface (Figure 14.8).

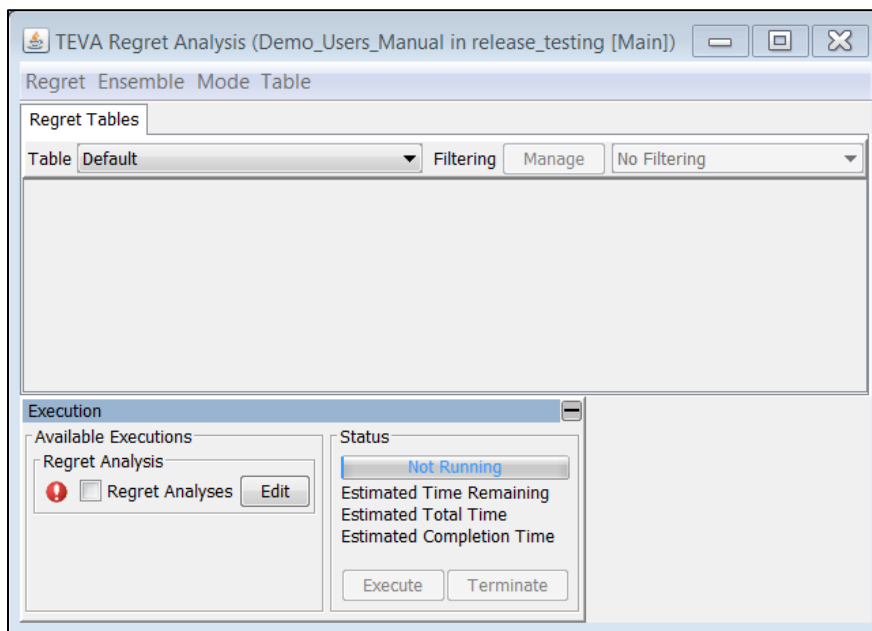


Figure 14.6. Regret Analyses Execution Control Panel

The “Regret Analysis Parameters” interface is composed of a top portion that specifies “Sensor Designs” and a bottom portion that specifies “Impact Sets.” The default is for checkmarks to appear in all of the boxes associated with “Sensor Designs” and “Impact Sets” (see “Filter Settings:” for each portion of Figure 14.8).

Regret analyses are created by selecting and moving selected “Sensor Designs” and “Impacts Sets” to their respective “Available” windows on the far right of the screen in Figure 14.8 and then selecting needed “Impacts” (bottom of screen) and “Statistics” (bottom right of screen). The “Impacts” will be

enabled once “Impacts Sets” are moved to the “Selected” window. Finally, the “Available” sensor designs that appear are a result of which boxes are checked in the “Filter Settings.” box.

For example, if the checkmark next to the “0” under “Number of Sensors” is unselected, all of the zero sensor network designs will be removed from the middle “Available” window. Next, all of the remaining sensor designs in the top, middle “Available” column are selected by clicking the “Right” arrow to move all the sensor designs to the far right “Selected” window. Next, all of the impact sets in the “Available” window are selected by moving them to the “Selected” window. Next, checkmarks are placed in the “Impacts” boxes of “pdi(0.0001)” and “pdi(100.0)” and in all of the “Statistics” boxes.

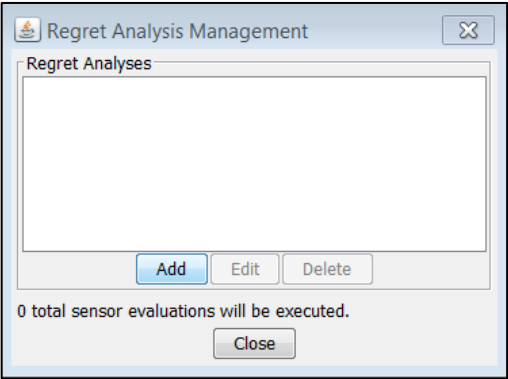


Figure 14.7. Regret Analysis Management

Finally, a name is typed in the “Name” panel at top of screen. Figure 14.9 provides a screen of this configuration of regret analyses. Notice that 136 sensor evaluations are indicated to be computed (middle bottom of Figure 14.9).

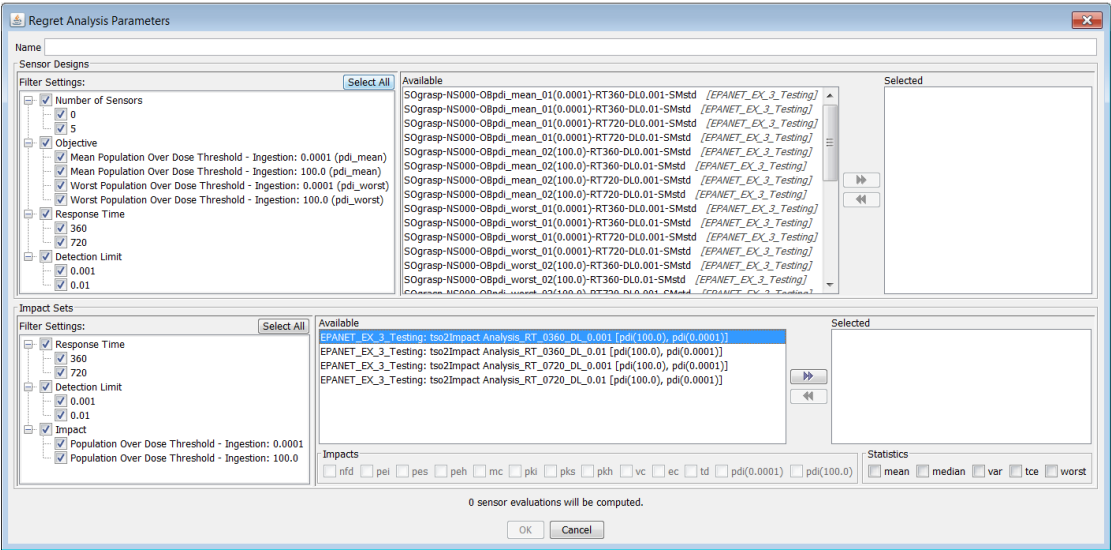


Figure 14.8. Regret Analysis Parameters

Regret Analysis Parameters

Name: Demo_5_Sensors_All

Sensor Designs

Filter Settings: Select All

- ☒ Number of Sensors
 - ☐ 0
 - ☐ 5
- ☒ Objective
 - ☒ Mean Population Over Dose Threshold - Ingestion: 0.0001 (pdi_mean)
 - ☒ Mean Population Over Dose Threshold - Ingestion: 100.0 (pdi_mean)
 - ☒ Worst Population Over Dose Threshold - Ingestion: 0.0001 (pdi_worst)
 - ☒ Worst Population Over Dose Threshold - Ingestion: 100.0 (pdi_worst)
- ☒ Response Time
 - ☒ 360
 - ☒ 720
- ☒ Detection Limit
 - ☒ 0.001
 - ☒ 0.01

Available: [Empty]

Selected:

- SOgrasp-NS005-OBpdi_mean_01(0.0001)-RT360-DL0.01-SMatd [EPANET_EX_3_Testing]
- SOgrasp-NS005-OBpdi_mean_01(0.0001)-RT360-DL0.01-SMatd [EPANET_EX_3_Testing]
- SOgrasp-NS005-OBpdi_mean_01(0.0001)-RT720-DL0.01-SMatd [EPANET_EX_3_Testing]
- SOgrasp-NS005-OBpdi_mean_01(0.0001)-RT720-DL0.01-SMatd [EPANET_EX_3_Testing]
- SOgrasp-NS005-OBpdi_mean_02(100.0)-RT360-DL0.01-SMatd [EPANET_EX_3_Testing]
- SOgrasp-NS005-OBpdi_mean_02(100.0)-RT360-DL0.01-SMatd [EPANET_EX_3_Testing]
- SOgrasp-NS005-OBpdi_mean_02(100.0)-RT720-DL0.01-SMatd [EPANET_EX_3_Testing]
- SOgrasp-NS005-OBpdi_mean_02(100.0)-RT720-DL0.01-SMatd [EPANET_EX_3_Testing]
- SOgrasp-NS005-OBpdi_worst_01(0.0001)-RT360-DL0.01-SMatd [EPANET_EX_3_Testing]
- SOgrasp-NS005-OBpdi_worst_01(0.0001)-RT720-DL0.01-SMatd [EPANET_EX_3_Testing]
- SOgrasp-NS005-OBpdi_worst_01(0.0001)-RT720-DL0.01-SMatd [EPANET_EX_3_Testing]
- SOgrasp-NS005-OBpdi_worst_02(100.0)-RT360-DL0.01-SMatd [EPANET_EX_3_Testing]
- SOgrasp-NS005-OBpdi_worst_02(100.0)-RT360-DL0.01-SMatd [EPANET_EX_3_Testing]

Impact Sets

Filter Settings: Select All

- ☒ Response Time
 - ☐ 360
 - ☐ 720
- ☒ Detection Limit
 - ☐ 0.001
 - ☐ 0.01
- ☒ Impact
 - ☐ Population Over Dose Threshold - Ingestion: 0.0001
 - ☐ Population Over Dose Threshold - Ingestion: 100.0

Available: [Empty]

Selected:

- EPANET_EX_3_Testing: tso2Impact Analysis_RT_0360_DL_0.001 [pdi(100.0), pdi(0.0001)]
- EPANET_EX_3_Testing: tso2Impact Analysis_RT_0360_DL_0.01 [pdi(100.0), pdi(0.0001)]
- EPANET_EX_3_Testing: tso2Impact Analysis_RT_0720_DL_0.001 [pdi(100.0), pdi(0.0001)]
- EPANET_EX_3_Testing: tso2Impact Analysis_RT_0720_DL_0.01 [pdi(100.0), pdi(0.0001)]

Impacts: ☐ nfd ☐ pei ☐ pes ☐ peh ☐ mc ☐ plk ☐ pks ☐ pkh ☐ vc ☐ ec ☐ td ☒ pdi(0.0001) ☒ pdi(100.0)

Statistics: ☒ mean ☒ median ☒ var ☒ tce ☒ worst

136 sensor evaluations will be computed.

OK Cancel

Figure 14.9. Regret Analyses - Example

15. Map, Tables, and Charts

In the “Ensemble Analysis” mode, TEVA-SPOT-GUI provides output results through the main interface tabs of “Map,” “Charts,” and “Tables.” The “Filtering” “MANAGE” button (See Figure 16.1) can be used to organize and sort results according to tab (i.e., “Map,” “Charts,” and “Tables”). How to use the “Filtering” controls is discussed in Section 16. The “Filtering” design will be used here to describe choices available under the maps, tables, and charts tabs associated with the main menu of TEVA-SPOT-GUI. The output results provided in the “Map,” “Tables,” and “Charts” are described in sections 15.1, 15.2, and 15.3, respectively.

15.1 MAP

Output maps are produced in the “Ensemble Analysis” mode by performing a health impacts analysis and by running sensor placement. The network model of the currently loaded ensemble is the “Default” map in the pull-down list of maps. The “Default” map is characterized generically by black and red nodes and black pipes (as shown in Figure 15.1).

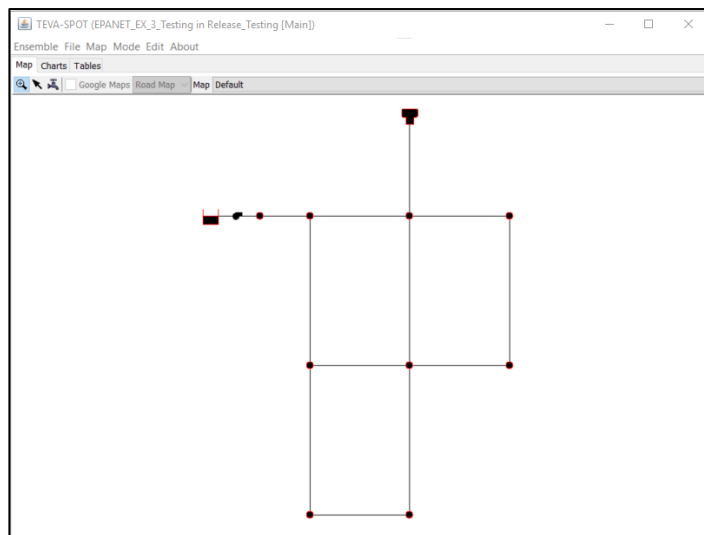


Figure 15.1. Default Map

The “Map” tab provides a drop down menu of map results for six categories of output results: (1) “Ensemble Execution,” (2) “Health Impacts Analysis,” (3) “Infrastructure Impacts Analysis,” (4) “Population,” (5) “Sensor Placement,” and (6) “Upstream and Downstream Nodes” as shown in Figure 15.2. Please note that “Ensemble Execution” is also referred to as EPANET simulations. Also, “Sensor

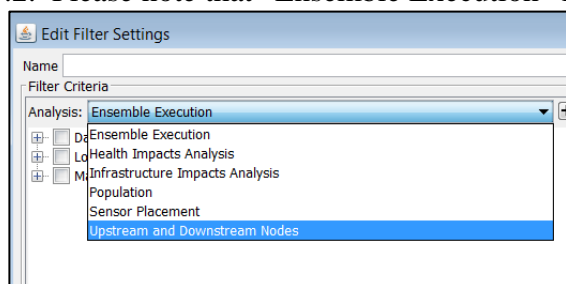


Figure 15.2. Categories for Maps

Placement” is described by SO or sensor objective and the algorithm, which is the Grasp heuristic, in the sensor network design maps.

Example output results from the “Map” tab are provided below for categories (2) through (6). Category (1) “Ensemble Execution” is covered in the “Animation” section.

HEALTH IMPACTS:

Within the “Map” tab, the “Health Impacts Analysis” results are extensive and can appear overwhelming without using the “Filtering” capabilities. The structure of the output results is best described by the “Filtering” capability for health impacts analysis. Using the “Filtering” structure, Figure 15.3 is a screen shot of the “Health Impacts Analysis” mapping options.

Output maps are organized within the “Map” tab by “Data Type” and “Map Type.” Four “Data Type” maps are available:

- “Dosage” – total dosage (by each exposure pathway) for each contaminant injection scenario
- “Dose Over Threshold” – number of people who receive a certain dose or higher
- “Estimated Fatalities” – number of people who receive a lethal dose and are expected to die for each contaminant injection scenario
- “Response” - total number of people who receive a response for each contaminant injection scenario

Two “Map Type” maps are available:

- “Injection Location”
- “Receptor Location”

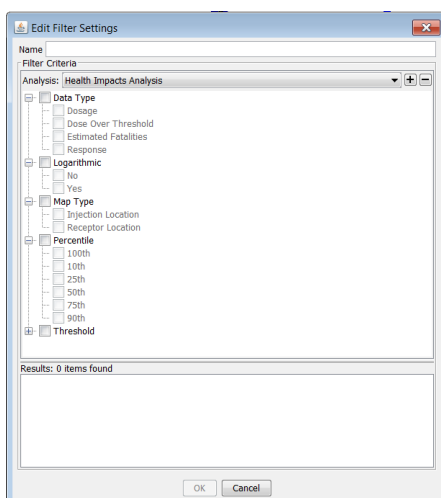


Figure 15.3. Health Impacts Analysis Maps

“Dosage” maps correspond to the total dosage (either by ingestion, inhalation, and/or humidifier use) attributable to each possible injection node. “Dose Over Threshold” maps correspond to consequence

results which have been binned based on the number of people who receive a certain dose or higher into *dose over threshold* bins. “Estimated Fatalities” maps correspond to water users who have received a certain dose and then are predicted to achieve a certain health effect endpoint (e.g., fatality) based on the dose response model and parameters used. “Response” maps depict the total response (e.g., number of individuals who become diseased or die) attributable to each possible injection location.

For the “Dose Over Threshold” map type, the output maps correspond to the “Dose Thresholds” chosen, which are selected from the “Threshold” box(s). For each type of map, output maps are also organized by linear or logarithmic presentation of contaminant threat scenario consequences and ensemble “Percentile” maps corresponding to doses, response, or fatalities. A percentile map represents, for example, a map of consequences for a ranked (e.g., 90th percentile for fatalities) threat scenario or network model release location. Percentile maps illustrate a single contamination threat scenario, with a red square showing the injection location and then color-coded receptor nodes indicating how many people downstream of the injection node receive a certain dose or a certain health effect end point (e.g., fatality).

An example “Dosage” map is shown in Figure 15.4. This “Dosage by Injection Location” map corresponds to an ensemble of contamination events that consists of a contaminant injection of a biological contaminant at all nodes in the network model (i.e., 97 nodes). This map depicts all nodes in the network model that have been color-coded based on the total dosage that would result across the network given an injection of the biological contaminant at the location color-coded. Notice the “Thematic Legend” on the right hand side of the map providing a scale of the total dosage depicted. The top and bottom arrows of the legend can be moved to identify on the map an injection node or nodes that resulted in a particular dosage. “Dosage” maps typically contain very large dosages because each color-coded node represents the total dose that all the potential receptors would receive given the contaminant release at the indicated node.

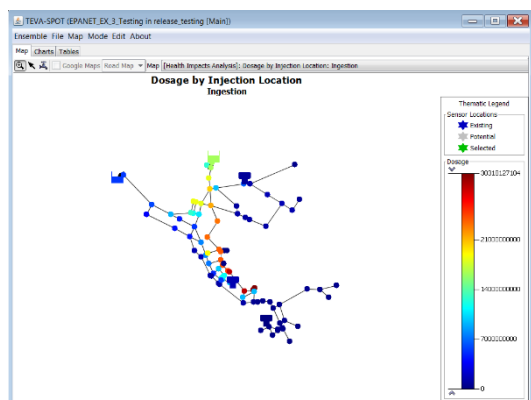


Figure 15.4. Example Dosage by Injection Location Map

An example “Dose Over Threshold” map is shown in Figure 15.5. In this figure, a color-coded map of the number of people who receive an inhalation dose above the indicated value of 1.0E-4 mg due to humidifier use is depicted by injection location. The adjustable “Thematic Legend” is included in the figure to preferentially highlight certain injection node(s) and the consequences that could result given an injection at the particular node.

Figure 15.6 provides an example map of “Estimated Fatalities by Injection Location: Ingestion” due to the ingestion of contaminated tap water. This map appears very similar to that of Figure 15.5, but instead of the number of people above a certain dose being displayed, Figure 15.6 provides the number

of estimated fatalities by injection location. The “Estimated Fatalities by Injection Location” map combines estimates of dose with dose response to predict a health effect endpoint.

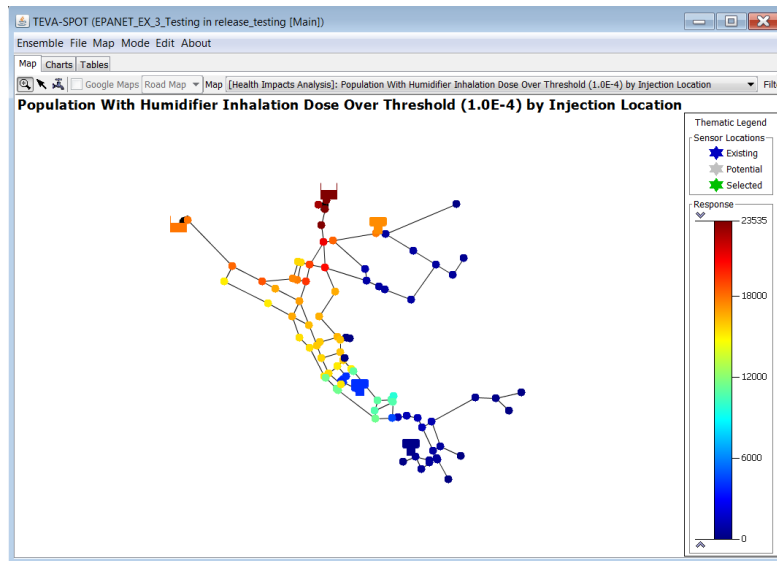


Figure 15.5. Example Dose Over Threshold by Injection Location Map

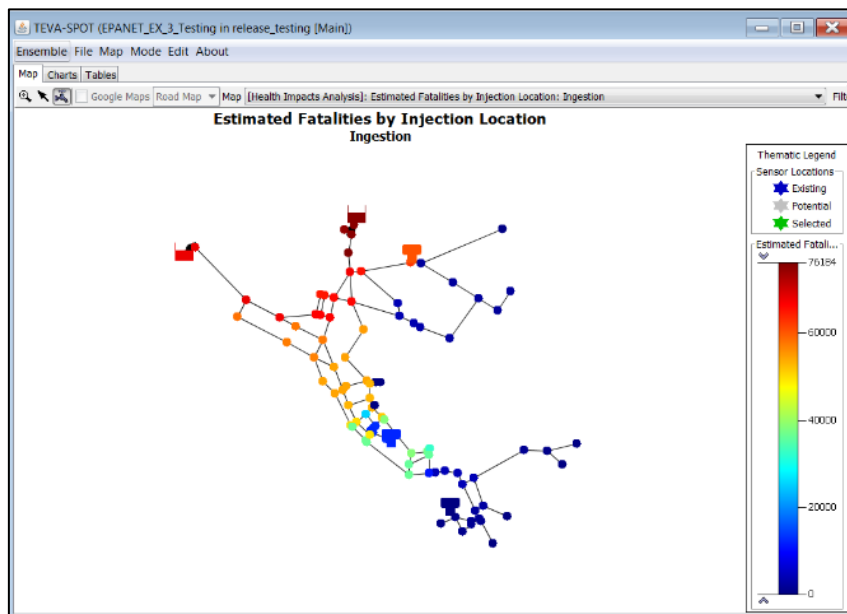


Figure 15.6. Example Estimated Fatalities by Injection Location Map

Figure 15.7 provides an example map of “Response by Injection Location: Ingestion” due to the ingestion of contaminated tap water. The “Response by Injection Location” maps depict the total response (i.e., number of individuals who become diseased or sick) attributable to each possible injection. The data are depicted at the single node where the injection occurs.

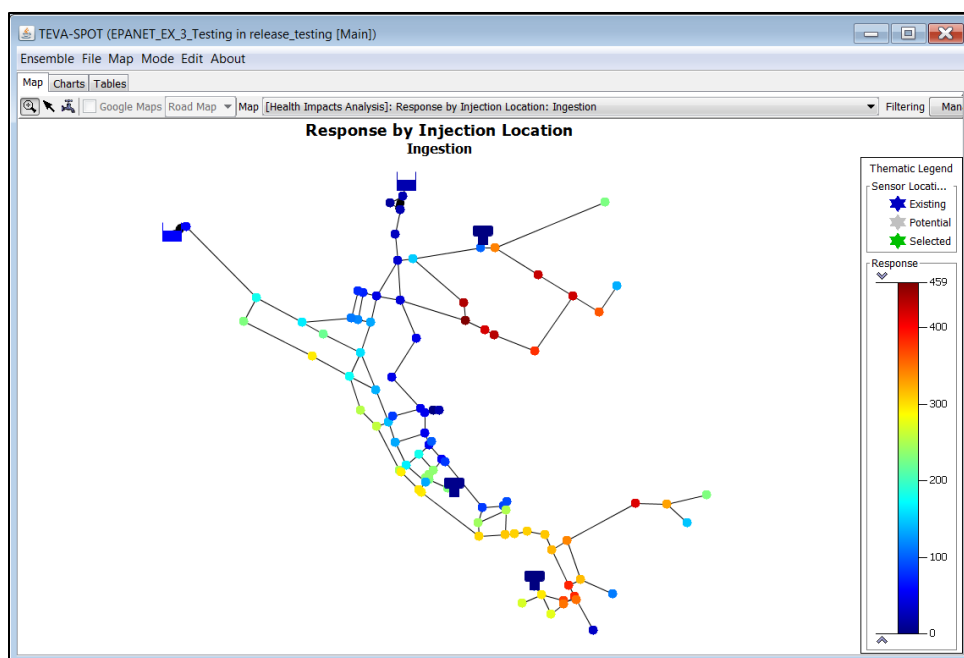


Figure 15.7. Example Response by Injection Location Map

Figure 15.8 provides an example percentile map, titled, “Estimated Fatalities by Receptor Location”. As shown in the figure, this health impacts output map shows a contaminant injection at the red square (labeled as “Source” in the “Thematic Legend”) and a set of receptor nodes colored blue (five) nodes and a red (one) node. The legend indicates that for each *blue receptor node* between 1 and approximately 30 people died. For the one *red receptor node*, it is shown that 121 people died. Maps that depict consequences (e.g., fatalities) by injection location do not show where exposed receptors were impacted; whereas, maps that depict consequences by receptor location show where in the network model exposures, doses, and consequences occurred due to the contaminant injection. Notice in the map header that the map depicts the 90th percentile case (190 estimated fatalities) for an injection of contaminant at node 145. The header also indicates that the contaminant injection was for 24 hours and consisted of 500,000. The “500,000” refers to the contaminant mass injection rate (mg or units of contaminant per minute) that was injected for one day as shown in the associated parentheses “(0 days – 1 day)”.

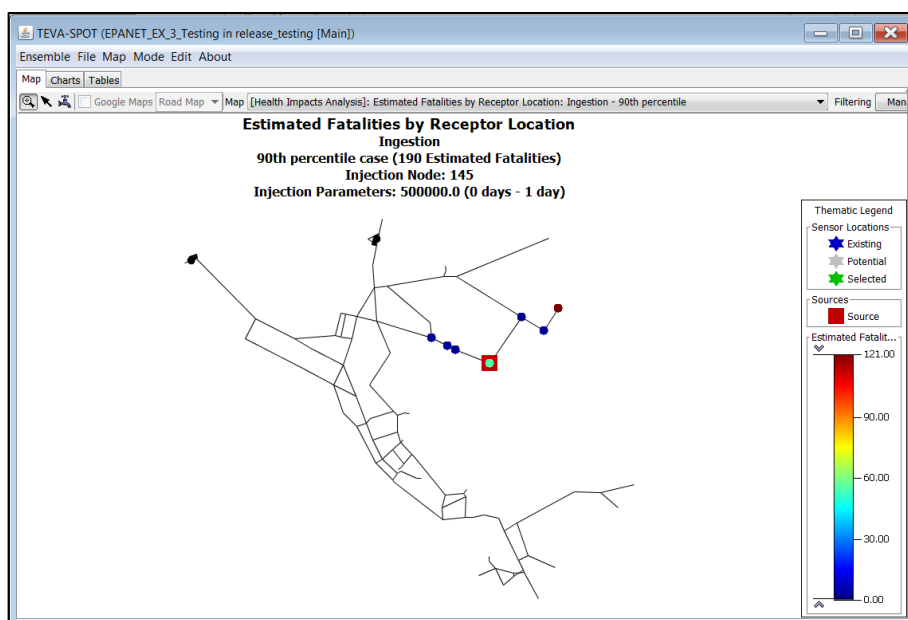


Figure 15.8. Example Estimated Fatalities by Receptor Location Map

INFRASTRUCTURE IMPACTS:

Within the “Map” tab various “Infrastructure Impacts Analysis” maps appear in the drop down menu. The structure of the output results is best described by the “Filtering” capability for infrastructure impacts analysis. Using the “Filtering” structure, Figure 15.9 is a screen shot of the “Infrastructure Impacts Analysis” mapping options. The maps fall into categories based on “Map Type” and “Data Type.” “Map Type” maps display infrastructure impacts based on injection location or receptor location. By “Injection Location” maps display *ensemble* results whereas maps by “Receptor Location” display individual percentile, ranked contamination scenarios. The “Data Type” maps show the basic two data type maps for infrastructure impacts: (1) “Feet of Contaminated Pipe” and (2) number of “Contaminated Pipes.” The “Contaminant Limit” option specifies the criteria for a map to display either the number of feet of contaminated pipe or the number of contaminated pipes. The “Percentile” option specifies the available scenarios that can be examined within the map user interface.

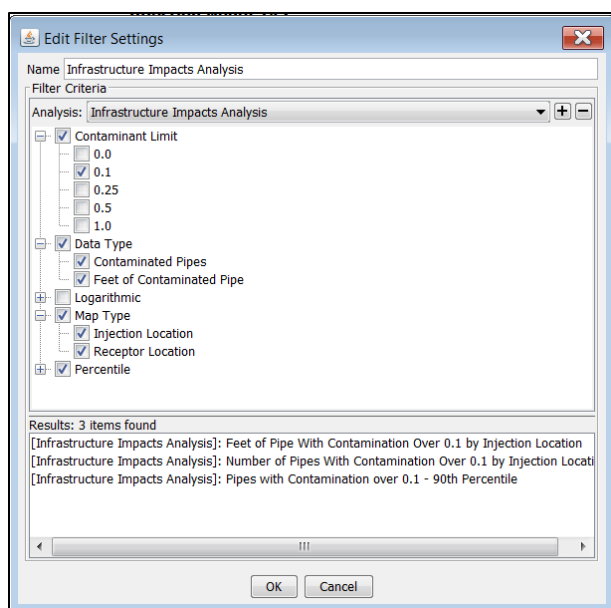


Figure 15.9. Infrastructure Impacts Analysis Maps

Figure 15.10 provides an example map illustrating the infrastructure impacts analysis for “Feet of Pipe with Contamination Over 0.1 by Injection Location.”

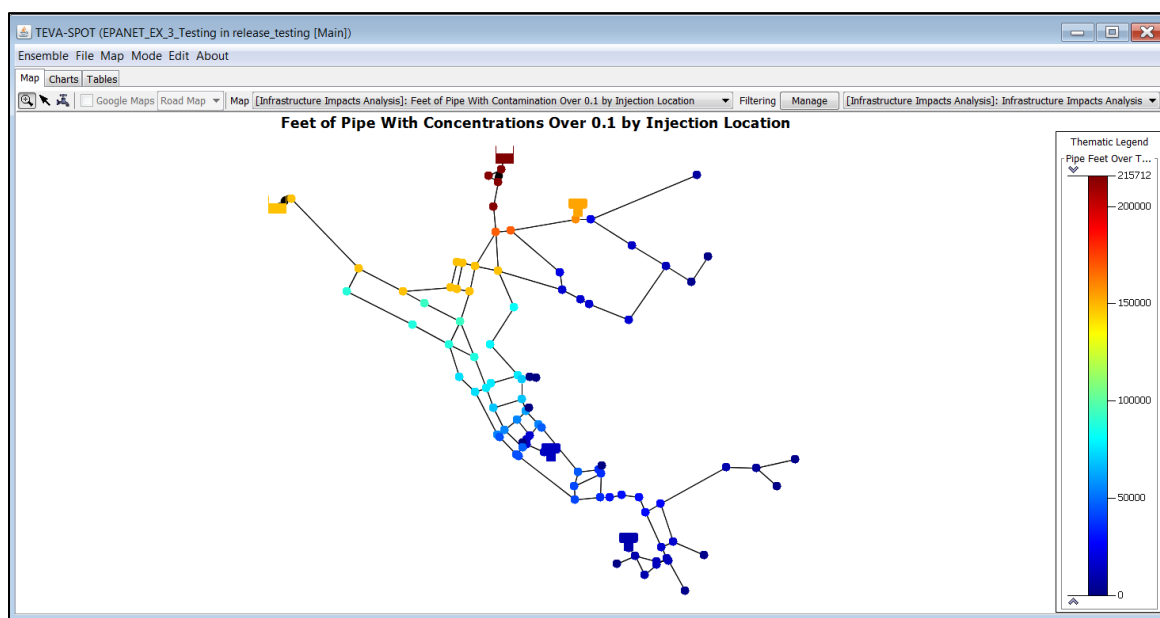


Figure 15.10. Example Feet of Pipe Contaminated by Injection Location

Figure 15.11 provides an example map illustrating the infrastructure impacts analysis for “Number of Pipes with Concentrations Over 0.1 by Injection Location.”

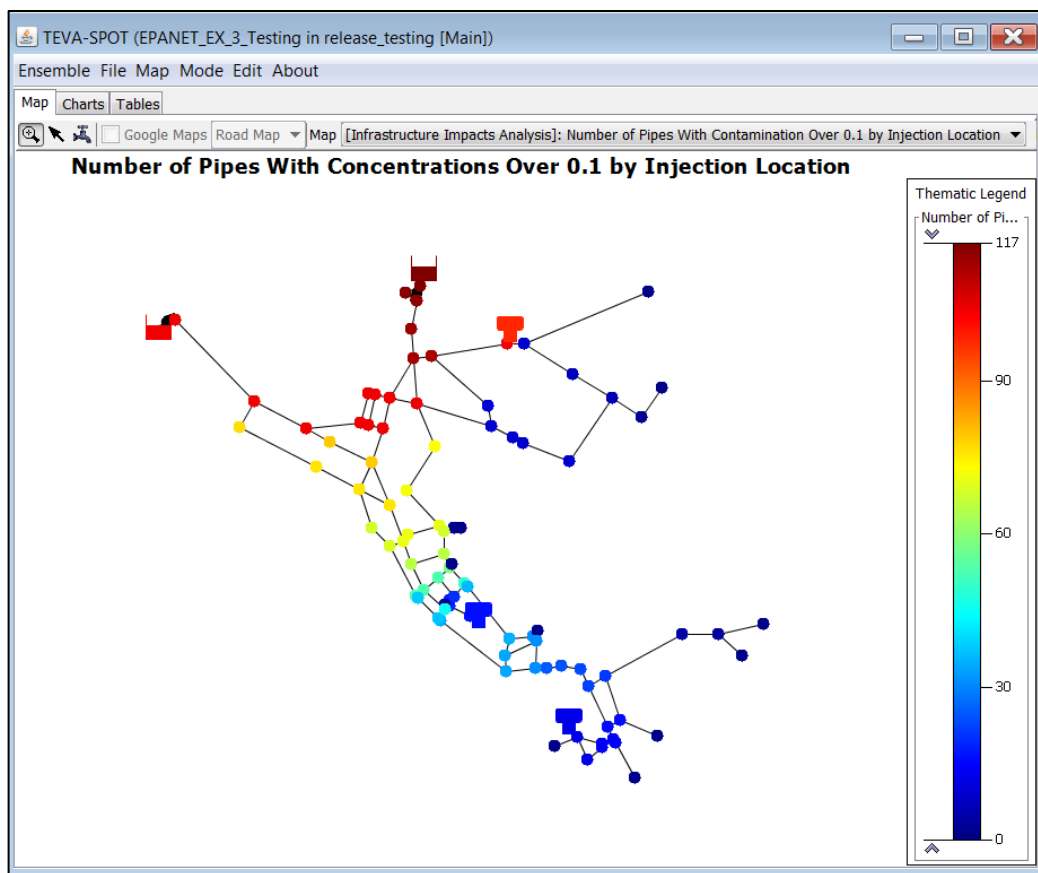


Figure 15.11. Example of Number of Pipes Contaminated by Injection Location

Figure 15.12 provides an example map illustrating the infrastructure impacts analysis for “Pipes with Contamination Over 1.0 – by Receptor Location.” The “by receptor location” refers to pipes that are either witnessing contamination or has adhered contaminants after an injection has occurred at the indicated red square. For maps by receptor location, the map is providing the contamination footprint of a specific contamination scenario, identified here as the 90th percentile threat scenario given contamination limit of 1.0.

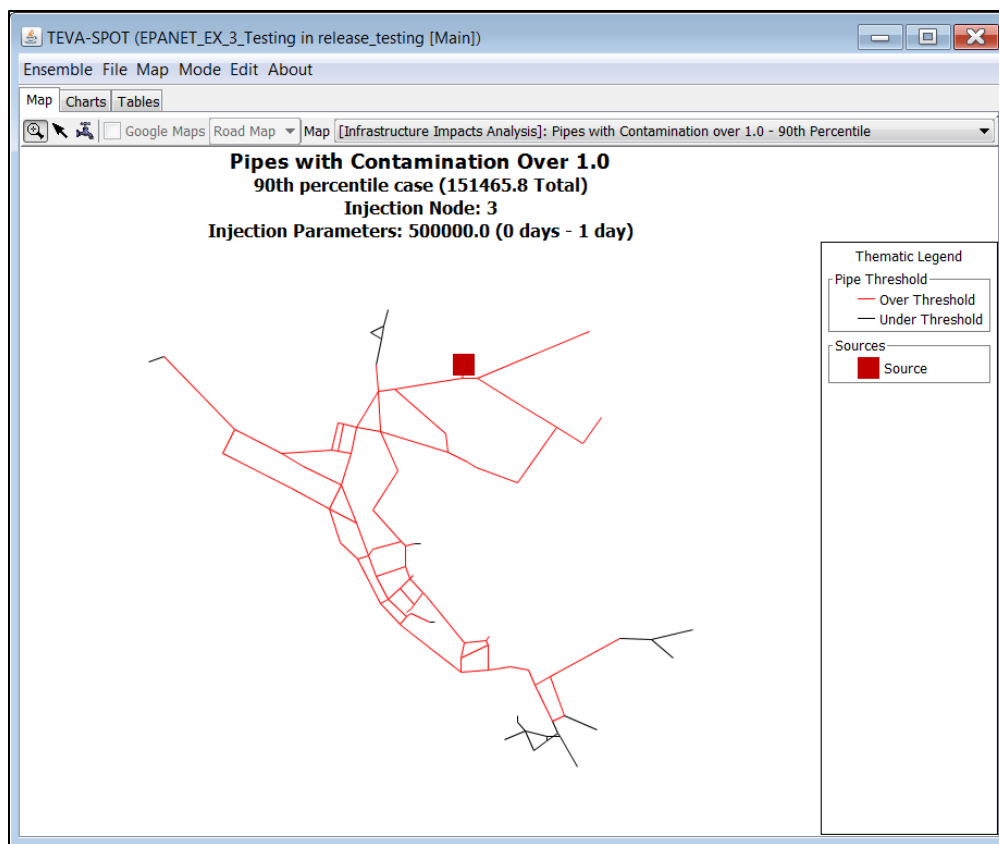


Figure 15.12. Example of Pipes with Contamination Over 1.0 by Receptor Location

POPULATION:

Within the “Map” tab, the user can display a map of the population distribution for the system. Figure 15.13 provides a screen shot of an example “Demand-based Population Estimate.” If the “Census-based” population distribution option is chosen, this population map will reflect the population distribution of the uploaded (census-based) population.

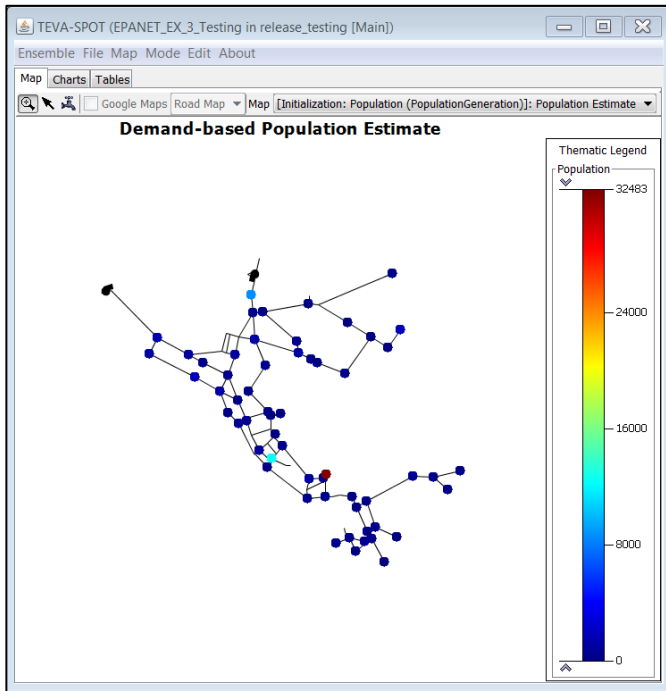


Figure 15.13. Demand-based Population Estimate

Figure 15.14 provides a screen shot of an example “Census-based Population Estimate.” For this example, a text file was imported under the “Initialization: Population” from the “Execution” control panel by choosing “Census-based.” This example census-based population assumed that the population of approximately 78,000 people was evenly divided among the non-zero demand nodes in the network model.

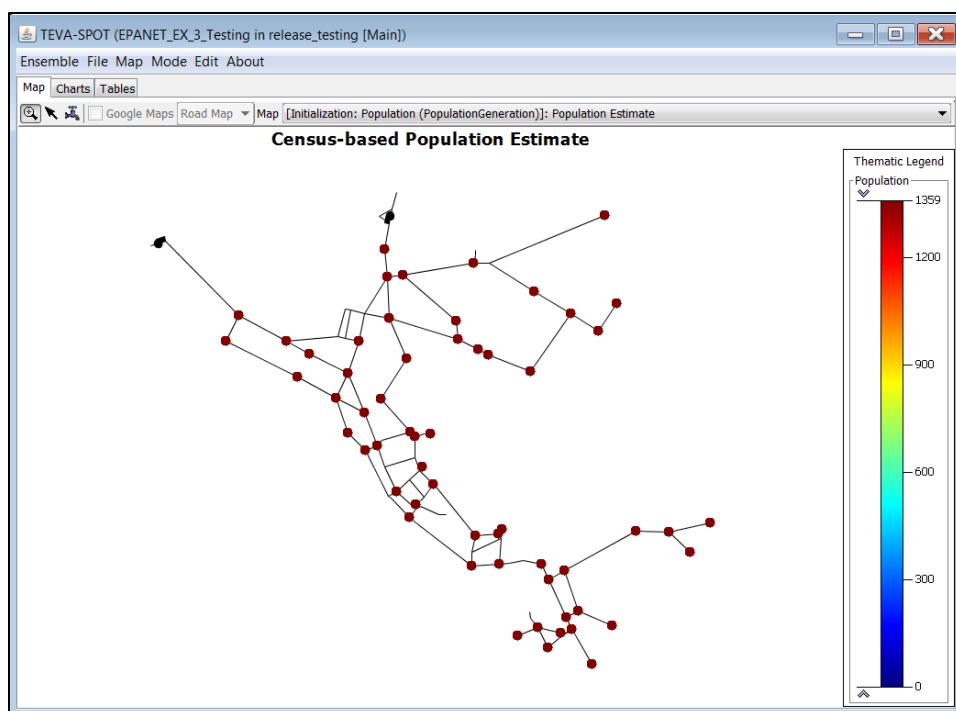


Figure 15.14. Example Census-based Population Estimate

SENSOR PLACEMENT:

Sensor placement network designs appear in the drop down list from within the “Map” tab. The naming structure for each sensor network design is as follows:

“[SOgrasp –NS##-OBxxx_Statistic_Index for dose level if needed_RT_DL##-SMstd]: Map Type,”

where “SO” refers to sensor objective, “NS” is the number of sensors in the sensor network design, “Statistic” is the statistical measure on the impact objective (e.g., mean or worst case), “RT” is response time, “DL” is detection limit, and “SMstd” is a place holder and not in use.

The “Map Type” option consists of “Sensor Counts,” “Sensor Detected Events,” and “Sensor Locations.” The choices within the “Map” tab for sensor placement results are extensive and can appear overwhelming without using the “Filtering” capabilities. The structure of the output results is best described by the “Filtering” capability for Sensor Placement analysis. Using the “Filtering” structure, Figure 15.15 is a screen shot of the “Sensor Placement” mapping options. Output maps are primarily organized for sensor placement within the “Map” tab by “Map Type” and “Objective.”

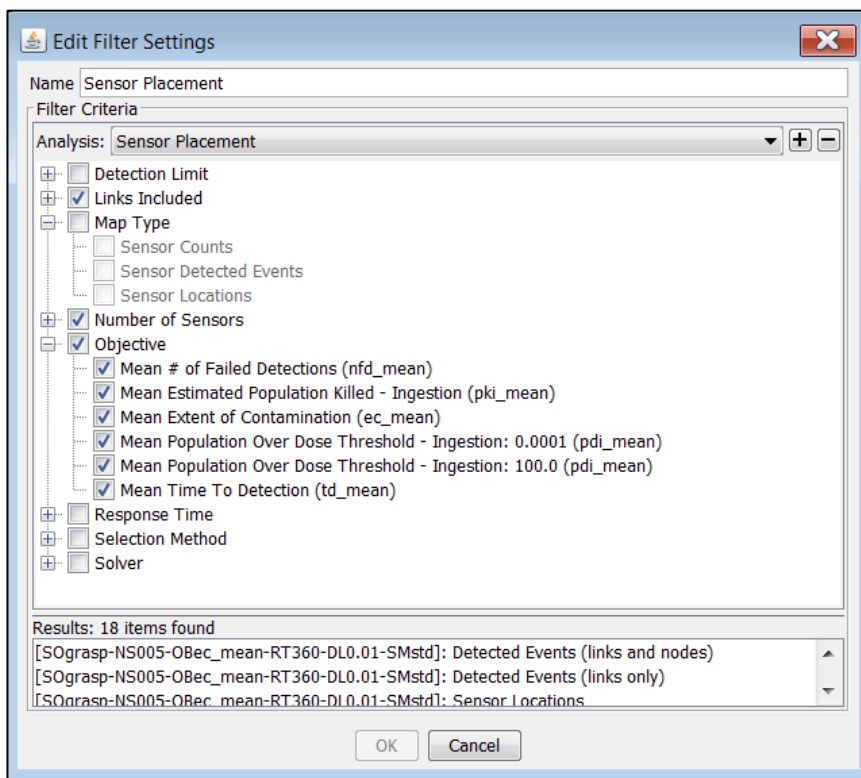


Figure 15.15. Edit Filter Settings – Sensor Placement

Figure 15.16 provides an example “Sensor Event Detection” map for the sensor placement objective

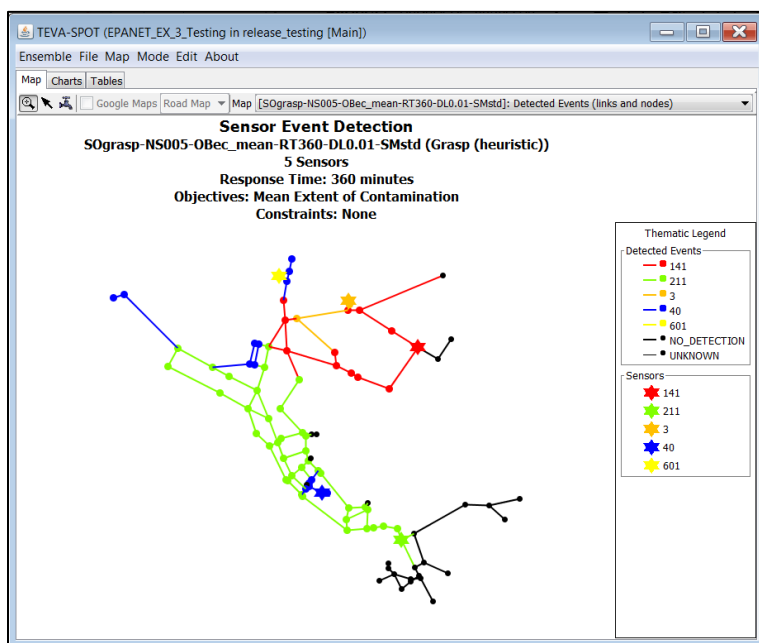


Figure 15.16. Example Sensor Event Detection Map

“Extent of Contamination” or “ec.” Notice that the sensor event detection map shows five sensor monitoring locations that are color-coded with the nodes and links that each sensor is able to detect. Black colored nodes and links indicate that either there was “NO DETECTION” or that detection is “UNKNOWN” – using the “Thematic Legend.” Users can right click on the legend to turn on or off “Detected Events” and/or “Sensors.” “Sensor Event Detection” maps can be either just nodes, just links, or links and nodes.

Figure 15.17 provides an example map for “Sensor Locations.” Similar maps would be available for each combination of objective, statistic, number of sensors, response time, detection limit, and location category.

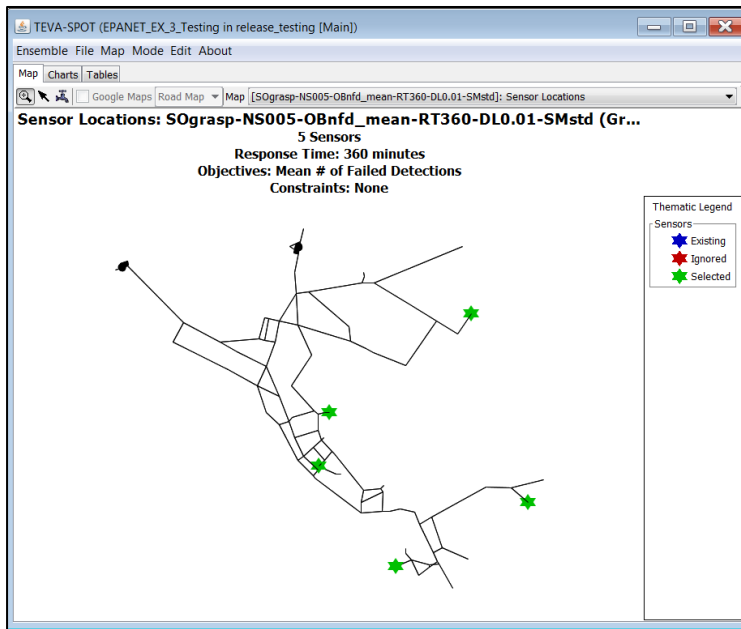


Figure 15.17. Example Sensor Locations Map

Figure 15.18 provides an example of the “Sensor Counts” map. The “Sensor Counts” map provides a color-coded display for which node locations have been chosen for sensor monitoring station placement and the number of times that each node was chosen. A “Sensor Counts” map tallies the number of times a node is chosen for all sensor networks designs that were developed.

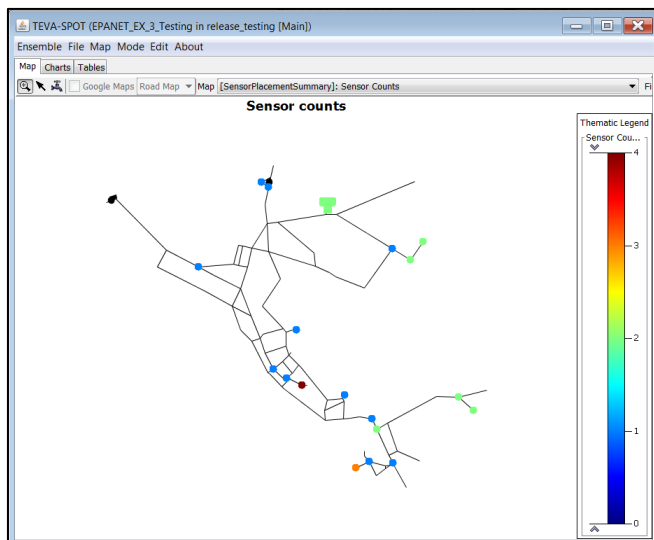


Figure 15.18. Example Sensor Counts Map

UPSTREAM AND DOWNSTREAM NODES:

Using the “Manage” and “Filtering” capabilities, the map options for “Upstream and Downstream Nodes” are shown Figure 15.19. Basically, four types of maps are available after running the “Upstream and Downstream Nodes” module. These four types consist of: (1) Dead-end Nodes, (2) Downstream Node Count, (3) Downstream Population, and (4) Upstream Node Count. All dead-end and downstream and upstream node maps are based on the hydraulic simulation performed. In these examples, the simulation length was used, which was 24 hours.

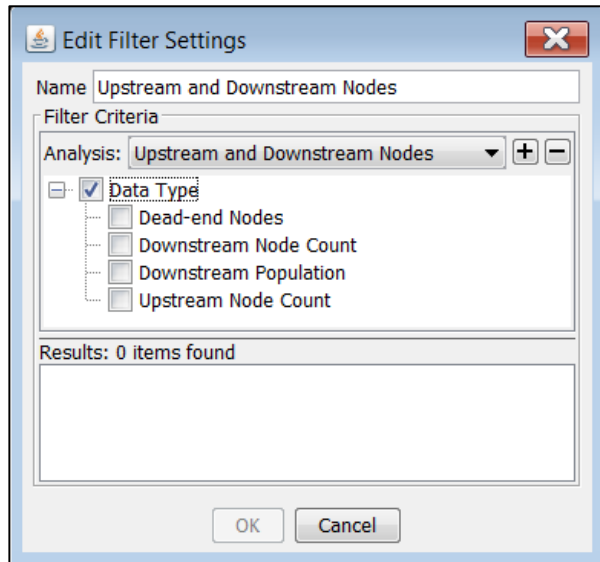


Figure 15.19. Edit Filter Settings – Upstream and Downstream Nodes

Figure 15.20 provides a screen shot of an example “Dead-end Nodes” map. Nodes are color-coded blue if they are not dead-end nodes and red if they are dead-end nodes.

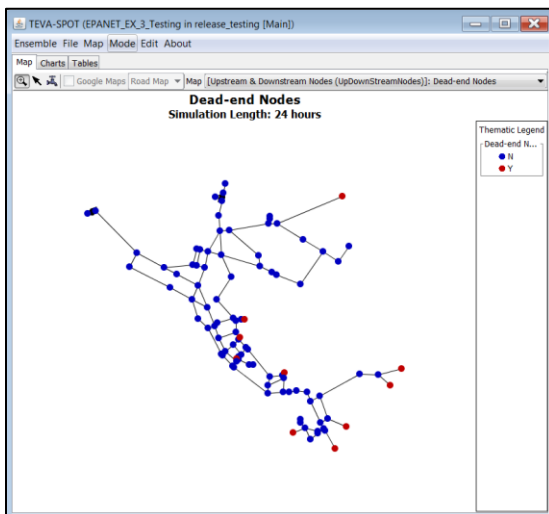


Figure 15.20. Example Dead-end Nodes Map

Figure 15.21 provides a screen shot of an example “Downstream Node Count” map. A “Downstream Node Count” map provides a color scale indicating how many nodes are downstream of each colored node in the map.

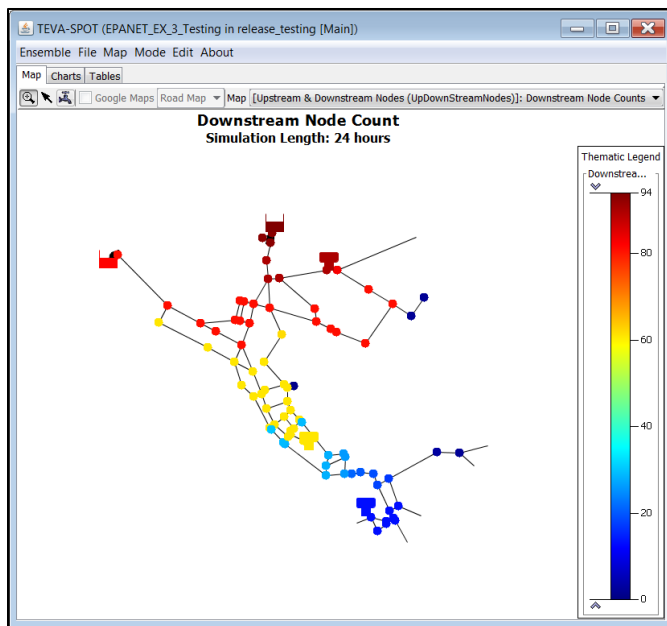


Figure 15.21. Example Downstream Node Count

Figure 15.22 provides a screen shot of an example “Downstream Population” map. Similar to the “Downstream Node Count” map, the “Downstream Population” map provides a color scale showing how many people are connected *downstream* of the indicated node.

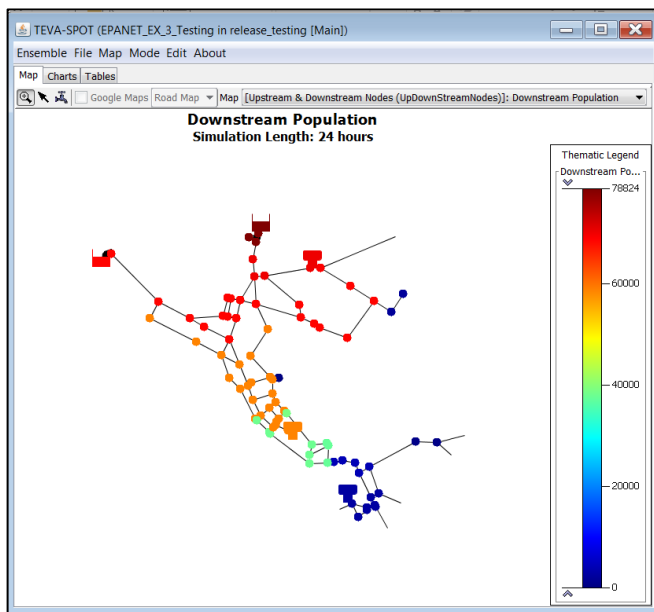


Figure 15.22. Example Downstream Population Map

Figure 15.23 provides a screen shot of an example “Upstream Node Count” map. In “Upstream Node Count” maps, nodes are color-coded based on the number of nodes that are *upstream* of each colored node.

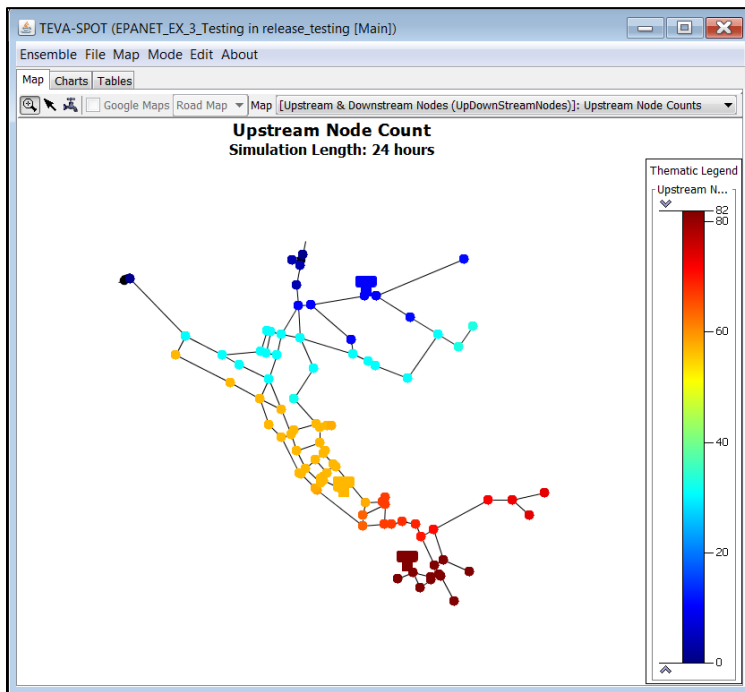


Figure 15.23. Example Upstream Node Count

15.2 Charts

The “Charts” tab provides the user with a wide variety of health impacts analysis charts. Using the “Manage” and “Filtering” capabilities, Figure 15.24 provides the charts options available to the user. The choices available will be dependent on the health impact analyses performed. Three types of charts are available: (1) “Cumulative Distribution,” (2) “Histogram,” and (3) “Time Series.”

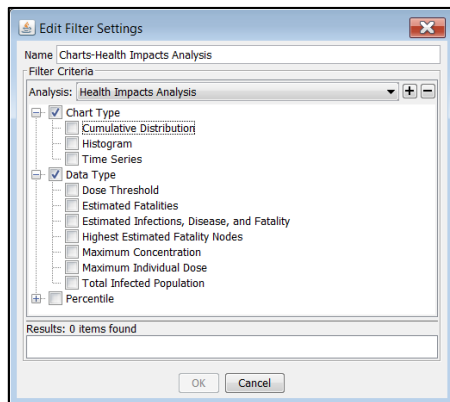


Figure 15.24. Edit Filter Settings: Charts-Health Impacts Analysis

CUMULATIVE DISTRIBUTION:

For cumulative distribution plots, there are two basic choices. The “Consequences versus Dose Level” plots are for dose level based consequences and the “Estimated Fatalities Cumulative Distribution” plots are for dose response based consequences.

Figure 15.25 provides a screen shot of an example “Cumulative Distribution” chart for dose level based consequences for the exposure pathway of humidifier use. For these charts, prescribed percentile based consequences are plotted against dose levels (thresholds).

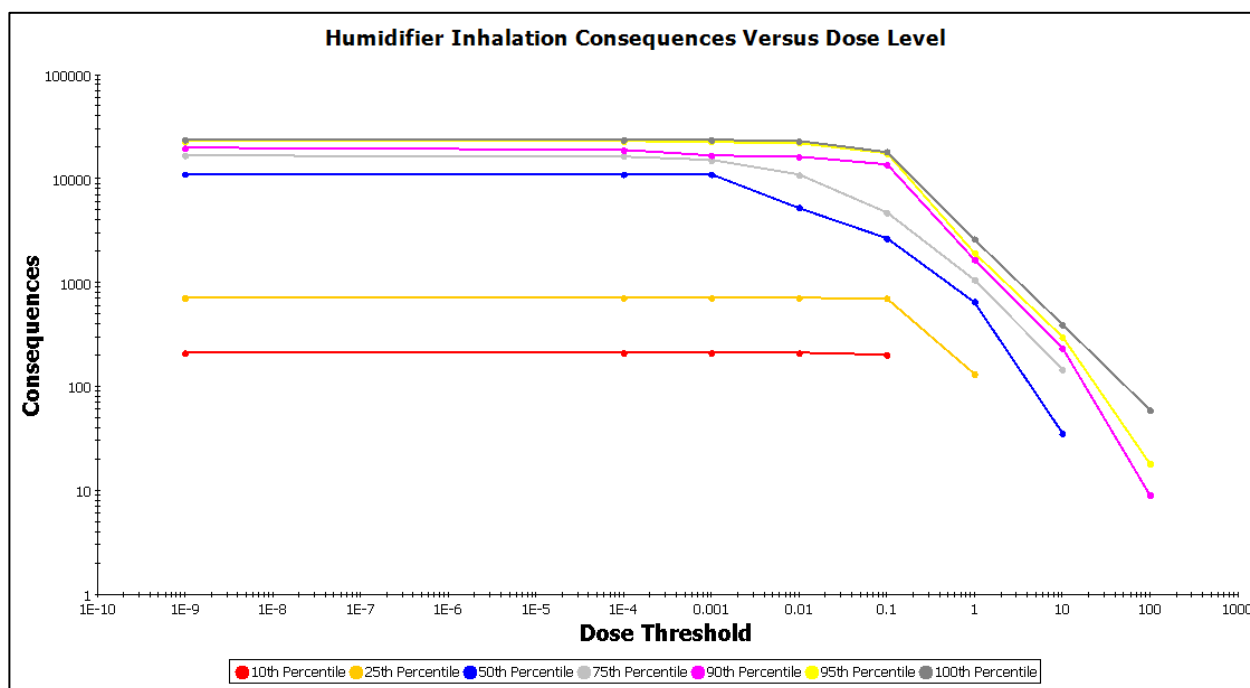


Figure 15.25. Example Cumulative Distribution Chart – Dose Threshold vs Consequences

Figure 15.26 shows an example “Cumulative Probability Distribution” plot for showering inhalation health impacts. In these types of plots, “Estimated Fatalities” are plotted on the x-axis versus their probability on the y-axis.

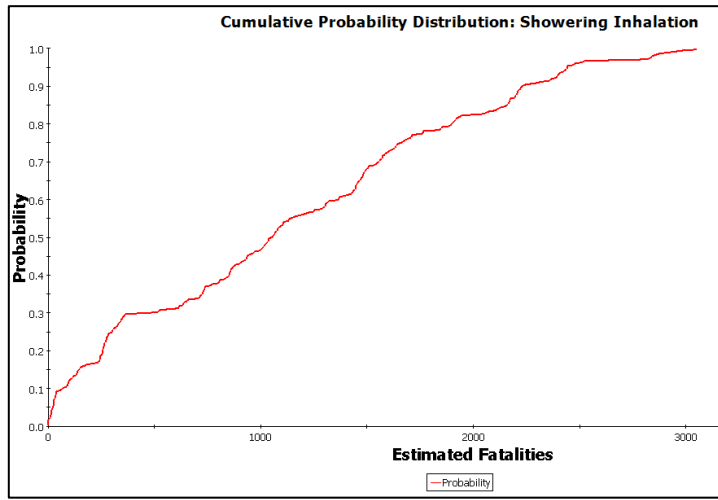


Figure 15.26. Example Cumulative Probability Distribution Chart

HISTOGRAM:

The number of histogram charts available for analysis and evaluation can be quite large. Depending on exposure pathways being simulated, histogram plots will consist of the following:

- Maximum concentration by contamination scenario
- Highest estimated fatality nodes by scenario
- Maximum individual dose by scenario
- Total estimated fatalities by scenario and total estimated infected/ill population by scenario

Here “Scenario” refers to the ensemble of contamination scenarios evaluated. The relationship between total estimated fatalities and total estimated infected or ill population is determined by the “Fatality Rate” in the “Edit Health Impacts Analysis Parameters” panel.

Figure 15.27 provides an example histogram plot for the “Maximum Concentration by Contamination Scenario” option.

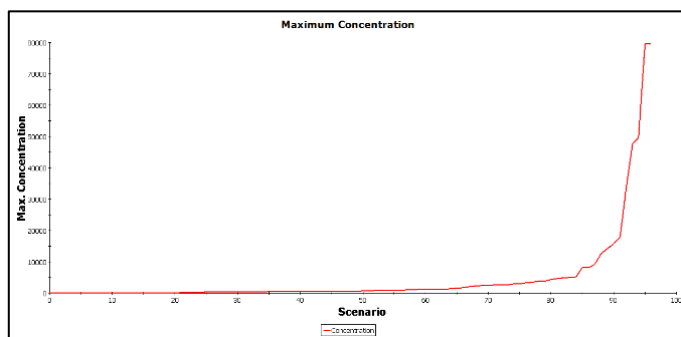


Figure 15.27. Example Maximum Concentration Chart

Figure 15.28 provides an example chart for the “Highest Estimated Fatality Nodes by Scenario,” which is the name for plot from the pull down menu in the “Charts” tab. The plot title is “Nodes Required to Provide 90% of Total Estimated Fatalities,” which provides the number of nodes by contamination scenario that are required to produce 90% of the total estimated fatalities for the simulation. For example, the ten scenarios between scenarios 45 and 55 in the plot each had five receptor nodes that provided at least 90% of the total fatalities estimated for each of these injection nodes or scenarios.

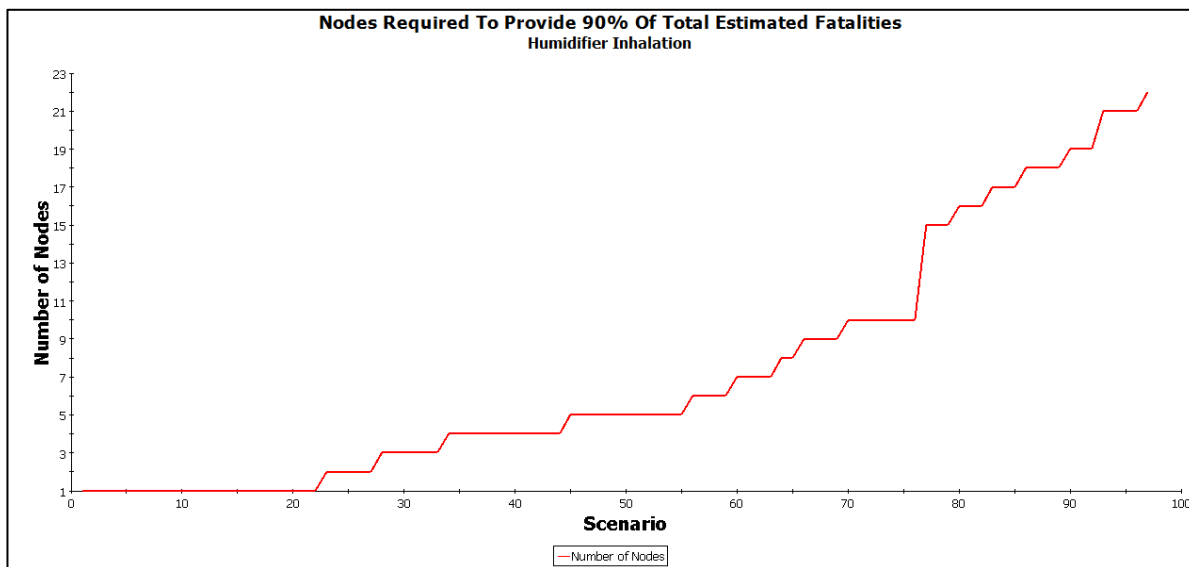


Figure 15.28. Example Chart - Highest Estimated Fatality Nodes By Scenario

Figure 15.29 provides an example chart for “Maximum Individual Dose by Scenario” option. This example is for the humidifier exposure pathway and plots the maximum dose received by a receptor versus the contamination scenario.

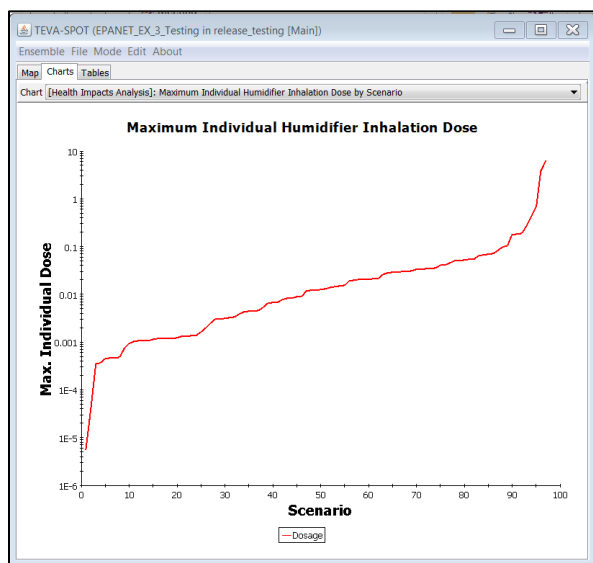


Figure 15.29. Example Chart – Maximum Individual Dose By Scenario

The relation between total estimated diseased, ill, and fatalities is a function of the dose response parameters (e.g., fatality rate). Figure 15.30 provides an example chart for the “Total Infected Population by Scenario” for the ingestion of tap water exposure pathway.

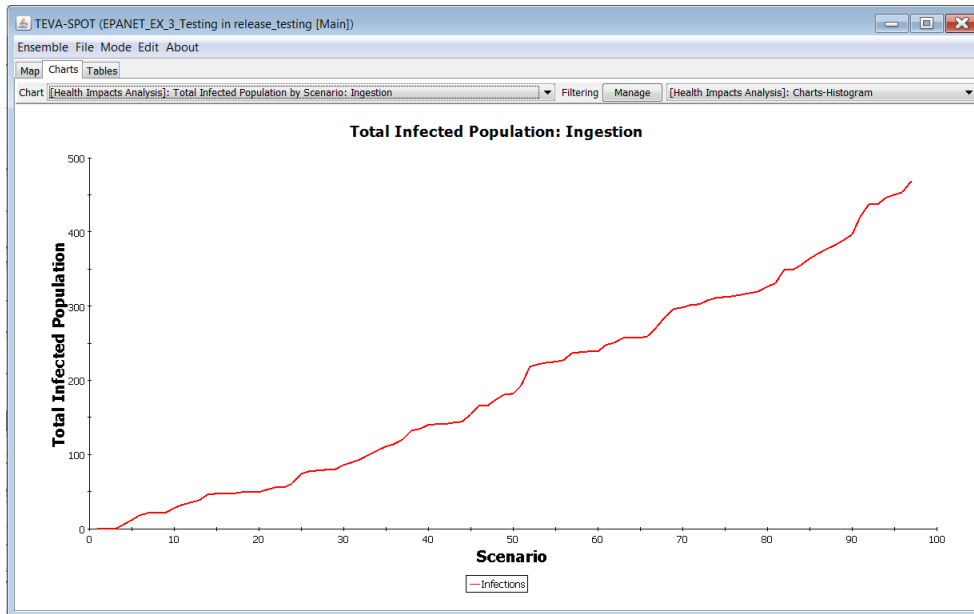


Figure 15.30. Example Chart - Total Infected Population by Scenario

TIME SERIES:

Within the “Charts” tab, potentially numerous plots can be created as a result of performing a health impacts analysis. Figure 15.31 shows, using the “Filtering” capability within the “Charts” tab, the potentially available options. Two examples of “Data Types” of these time series charts, specifically fatalities and infections and disease and fatalities, are provided.

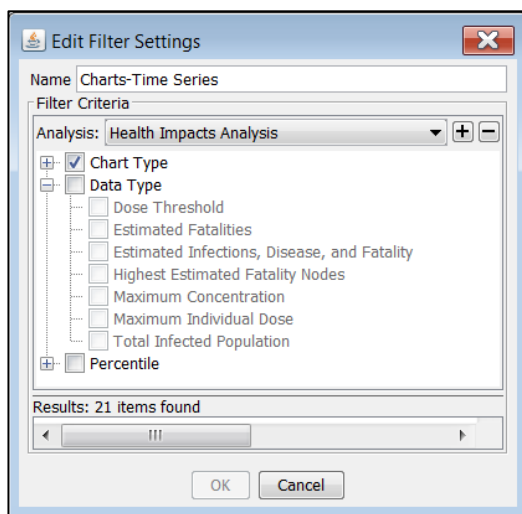


Figure 15.31. Edit Filter Settings – Time Series Charts

Figure 15.32 provides an example chart for the “Average Estimated Showering Inhalation Fatalities by Time” option. Here, average estimated fatalities are plotted against time of the simulation. Average fatalities is determined from the ensemble of contamination threat scenarios.

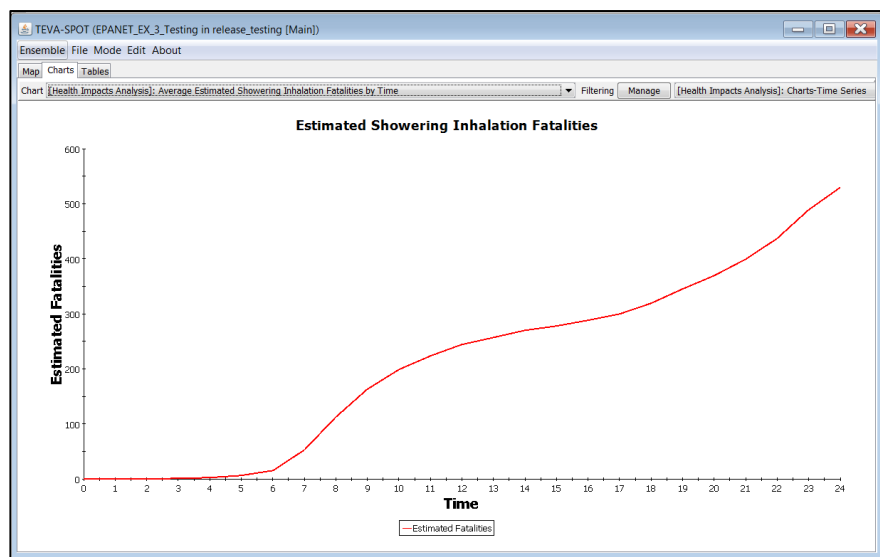


Figure 15.32. Example Chart – Estimated Showering Inhalation Fatalities by Time

Figure 15.33 provides an example chart showing “Estimated Showering Inhalation Infections, Disease, and Fatalities by Time – 100th Percentile Case” option. This plot shows, using color coded graphs, how estimated infections, estimated diseased individuals, and estimated fatalities develop over time. This plot, and other plots like it, also give critical information (e.g., injection node, injection parameters, and total number of fatalities).

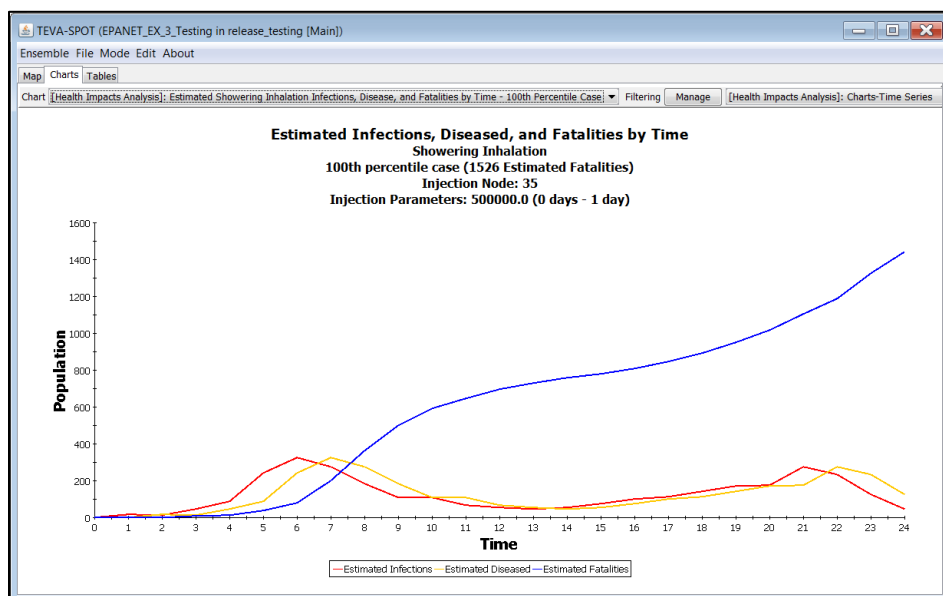


Figure 15.33. Example Chart – Estimated Infections, Diseased, and Fatalities by Time

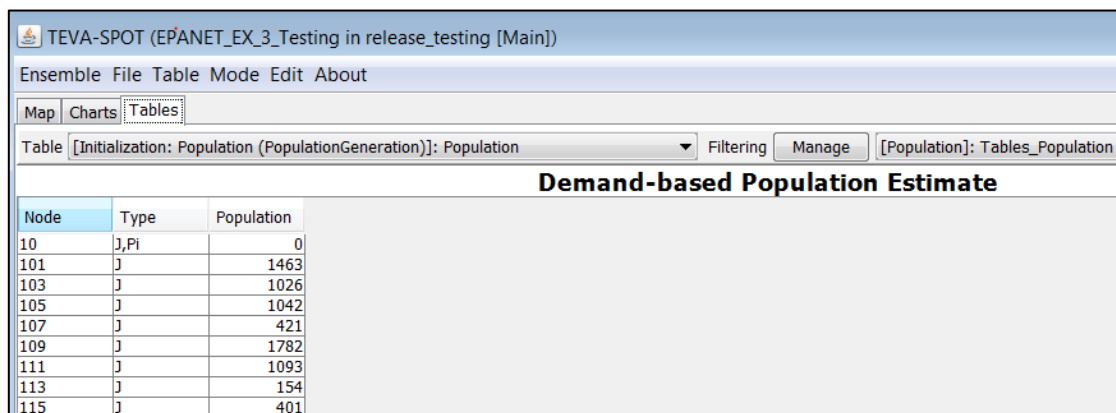
15.3 Tables

The number of tables created in TEVA-SPOT-GUI can be quite extensive. Tables are created by each module within TEVA-SPOT-GUI, specifically: (1) population, (2) up and downstream node and their associated population analyses, (3) health impacts analysis, (4) infrastructure impacts analysis, and (5) sensor placement. Generally, all the data from maps and charts are available in tabular form from either the “Tables” tab within the user interface or are available within the particular ensemble folders of the TEVA-SPOT-Database.

POPULATION TABLES:

Two population tables are created consisting of: (1) “Summary Population Statistics” and (2) “Node Identification (ID) Name Versus Number of People.” For each table, the table header specifies the population model (e.g., demand-based and census-based). The “Summary Population Statistics” table provides statistics on the population consisting of mean, median, 95th percentile, 99th percentile, and 100th percentile. The “Node ID Versus Number of People” table provides a node-by-node accounting for all potential receptors located at non-zero demand nodes in the network model. Included in this table is a middle column which specifies the type of node. Types of nodes include: Junctions (J), Junctions-Valves (J,Ve), Junction- Pumps (J, Po is start node and J,Pi is end node), Reservoir (R), Tank (T), or Junction connected to tank (J,Tc) or Junction connected to Reservoir (J, R).

Figure 15.34 provides a screen of an example table for “Demand-based Population Estimate”.



TEVA-SPOT (EPANET_EX_3_Testing in release_testing [Main])

Ensemble File Table Mode Edit About

Map Charts **Tables**

Table [Initialization: Population (PopulationGeneration)]: Population Filtering Manage [Population]: Tables_Population

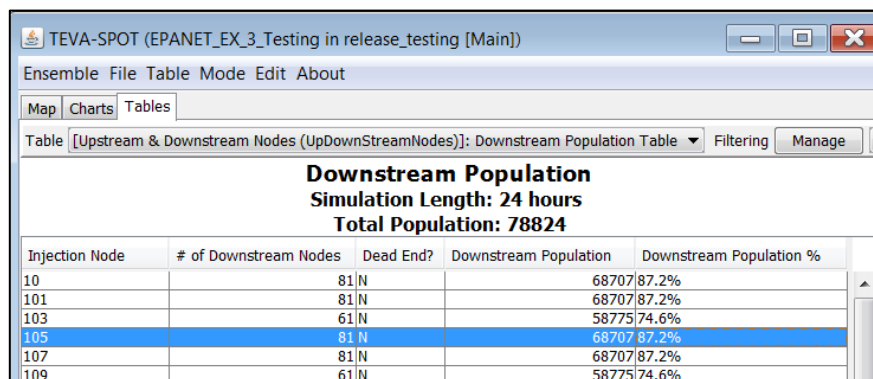
Demand-based Population Estimate		
Node	Type	Population
10	J,Pi	0
101	J	1463
103	J	1026
105	J	1042
107	J	421
109	J	1782
111	J	1093
113	J	154
115	J	401

Figure 15.34. Screen shot of example table for population

UPSTREAM AND DOWNSTREAM TABLES:

Three types of tables are available following an upstream analysis: (1) “Upstream Node Counts,” “Dead end Nodes,” and “Downstream Population.” The “Upstream Node Counts” table provides a two-column list of injection node versus number of upstream nodes. Included in the header of the table is the simulation length (hrs.) used. The “Dead end Nodes” table provides a listing of dead-end nodes. The “Downstream Population” table provides four columns consisting of (1) injection node ID, (2) number of downstream nodes, (3) “Y” or “N” as to whether the node is a dead-end, (4) downstream population, and (5) downstream population percentage. Included in the header of the table is the simulation length (hours) used.

Figure 15.35 provides an example table for “Downstream Population”.



TEVA-SPOT (EPANET_EX_3_Testing in release_testing [Main])

Ensemble File Table Mode Edit About

Map Charts Tables

Table [Upstream & Downstream Nodes (UpDownStreamNodes)]: Downstream Population Table Filtering Manage

Downstream Population
Simulation Length: 24 hours
Total Population: 78824

Injection Node	# of Downstream Nodes	Dead End?	Downstream Population	Downstream Population %
10	81	N	68707	87.2%
101	81	N	68707	87.2%
103	61	N	58775	74.6%
105	81	N	68707	87.2%
107	81	N	68707	87.2%
109	61	N	58775	74.6%

Figure 15.35. Example table for downstream population

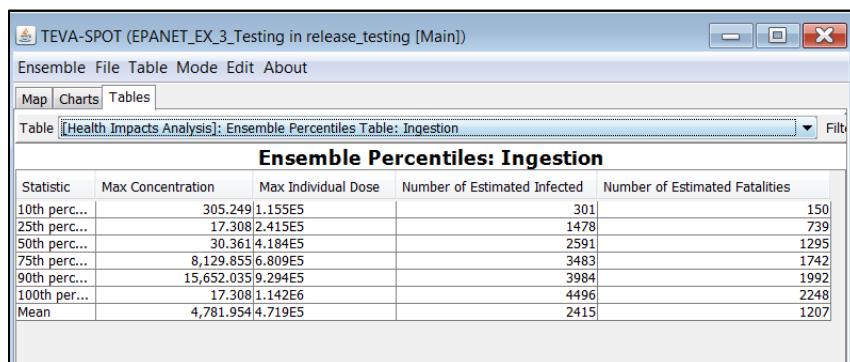
HEALTH IMPACTS ANALYSIS TABLES:

Numerous tables of health impacts analysis results are potentially created within the user interface after a “Health Impacts Analysis” execution. The number of tables created will depend on which exposure pathways are simulated and whether all the analyses are selected within each exposure pathway. Tables are exposure pathway specific. Not all tables are available for all exposure pathways. In the following paragraphs, each type of table will be described.

ENSEMBLE PERCENTILES [EXPOSURE PATHWAY] TABLE

- Exposure pathways: Ingestion, inhalation during showering, and humidifier use
- Consequences (total number of people impacted) for percentile scenarios of 10th, 25th, 50th, 75th, 90th, 100th, and mean
- Impacts are dose response model based and include estimated infected/ill and fatalities
- Also includes maximum concentration and maximum individual dose observed for each percentile scenario

Figure 15.36 provides a screen shot of an example table for “Ensemble Percentiles: Ingestion”.



TEVA-SPOT (EPANET_EX_3_Testing in release_testing [Main])

Ensemble File Table Mode Edit About

Map Charts Tables

Table [Health Impacts Analysis]: Ensemble Percentiles Table: Ingestion Filtering

Ensemble Percentiles: Ingestion

Statistic	Max Concentration	Max Individual Dose	Number of Estimated Infected	Number of Estimated Fatalities
10th perc...	305.249	1.155E5	301	150
25th perc...	17.308	2.415E5	1478	739
50th perc...	30.361	4.184E5	2591	1295
75th perc...	8,129.855	6.809E5	3483	1742
90th perc...	15,652.035	9.294E5	3984	1992
100th per...	17.308	1.142E6	4496	2248
Mean	4,781.954	4.719E5	2415	1207

Figure 15.36. Example table for ensemble percentiles - ingestion

ESTIMATED FATALITIES [EXPOSURE PATHWAY] TABLE

- Exposure pathways: Ingestion, inhalation during showering, and humidifier use
- Receptor fatalities by node ID for each of percentile scenarios of 10th, 25th, 50th, 75th, 90th, 100th, and mean

[EXPOSURE PATHWAY] INJECTION IMPACTS TABLE

- Summary Table: [Exposure Pathway]
- For each injection scenario (rows), columns of results include: maximum concentration, maximum individual dose, number of infected or ill people, number of fatalities, number of nodes required to achieve 90% of fatalities, and number of nodes with fatalities

[EXPOSURE PATHWAY] DOSE OVER THRESHOLD SUMMARY TABLE

- Left most column is ensemble statistic (i.e., 10th, 25th, 50th, 75th, 90th, 100th, and mean)
- Remaining columns are user specified dose thresholds
- Results are number of people who exceeded threshold specified in each column

[EXPOSURE PATHWAY] DOSE OVER THRESHOLD BY SOURCE LOCATION TABLE

- Exposure pathways: Ingestion, inhalation during showering, and humidifier use
- Columns from left to right: iteration number, Injection Node ID, Injection Definition, Node Type, and remaining columns user specified dose levels or thresholds.
- Results are number of people who exceed dose threshold for each injection scenario

[EXPOSURE PATHWAY] RELATIVE CONTRIBUTION BY SOURCE LOCATION TABLE - DOSE THRESHOLD

- Exposure pathways: Ingestion, inhalation during showering, and humidifier use
- Dose threshold-based tables (i.e., a table for each threshold or dose level specified)
- User-define dose levels and number of bins are used to breakdown population of receptors who received a dose greater than threshold according to bins
- Each bin represents a fraction (e.g., 0.2-0.3 or 20%-30%) of the total population that received the dose in a single event or major exposure event

[EXPOSURE PATHWAY] CT OVER THRESHOLD BY SOURCE LOCATION TABLE

- Exposure pathways: inhalation during shower and humidifier use
- Concentration (mg/m³) times Time (s) or CT with units of mg-s/m³
- Column headings (from left to right) include: Iteration, Injection Node, Injection [definition], and Node Type. Remaining column headings are CT thresholds
- Results are number of people who exceed the column CT threshold

[EXPOSURE PATHWAY] SEPARATE C AND T RESULTS FOR CONCENTRATION

- Exposure pathways: inhalation during shower and humidifier use
- Utilizes user defined bins for shower/humidifier duration (min): both number and size
- Utilizes user defined bins for shower/humidifier air concentration (mg/m³): both number and size
- A separate table is created for each air concentration
- Left most header rows are: Iteration, Injection Node, Injection [definition], and Node Type, while the remaining header columns are durations (min)
- Results are number of people that receive a certain air concentration and the duration they receive it

[EXPOSURE PATHWAY] SEPARATE C AND T RESULTS FOR DURATION

- Exposure pathways: inhalation during shower and humidifier use
- Utilizes user defined bins for shower/humidifier duration (min): both number and size
- Utilizes user defined bins for shower/humidifier air concentration (mg/m³): both number and size
- A separate table is created for each duration
- Left most header rows are: Iteration, Injection Node, Injection [definition], Node Type, while the remaining header columns are durations (min)
- Results are number of people that receive a certain air concentration within the duration they receive it

INFRASTRUCTURE IMPACTS ANALYSIS TABLES:

Four tables are created in the user interface after executing the “Infrastructure Impacts Analysis” module. These are “Percent of Pipe Feet over Threshold by Pipe Diameter,” “Pipe Feet over Threshold by Pipe Diameter,” “Percent of Pipe Feet over Threshold,” and “Pipe Feet over Threshold.”

PERCENT OF PIPE FEET OVER THRESHOLD CONCENTRATION BY PIPE DIAMETER

- Table created for each user specified contaminant threshold concentration
- Columns headings include: Injection Node ID, “Total” (pipe feet), and columns for pipe diameters, with each such column including parenthetical of how many pipe feet the diameter represents across the distribution system
- Each row represents a scenario (injection node) identified with its contaminant spread in terms of percentage (%) pipe feet given the threshold for contaminant concentration specified

PIPE FEET OVER THRESHOLD CONCENTRATION BY PIPE DIAMETER

- Table created for each user specified contaminant threshold concentration
- Column headings include: Injection Node ID, “Total” (pipe feet), and columns for pipe diameters, with each such column including parenthetical of how many pipe feet the diameter represents across the distribution system
- Each row represents a scenario (injection node) identified with its reach of percentage (%) pipe feet given threshold contaminant concentration

PERCENT OF PIPE FEET OVER THRESHOLD CONCENTRATION

- One table with results by injection location

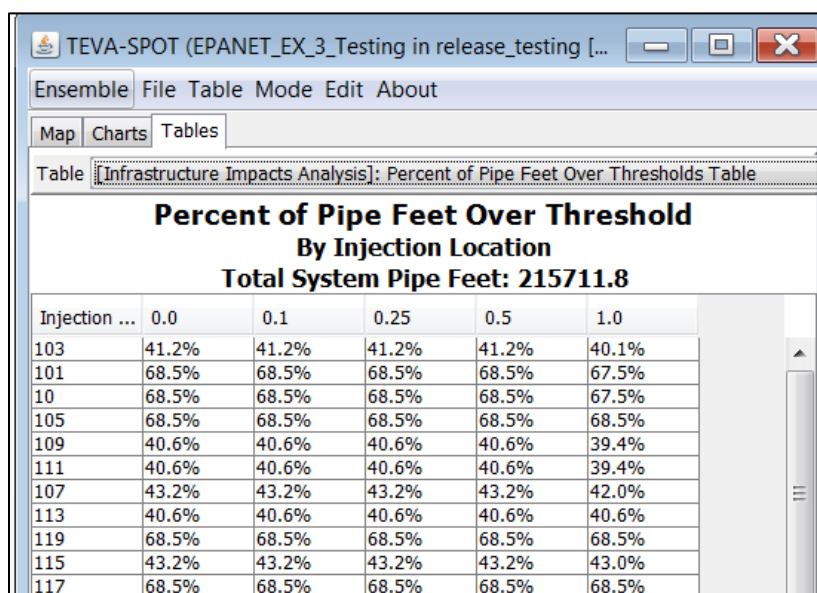
- Column headings include: Injection Node ID and user specified contaminant threshold concentrations
- Results are percentages of pipe feet over column threshold

PIPE FEET OVER THRESHOLD CONCENTRATION

- One table with results by injection location
- Column headings include: Injection Node ID and user specified contaminant threshold concentrations
- Results are pipe feet over column contaminant threshold concentrations

Figure 15.37 is an example table for the “Percent Of Pipe Feet Over Threshold – By Injection Location”. Thresholds are concentration of contaminant in mg/L.

SENSOR PLACEMENT TABLES:



Injection ...	0.0	0.1	0.25	0.5	1.0
103	41.2%	41.2%	41.2%	41.2%	40.1%
101	68.5%	68.5%	68.5%	68.5%	67.5%
10	68.5%	68.5%	68.5%	68.5%	67.5%
105	68.5%	68.5%	68.5%	68.5%	68.5%
109	40.6%	40.6%	40.6%	40.6%	39.4%
111	40.6%	40.6%	40.6%	40.6%	39.4%
107	43.2%	43.2%	43.2%	43.2%	42.0%
113	40.6%	40.6%	40.6%	40.6%	40.6%
119	68.5%	68.5%	68.5%	68.5%	68.5%
115	43.2%	43.2%	43.2%	43.2%	43.0%
117	68.5%	68.5%	68.5%	68.5%	68.5%

Figure 15.37. Example table for percent of pipe feet over contaminant concentration thresholds

Numerous tables are potentially created within the user interface after a “Sensor Placement” execution. The number of tables created will depend on how many sensor network designs are created and executed. Many of the tables are sensor network design specific. In the following paragraphs, each type of table will be described.

ALL SENSORS TABLE

- Column headings include: sensor network design name and sensor locations identified as Node IDs
- Each sensor location or Node ID has an accompanying “S” or “E” enclosed in brackets (i.e., [S] or [E]). [S] means *Selected* by the optimization algorithm and [E] means that was *Existing* or rather *fixed* location identified by the user

SENSOR COUNTS TABLE

- Column headings include: sensor IDs (Node ID) and the number of times the Node ID was selected considering all the sensor network designs created

SENSOR PLACEMENT SUMMARY TABLE

- Column headings include: sensor network design name, solver (GRASP), response time, detection limit, number of sensors, cost (always zero), objective identifier and objective statistic (e.g., pe_mean), constraints, and location category
- Results are contained in columns starting with number of attacks (Num Attacks), minimum impact (Min Impact), mean impact, lower quartile, median, upper quartile, VaR, TCE, and maximum impact (Max Impact)

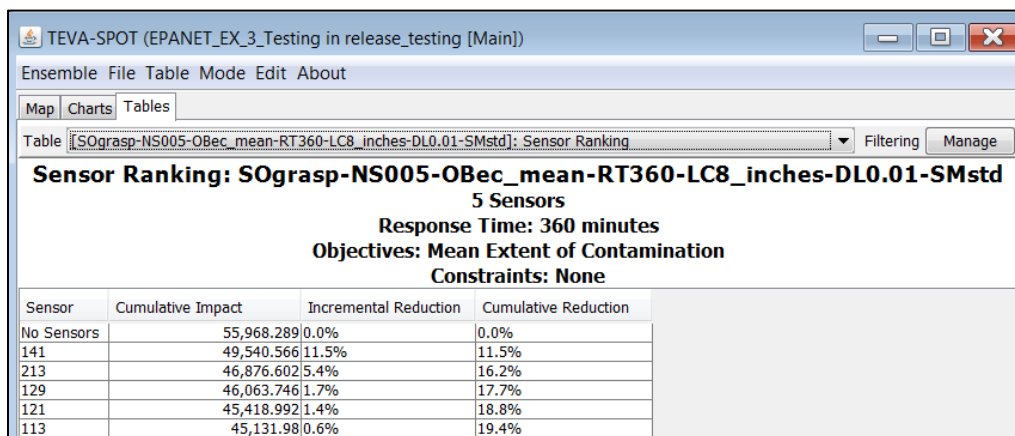
TRADE-OFF ANALYSIS DATA

- Column headings include: sensor network design name, solver (GRASP), number of sensors, objective (full descriptive name, e.g., “Mean Estimated Population Killed – Ingestion”), objective ID (e.g., pe), response time, constraints, location category, Cost [NA], detection limit, and selection method – standard (placeholder)
- Results are people impacted given the objective defined

SENSOR NETWORK DESIGN SPECIFIC TABLES

- Two types of tables: Impacts and Detection Time Table and Sensor Ranking Table
- These two tables are created for each sensor network design evaluated (i.e., the total number of tables is equal to two times the number of sensor network designs created)
 - [Sensor Network Design]: Impacts and Detection Time
 - Column headings include: Injection Node ID, Detected by [Node ID], Detection Time [minutes], and Impacts [#]
 - [Sensor Network Design]: Sensor Ranking Table
 - Column headings include: Sensor [Node ID], Cumulative Impact, Incremental Reduction [%], and Cumulative Reduction [%]

Figure 15.38 provides an example sensor ranking table.



Sensor	Cumulative Impact	Incremental Reduction	Cumulative Reduction
No Sensors	55,968.289	0.0%	0.0%
141	49,540.566	11.5%	11.5%
213	46,876.602	5.4%	16.2%
129	46,063.746	1.7%	17.7%
121	45,418.992	1.4%	18.8%
113	45,131.98	0.6%	19.4%

Figure 15.38. Example table for sensor ranking

16. Filtering and Organizing Results

TEVA-SPOT-GUI provides the user with options for filtering and organizing simulation and output results. Output products (i.e., maps, charts, and tables) are displayed in TEVA-SPOT-GUI'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.

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. Figure 16.1 provides a screen shot of the “Filtering Controls.”



Figure 16.1. Filtering Controls

Click the “MANAGE” button and the “DISPLAY OPTIONS FILTER MANAGEMENT” dialog box opens (Figure 16.2). Click the “ADD” button in the “DISPLAY OPTIONS FILTER MANAGEMENT” dialog box and a new box opens titled, “EDIT FILTER SETTINGS” opens (Figure 16.3).

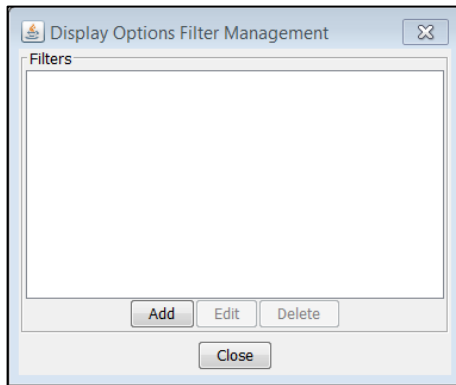


Figure 16.2. Filtering Controls - Manage

The “Edit Filter Settings” box allows the user to construct and save a filtering scheme according to the four groups of results: (1) Ensemble Execution, (2) Health Impacts Analysis, (3) Population, and (4) Sensor Placement (Figure 16.4). The four options are available from the drop down menu next to “Analysis:.”

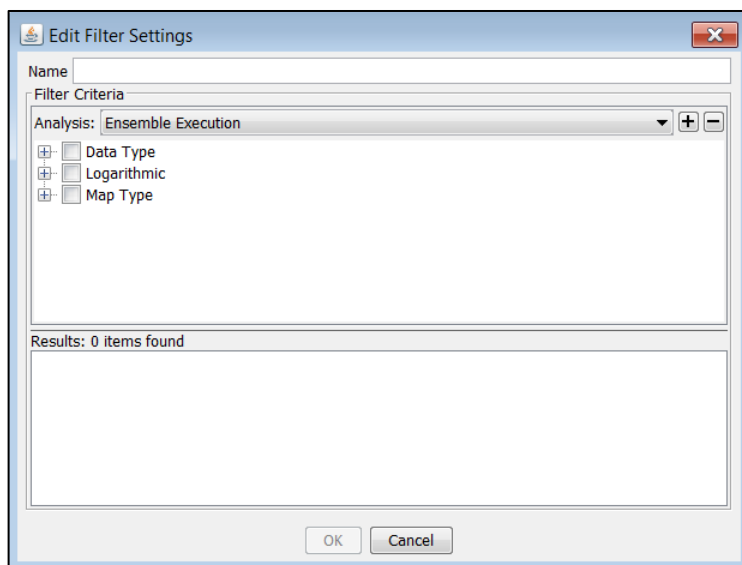


Figure 16.3. Edit Filter Settings

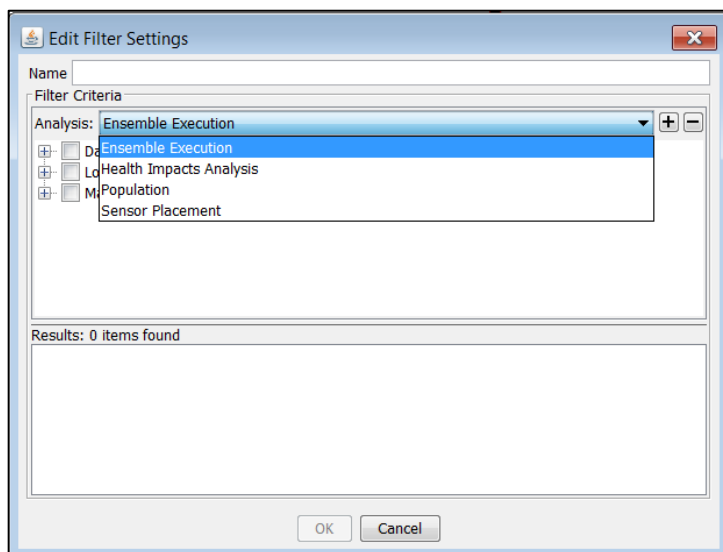


Figure 16.4. Edit Filter Settings – Filter Results Categories

17. Animation

Animation of EPANET water quality simulation results can be viewed in the user interface by choosing the “Map” tab and then selecting under “[EPANET Simulations (BaseEnsemble)]: Concentration Animation” results by either: (1) “Links Only,” (2) “Nodes & Links,” or (3) “Nodes Only.” A screen shot of the “Map” tab and the choices for viewing animation results is shown in Figure 17.1.

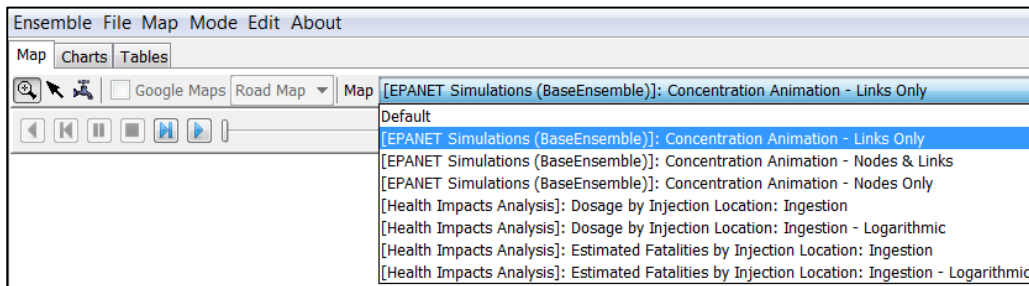


Figure 17.1. Animation Options

Once a particular option is chosen (as shown in Figure 17.2), the user will be presented with options to view animations by injection node. As can also be seen, controls are available to advance the simulation either by one time step at a time or continuous advance of the simulation.

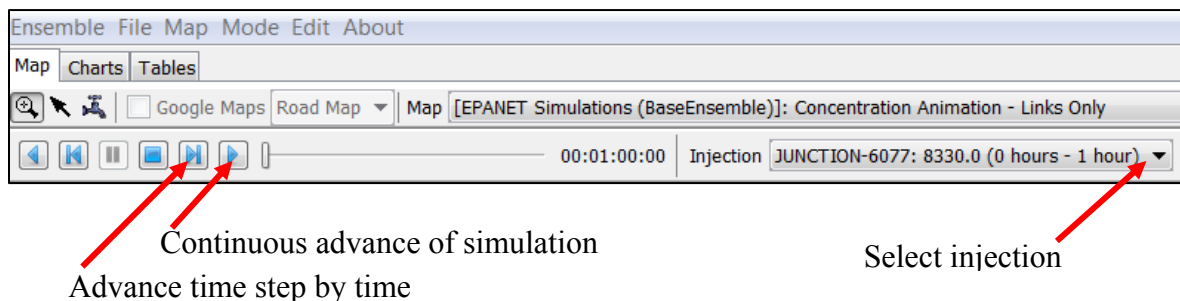


Figure 17.2. Animation – Links Only

Figure 17.3 provides an example illustration of an animation after choosing “Links Only.”

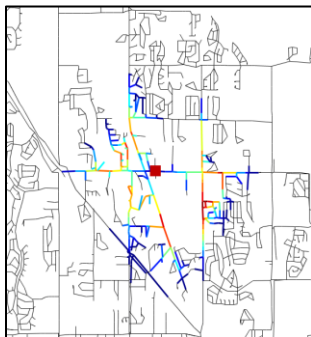


Figure 17.3. Example Illustration – Links Only Animation

18. Quality Assurance and Quality Control

TEVA-SPOT-GUI has several quality assurance (QA) features that a user can utilize to decrease errors and to improve the accuracy of the results. The three most important features are:

- Use of description boxes
- Running “Perform Mass Balance Analysis”
- Removing potentially problematic contamination scenarios using “Injection Location Exclusions”

Description boxes are available within various modules of TEVA-SPOT-GUI to allow the user to add additional information to describe the purpose and scope of the analysis. For example, within the “Injection Definition” box the user can enter descriptive or derivative information about the contaminant being modeled. Such information could be pertinent to the mass injection rate being used. This description is in addition to the contaminant name specified both in the “Injection Definition” and within the “Health Impacts Analysis” module. A more complete description of the ensemble as well as the consequence assessment and sensor network design being developed can be outlined in the description box associated with the “Ensemble Options” box.

It is highly recommended that sufficient documentation be included in the various description boxes to enable a quick and easy recognition of the simulations in case the documentation is needed months or years after execution.

For EPANET INP files (models) that do not run in EPANET without errors or warnings, the user is advised to investigate the errors and warnings. The user might also want to click the box “Perform Mass Balance Analysis” within the “Ensemble Options” dialogue box and run the mass balance analyses. Figure 18.1 is a screen shot from TEVA-SPOT-GUI displaying the “Perform Mass Balance Analysis” check box. Checking this box will enable the mass balance analyses to run when the “EPANET Simulations” module is run.

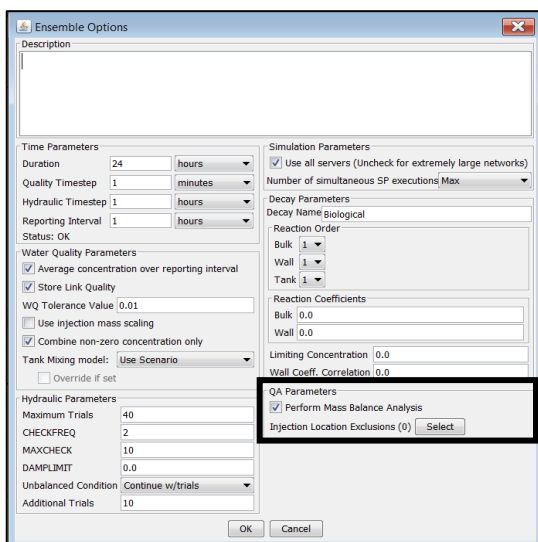


Figure 18.1. Perform Mass Balance Analysis

The results of the mass balance analyses will appear as text (.txt) files within the “BaseEnsemble” directory, for instance within:

C:\TEVA-SPOT-Database\ENSEMBLE_COLLECTION\YOUR_ENSEMBLE\BaseEnsemble.

Additionally, two other mass balance text files will appear in “BaseEnsemble” folder:

(1) massDataRatio.[ENSEMBLE_NAME]

(2) massData.[ENSEMBLE_NAME]

The file “massDataRatio[ENSEMBLE_NAME]” is a text file with data that can be opened with either a text editor or Microsoft® Excel. It provides the results of a mass balance analysis for each contamination scenario executed within the “EPANET Simulations” module. The file “massDataRatio[ENSEMBLE_NAME]” contains a table with six columns of data:

- Column 1 specifies the contamination scenario or node ID
- Column 2 reports the ratio of mass removed to mass injected (i.e., (mass removed + mass in pipes + mass in tanks)/mass injected)) for each contamination scenario
- Columns 3 through 6 detail the mass of contaminant injected, removed, in tanks, and in pipes, respectively, at the end of the simulation

The mass balance analysis results used to create the table of mass removed to injected ratios is contained in the file “massData.[ENSEMBLE_NAME].” Within this file are the complete mass balance results for each contamination scenario and for each time step of the simulation. The “massData.[ENSEMBLE_NAME]” file is composed of:

- A header row describes the contents of each column.
- Column 1 specifies the node ID of the contamination scenario
- Column 2 specifies the type or category of data that appears in columns 3 through n . Four categories of data are associated with each contamination scenario: (1) mass removed, (2) mass injected, (3) mass in pipes, and (4) mass in tanks
- Columns 3 through n provide the mass balance data associated with each contamination scenario and category of data at each time step of the simulation
- The table has been automatically constructed to show those scenarios (node IDs) that have the highest ratio of mass removed to mass injected first

The contamination scenarios (node IDs) that have a ratio greater than 1.1 or less than 0.9 should be investigated further. For more information on investigating such scenarios, the user is referred to the paper “Mass imbalances in EPANET water-quality simulations” [19]. For those contamination scenarios that have a ratio greater than 1.1 or less than 0.9, a text file (.txt) maybe be created from the file “massDataRatio.[ENSEMBLE_NAME]” file. The resulting text file must be formatted to contain a

single column of node IDs corresponding to those nodes that will be eliminated from the ensemble as injection nodes. The resulting file is saved to a suitable location and then uploaded through the “Select” box associated with “Injection Location Exclusions” box within the “Ensemble Options” dialogue box (Figure 18.1).

Some trouble shooting tips for using TEVA-SPOT-GUI are provided in the next subsections. In Section 18.1, some trouble shooting tips for ensuring that TEVA-SPOT-GUI is running properly are described. In Section 18.2, some information about the numerous log files that are created by TEVA-SPOT-GUI are provided to help identify potential problems.

18.1 Execution

The uncertainty as to whether TEVA-SPOT-GUI is operating properly after clicking “Execute” can sometimes be difficult to ascertain to the user. It is important that the network model (INPfile) first be run and examined in EPANET to identify any problems. For example, if the INP file has STOP for the unbalanced hydraulic condition and the system is unbalanced, TEVA-SPOT-GUI will fail.

The following checks can be performed to determine if TEVA-SPOT-GUI is operating or has malfunctioned or frozen up and, therefore, should be terminated.

- Examine the “DOS Command” box open associated with TEVA-SPOT-GUI. Visually inspect the DOS screen looking for the keyword “Severe.” If “Severe” appears in the “DOS Command” window box, there is a problem that will need to be investigated. Choose “Restart TEVA-SPOT Services” program available from the START Menu under TEVA-SPOT. Close TEVA-SPOT-GUI and investigate the problem.
- During EPANET simulations, check to ensure that a temporary hydraulic file has been created within one or more of the “server” folders (e.g., C:\Program Files\TEVA-SPOT\Server\Server-1). Also, check to make sure no error files (error.txt) appear in the same folder (e.g., the “Server-1” folder).
- Be sure there is sufficient hard drive space to accommodate all the temporary hydraulic files. For very large networks, each temporary hydraulic file created within each server folder (e.g., Server-1) might be several gigabits or more in size and when combined across all server folders the total disk space required can be very large. Remember multiple computer cores are likely processing the simulations across multiple server folders.
- During sensor placement (SP), use WINDOWS task manager to check whether the service “Randomsample.exe” is running. If the network is large, the tso-2-impacts file(s) will be large and it could take some time before “Randomsample.exe” execution(s) begin. On multi-core computers with sufficient memory, multiple “Randomsample.exe” services might be running.

A key trouble-shooting tool within TEVA-SPOT-GUI is the “Restart TEVA-SPOT Services” program available from the START Menu under TEVA-SPOT-GUI. If TEVA-SPOT-GUI freezes up, “Restart TEVA-SPOT Services” stops and restarts the required JAVA and TEVA services. Rebooting the computer will also restart TEVA-SPOT services. Simply closing the TEVA-SPOT-GUI application does NOT stop TEVA-SPOT-GUI services from running. Stopping a TEVA-SPOT-GUI execution can only be done by (1) choosing “Terminate” from Execution Controller panel and then closing TEVA-

SPOT-GUI, after the execution of termination, (2) choosing “Stop or Restart TEVA-SPOT Services,” or (3) rebooting computer.

Choosing “Terminate” could take some time to execute, depending on the particular module that is running. Generally, only use “Terminate” to stop executions that are running but waiting to begin due to another execution that is currently running. Otherwise use “Restart TEVA-SPOT Services.”

“Stop TEVA-SPOT Services” and “Restart TEVA-SPOT Services” might not fully work on Microsoft® Windows 7 operating systems when running sensor placement optimization or regret analyses. Microsoft Windows 7 does not allow users to alter processes started by an application (in this case TEVA-SPOT-GUI) unless executed from the START Menu in Windows 7 using “Run as an administrator.” Therefore, right clicking on “Restart TEVA-SPOT Services” and choosing “Run as an administrator” will need to be selected.

18.2 Log Files

TEVA-SPOT-GUI generates numerous log files to help the user identify whether TEVA-SPOT-GUI has malfunctioned. However, to view the log files, a live or real-time editor is needed. Windows Notepad is a live editor, but it is not compatible with easy viewing of the log files output by TEVA-SPOT-GUI (i.e., everything looks jumbled and unformatted). An open source program called *XEmacs* can be downloaded from the link below to view the log files.

<http://www.xemacs.org/Download/win32/index.html#InnoSetup-Stable-Download>

TEVA-SPOT-GUI log files are contained in various folders located within the “tevalogs” folder: C:\Program Files\TEVA-SPOT\tevaLogs. Specifically, there are five folders representing the various TEVA-SPOT-GUI services, with various log files associated with each. Generally, however, the three most important log files to examine to identify problems are: (1) “ExecutionController,” (2) “Server,” and (3) “DBServer.”

The number of “Server” folders will correspond to the number of computer cores that were setup by TEVA-SPOT-GUI at installation to process the simulations, with each numbered sequentially. For example, for the quad core computer with 32 gigabytes of random access memory used in the examples, four “Server” folders were established (i.e., named “Server-1” through “Server-4”).

Files are kept for 30 days, so when examining the various log files be sure to first sort the folder by the latest date or the date corresponding to the time of the problem.

The “ExecutionController” log files are described first, followed by the “Server” and “DBServer” log files. The log files that are **BOLDED** are recommended for examination. Generally, searching “.log” files starting with the “ExecutionController” and then within the various “Server” or “DBServer” log files for the word “severe” will likely identify whether TEVA-SPOT-GUI has malfunctioned.

EXECUTION CONTROLLER

- **ExecutionController_[Date].log** – Provides communication and status information about the “ExecutionController;” look for the key words “Severe Exceptions”
- **ExecutionController_[Date].memory.log** – Provides memory utilization information

- ExecutionController_[Date].execstats.log - Provides a summary level description of the completion (True or False) of each EPANET simulation, HIA, and IIA scenario as well as each tso-2-impact scenario and sensor placement design
- ExecutionController_[Date].stats.log – Provides a description of the completion (True or False) of each EPANET simulation, HIA, and IIA scenario as well as each tso-2-impact scenario and sensor placement design. If a TEVA-SPOT-GUI application is failing because of insufficient computer RAM memory, simulations will be classified as “FALSE.” For example, examine this file for “False” simulations when running large networks for sensor placement
- ExecutionController_[Date].stats.detail.log - Provides a detailed, complete description of the completion of each EPANET simulation, HIA, and IIA scenario as well as each tso-2-impact scenario and sensor placement design
- ExecutionController_[Date].assign.log – Details the location (e.g., “Server-1) for the stated simulation, analysis, or sensor network design. This is useful to determine where (“Server”) sensor placement designs are being developed

SERVER

- Server.[x]_[Date].compression.log – Provides information on file compression
- Server.[x]_[Date].log – Provides communication and status information about the “Server;” look for “SevereExceptions”
- Server.[x]_[Date].memory.log – Provides memory utilization information on the “Server” processes taking place

DBSERVER

- DBServer_[Date].log – Provides communication and status information about the DBServer, which is the communicator between simulations running on the various computer cores and TEVA-SPOT-Database established to store the data and results; look for “SevereExceptions” or “unable to connect to DBServer”
- DBServer_[Date].memory.log – Provides memory utilization information
- DBServer_[Date].tokens.log – Provides information on the processing of “tokens” or information between the simulations running on the computer cores and the “DBServer”

Once it is determined that TEVA-SPOT-GUI has malfunctioned, the user should terminate TEVA-SPOT-GUI (close the application and ensure that “Restart TEVA-SPOT Services” occurs). If the source of the problem cannot be identified and corrected (e.g., correcting a problem with the INP file), the user should contact Robert Janke at janke.robert@epa.gov. To help facilitate a quick resolution to the problem, the user should choose “ZIP Log Files” from the Microsoft® Windows START MENU (note that this may change depending on the Windows version being used). The zipped log files can be found at C:\Users\...\Documents\TEVA-SPOT\logs. Please email these log files to janke.robert@epa.gov. In order for the files to be successfully sent via email, please rename the ZIP extension to the TXT extension. Coordination through email can be used for any other problems, including installing or using the TEVA-SPOT-GUI software.

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Appendix A: Water Utility Requirements for Using TEVA-SPOT-GUI Software

The Threat Ensemble Vulnerability Assessment Sensor Placement Optimization Tool, TEVA-SPOT-GUI, 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-GUI 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-GUI software. In order to streamline the application of TEVA-SPOT-GUI, this appendix was developed to describe the requirements and steps that utilities must follow to use TEVA-SPOT-GUI.

Table A.1 summarizes the data and information required for a water utility to use TEVA-SPOT-GUI; 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 A 1. Information and data required to design sensor networks using TEVA-SPOT-GUI

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-GUI software relies upon an EPANET hydraulic and water quality model of the network as the mechanism for calculating the impacts resulting from contamination incidents. Therefore, an acceptable network model of the drinking water 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-GUI.

EPANET Software Requirement. TEVA-SPOT-GUI uses EPANET, a public domain water distribution system modeling software package. In order to utilize TEVA-SPOT-GUI, existing network models that were not developed in EPANET must be converted to and be demonstrated to properly operate within EPANET (Version 2.00.12). 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 might 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 might need to be modified in order to operate properly under EPANET; (2) additionally, the conversion programs developed by the commercial software vendors could also introduce some unintended representations within EPANET that could 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-GUI 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-GUI though shorter periods might 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-GUI. Specific guidance on selecting models is provided below:

- Optimal situation: 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).
- Minimal situation: the utility has a single model representing relatively average conditions throughout the year.
- Situations to avoid: 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-GUI. 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-GUI 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-GUI, 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 might represent commercial usage and be assigned to a representative commercial diurnal water use pattern. TEVA-SPOT-GUI 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. Formal standards do not exist 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 might 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 might 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-GUI is to put the model through a series of candidate tests. Following is a list of potential tests that should be considered.

- 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.

- 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.
- 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.
- 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-GUI 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-GUI. Many utilities will not be able to make all of the above modifications to their network model. In that case, TEVA-SPOT-GUI 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-GUI 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-GUI 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 might need to be increased in the design of a sensor network for a chloraminated system.

The utility pilot studies conducted by EPA for the Water Security Initiative used 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 might 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 $\mu\text{S}/\text{cm}$, 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-GUI 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 A.2. 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 A.3. Each line of the sensor file for loading HIA sensors into TEVA-SPOT-GUI consists of nine text fields separated by one or more spaces or tabs. The contents of the fields are defined in bullets below Table A.3. The HIA Sensors feature is used to load a single sensor network design into TEVA-SPOT-GUI 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” file extension.

Table A 2. Sensor File for Use in Sensor Placement Module

Field	Description
#Name	Literal string.
<Keyword>	<i>feasible, infeasible, fixed, and unfixed</i>
<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 file must begin with a keyword.

Table A 3. Fields of Sensor Data Files for Loading Sensor Monitoring Stations into 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
- 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 might 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 might 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 might wish to design a system that can detect not only high impact incidents, but also low impact incidents that could 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 could face. The TEVA-SPOT-GUI 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 might 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-GUI 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. Several performance measures are currently supported by TEVA-SPOT-GUI including:

- Number (#) of failed contaminant detections
- Estimated population exposed [to a contaminant] – humidifier, ingestion, showering
- Estimated population killed [to a contaminant] – humidifier, ingestion, showering
- Extent of contamination
- Mass [contaminated] consumed
- Population over dose threshold – humidifier, ingestion, showering

- Time of detection
- Length of pipe contaminated
- Volume [contaminated] 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-GUI:

- Minimum impact over all contamination events
- Mean impact over all contamination events
- Worst impact over all contamination events
- Lower quartile: 25% of contamination incidents have an impact value less than this quartile
- Median: 50% of contamination incidents have an impact value less than this quartile
- Upper quartile: 75% of contamination incidents have an impact value less than this quartile
- Value at risk (var): $100 \times \text{beta}\%$ of contamination incidents have an impact value less than this value, where beta is a user-defined parameter
- 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-GUI 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-GUI 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 CWS are very dependent on a rapid response time. Typically, the TEVA-SPOT-GUI 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-GUI 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-GUI analysis.

POTENTIAL SENSOR LOCATIONS

TEVA-SPOT-GUI 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 might 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 could 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.). In addition, many publicly-owned sites could be easily adapted, such as fire and police stations, schools, city, and/or county buildings. Finally, many consumer service connections would also meet many of the requirements for sensor placement, although there might be difficulties in securing access to private homes or businesses. Nevertheless, the benefit of using these locations might be worth the added cost. Compliance monitoring locations could 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-GUI 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) can 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-SPOT-GUI 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. Four keywords are available: 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 A.4.

Table A 4. Meaning of the Keywords in Location Categories File

Property	Keyword	Meaning
Feasibility	feasible	Node is <i>permitted</i> to have a sensor
	infeasible	Node is <i>not permitted</i> to have a sensor
Forceability	fixed	Node is <i>required</i> to have a sensor
	unfixed	Node is <i>not required</i> 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 A.5. The table also shows how the sensor placement algorithm treats the specified nodes if the values of their properties are not subsequently changed.

Table A 5. Effect of Keyword in LC File and Treatment of Nodes by Sensor Placement Algorithm

Specified Keyword	Values Conferred on Specified Nodes				Eligibility for Sensor Placement When Values Are Final
	Feasibility Property		Forceability Property		
	feasible	infeasible	fixed	unfixed	
feasible	✓			✓	Eligible
unfixed					
infeasible		✓		✓	Ineligible
fixed	✓		✓		Forced

POPULATION

In TEVA-SPOT-GUI analyses, the most commonly used performance measure for sensor placement is the number of persons who receive a dose above some threshold for ingestion of contaminated drinking water. In order to estimate exposures and doses or health impacts, information is needed on the population at each node. A variety of methods 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) 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-GUI 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 A.6 below.

Table A 6. Fields for 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.**

Appendix B. Example EPANET-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 C1- BOOSTER} CL 1.0
SETPOINT { SPECIFY NODE FOR C1- BOOSTER} CL 1.0
SETPOINT { SPECIFY NODE FOR C1- 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
```


Appendix C. Supporting Papers and Reports

MODELING AND GENERAL INFORMATION:

- “Water Security Toolkit User Manual” describes the different components of the Water Security Toolkit (WST). WST is a suite of tools that help provide the information necessary to make better decisions resulting in the minimization of further human exposure to contaminants, and the maximization of the effectiveness of intervention strategies. The sensor placement components contained in the TEVA-SPOT-GUI were originally developed as part of the TEVA-SPOT Toolkit which was the forerunner to WST [23].
- “Securing Water and Wastewater Systems, Chapter 2: Protecting Water Supply Critical Infrastructure: An Overview” provides a literature review of threats facing water systems with a focus on contamination threats. The book chapter discusses general principles and characteristics of water and wastewater system security and summarizes current research as it relates to improving the security of water systems from intentional contamination threats [14].
- “Modeling reaction and transport of multiple species in water distribution systems” provides the methodological basis for EPANET-MSX along with examples for the user [12].
- “Mass imbalances in EPANET water-quality simulations” identifies and examines the problem of mass imbalances in EPANET’s water quality simulation. Overly long water quality time steps (> 5 minutes) can yield errors in contaminant concentration estimates and can result in situations in which contaminant mass is not conserved. The paper provides examples illustrating mass imbalances and explains how such imbalances can occur [19].

EXPOSURE, DOSE, AND CONSEQUENCE ASSESSMENT:

- “Model for estimating acute health impacts from consumption of contaminated drinking water” provides the underlying methodology for assessing public health effects of contaminants in potable distribution systems [4].
- “Importance of exposure model in estimating impacts when a water distribution system is contaminated” provides the motivation for investigating and developing a realistic timing model to describe when people are most likely going to drink tap water each day [5].
- “Development of a probabilistic timing model for the ingestion of tap water” develops the methodology for the American Time Use Survey (ATUS) based probabilistic timing model for the likely timing of ingestion of tap water by water system users [6].
- “Patterns in potential impacts associated with contamination events in water distribution systems” provides a case study analysis of potential public health consequences for 12 real and diverse distribution systems [7].
- “Assessing Potential Impacts Associated with Contamination Events in Water Distribution Systems: A Sensitivity Analysis” extends the analysis provided in [7] to provide a better understanding of the nature of adverse public health consequences that could be associated with contamination events [8].
- “A Framework for Estimating the Adverse Health Effects of Contamination Events in Water Distribution Systems and Its Application” develops and describes a flexible analysis framework for estimating the magnitude of public health consequences given detailed information or very limited information [9]. This paper builds on the work in [7] and [8].
- “Influence of Network Model Detail on Estimated Health Effects of Drinking Water Contamination Events” examines the influence of distribution system model detail on estimating

public health effects from drinking water contamination events [11]. This paper examines the loss of model (distribution system) detail on estimating public health consequences and helps to guide the TEVA-SPOT user on how to minimize such adverse effects by restricting attention to the high percentile contamination scenarios.

- “Assessing inhalation exposures associated with contamination events in water distribution systems” describes TEVA-SPOT-GUI capabilities for assessing the potential effects of short-term, system-wide inhalation exposures that could result from showering and the use of aerosol-producing humidifiers during a water contamination event. The paper also applies these capabilities using network models for three water distribution systems [17].
- “Application of TEVA-SPOT for Prioritizing Security Enhancements at Utility Facilities and for Protection of Critical Facilities” is a user’s manual for applying TEVA-SPOT-GUI to the protection of utility facilities and critical facilities [21].
- “Incorporating a Capability for Estimating Inhalation Doses in TEVASPOT” is the design document that describes the inhalation exposure, dose, and consequence pathways with inhalation during showering and humidifier use [22].

SENSOR NETWORK DESIGN:

- “Robustness of Designs for Drinking-Water Contamination Warning Systems under Uncertain Conditions” examines the performance of contamination warning system based sensor network designs [10]. Specifically, this manuscript analyzes performance in the context of changed conditions, i.e., conditions different from those used in the design. The analysis helps users of the TEVA-SPOT-GUI software to develop sensor network designs that are more robust while reducing computational requirements.
- “Sensor Network Design for Drinking Water Contamination Warning Systems: A Compendium of Research Results and Case Studies Using TEVA-SPOT Software” provides supporting documentation to assist in the design of contamination warning systems [13].
- “Influence of Network Skeletonization on Contamination Warning System Design: Case Studies” this paper is an extension to “Influence of Network Model Detail on Estimated Health Effects of Drinking Water Contamination Events” by examining the influence of lack of structural detail in the network model and its effect on contamination warning system (CWS) based network designs [20].