

Application of TEVA-SPOT for Prioritizing Security Enhancements at Utility Facilities and for Protection of Critical Facilities



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Disclaimer

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Due to the complexity of some graphs, equations, and tables, some information is not amenable to screen readers. For accommodation, please contact Kathy Nickel (nickel.kathy@epa.gov).

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.

Lagrangian – Heuristic algorithm that uses the structure of the p-median MIP formulation to find near-optimal solutions while computing a lower bound on the best possible solution. Uses less RAM memory than GRASP.

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.

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

IIA – Infrastructure Impacts Analysis

Kg – Kilograms

LD – Lethal dose

MIP – Mixed integer program

NHSRC – National Homeland Security Research Center

NZD – Non-zero demand nodes

PICO - Parallel Integer and Combinatorial Optimizer

pd – Population dosed

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).

WQ – Water quality

1 INTRODUCTION.

The purpose of this manual is to describe two applications of the Threat Ensemble Vulnerability Assessment, Sensor Placement Optimization Tool (TEVA-SPOT) software program to the design of a Surveillance and Response System (SRS). The first is to prioritize security enhancements to *utility facilities* located in the distribution system (e.g., tanks and pump stations). The second is to design a water quality monitoring sensor network to monitor the water serving *critical facilities* (e.g., hospitals or government buildings). This manual supports implementation of the Enhanced Security Monitoring and Online Water Quality Monitoring components of an SRS under the Water Security Initiative, a program developed by U.S. Environmental Protection Agency's Water Security Division.

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. The TEVA-SPOT software tool quantifies consequences from an array of contaminant-release scenarios. The emergency planner's ability to prioritize enhancements to distribution system monitoring & surveillance and response capabilities through deployment of a water quality SRS, hinges on effective consequence analysis. The quantification of consequences is needed to support the design of an effective SRS. One key component of SRS 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 SRS for the protection of drinking water distribution systems.

Public health consequences can be estimated in terms of infections and fatalities, or more generically as simply exposures or doses. Infrastructure consequences of a particular contamination injection event can be estimated based on the length of pipe (pipe feet) that witnesses (or exhibits) contamination above some level (specified as a contaminant water concentration in units of milligrams per liter).

The prioritization of security enhancements at utility facilities is implemented in TEVA-SPOT using the consequence modules to calculate *Utility Facility*-based consequence values (C-Values). Utility facilities include, for example, tanks, pump stations, and valves. A C-Value for a particular utility-owned facility is defined by the consequences that could result when contamination is introduced at such a facility. A group of utility facilities are ranked based on the magnitude of consequences that result when contamination is introduced at the facility. Once C-Values are determined, users (e.g., utility managers or engineers) can use the information to prioritize their SRS efforts for increased surveillance and facility hardening.

Another application of TEVA-SPOT during development of an SRS is to identify optimal locations for placing water quality monitoring sensors to detect contamination incidents. The design of a water quality monitoring sensor network to monitor the water serving critical facilities is implemented in TEVA-SPOT using the sensor placement optimization tool (SPOT) components. In order to avoid

confusion with the C-Values analysis demonstrated on utility facilities, we restrict our attention here to critical facilities that are NOT utility facilities. For example, a user may determine that their critical facilities include hospitals, police and fire stations, and government buildings. A user can identify a set of locations as critical facilities and TEVA-SPOT will determine the set of upstream network locations that supply water to and, therefore, could potentially contaminate a critical facility. Using this approach critical infrastructure, other than or in addition to utility infrastructure, can be identified and TEVA-SPOT can be used to help protect them. By determining the upstream locations that could affect the critical facilities, TEVA-SPOT allows the user to evaluate the consequences from each of the identified upstream locations (evaluated as possible contamination injection locations) to prioritize SRS efforts at those upstream locations that present the greatest risk to identified critical facilities. This feature can also be used to help determine the best locations to place monitoring stations to protect the critical facilities.

This manual begins with a brief background discussion of TEVA-SPOT and TEVA-SPOT-GUI. In Section 2, we provide installation instructions for TEVA-SPOT-GUI and some references to supporting journal articles and reports that can be examined for additional information if needed. We describe the TEVA analysis approach for determining Utility Facility C-Values in Section 3 through a step-by-step illustration process using an example network and example biotoxin. In Section 4 we describe how to use TEVA-SPOT-GUI to help protect user-identified critical facilities and how to use TEVA-SPOT-GUI to optimally locate sensor monitoring devices. In Section 5, we provide tips on using and applying the TEVA analysis approach to determining C-Values and protecting critical facilities. Section 6 provides supporting references.

2 INSTALLATION AND BACKGROUND.

This manual is not meant to replace the TEVA-SPOT-GUI Users Manual. The TEVA-SPOT-GUI Users Manual is available at:

<http://cfpub.epa.gov/si/si_public_record_report.cfm?address=nhsrsrc/&dirEntryID=202703>.

TEVA-SPOT uses EPANET 2.00.12 as its hydraulic and water quality modeling engine [1]. Two versions of TEVA-SPOT are available for download. TEVA-SPOT Toolkit is a command-line based set of software tools designed for software developers or researchers. The TEVA-SPOT graphical user interface (GUI) version 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 and TEVA-SPOT Toolkit are available for download at: <<http://www.epa.gov/nhsrsrc/index.html>> [2]. Users should contact Robert Janke at <janke.robert@epa.gov> to ensure that they have the latest update to TEVA-SPOT-GUI prior to using the web version of TEVA-SPOT-GUI.

TEVA-SPOT 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 is available from the same link as TEVA-SPOT: <<http://www.epa.gov/nhsrsrc/index.html>>, see “EPANET Extensions” [3].

The distribution executable (.exe file) contains the TEVA-SPOT-GUI program and Users Manual. The prerequisite software can be obtained from the FTP site below or from the internet by searching for the required items below. Prerequisite software includes the Java Development Kit (JDK) (e.g., Version 1.6 update 20) and the Python Scripting Language (version 2.6 or later). The JDK and Python products need to be installed first prior to the installation of TEVA-SPOT-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, not Windows Vista. Below are the JDK and Python installers needed depending on the computer hardware and operating system that TEVA-SPOT-GUI will be installed on. The latest versions should be installed, these are for example only.

- jdk-6u41-windows-586.exe (32 bit version)
- jdk-6u41-windows-x64.exe (64 bit version)
- python-2.7.3.msi (32 bit version)
- python-2.7.3amd64.msi (64 bit version)

After the prerequisites of JAVA and Python are installed, the TEVA-SPOT-GUI software is 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.

Updates to TEVA-SPOT-GUI can be installed by downloading the most recent update from the EPA TEVA-SPOT Research Program website (<http://www.epa.gov/nhsr/index.html>). TEVA-SPOT-GUI can also be obtained from the following File Transfer Protocol (ftp) website: <<ftp://scienceftp.epa.gov/>> and entering the appropriate login and password information which can be obtained via email from Rob Janke at <janke.robert@epa.gov>.

Each TEVA-SPOT-GUI installation (.exe) file is tagged with a date of release, e.g., TEVA-SPOTInstaller-2.3.1b-20130723.exe, signifying a release date of July 23, 2013 (last eight digits in the file name). The initial two numbers in the file name describe the version number, i.e., 2.3, refers to the major release number (2) and the minor release number (3) and are consistent with the version numbering for the TEVA-SPOT toolkit. The final number in the file name that describes the version number, i.e., 1, designates a sub-minor release which is specific to TEVA-SPOT-GUI.

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

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

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

2.1 Supporting Documents

We provide a listing of some relevant journal papers and reports that provide supplemental information supporting the underlying models within TEVA-SPOT and the application of TEVA-SPOT to water distribution systems.

“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].
- “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, the 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 software to develop sensor network designs that are more robust while reducing computational requirements.
- “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 how to minimize such adverse effects by restricting attention to the high percentile contamination scenarios.

- “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].
- “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].
- “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 waste water system security and summarizes current research as it relates to improving the security of water systems from intentional contamination threats [14].

3 TEVA ANALYSIS APPROACH FOR DETERMINING C-VALUES.

We describe a step-by-step method to determine C-Values for an example biotoxin and a real, but anonymous, water distribution system model using the TEVA-SPOT-GUI software program. C-Values can be used to help a water utility prioritize their resources and their efforts at hardening their facilities or at installing surveillance and monitoring equipment. Using this approach, a group of utility facilities can be identified and analyzed for consequences that could result if contamination were introduced independently at each of the utility facilities. For the purpose of this manual, we define utility facilities separately from critical facilities. With utility facilities the user is evaluating consequences from the introduction of a contaminant at a particular water utility facility. With critical facilities, the user is evaluating those upstream contaminant injection nodes that produce consequences at a particular critical facility.

To determine the scope of the C-Values analysis, the user must decide the scope of the utility-based consequence assessment that they want to investigate. Specifically, the user decides whether they want to examine the consequences of contamination being introduced at some group of utility facilities, e.g., all tanks, pump stations, or valves, or some subset of utility facilities, in order to determine those utility facility locations that will result in the greatest consequences if contamination were introduced.

First, the user *imports* their EPANET-based model (*.inp file) [1]. The EPANET model should be capable of running extended period simulation. The user will also input population information and define how people are served by the water system, as described by the network model. This is typically the population served by the water system, but could represent some fraction of the population served. Next, the user decides how they want to examine consequences. TEVA-SPOT-GUI provides the user with the capability to examine consequences in terms of public health measures (e.g., infections, fatalities, exposures or doses) and/or as feet of contaminated pipe.

Next, we describe how to open TEVA-SPOT-GUI, setup of a “Collection”, naming an “Ensemble”, importing an EPANET “.inp” file, and setting up the population distribution. Next, we describe and demonstrate the use of five modules within TEVA-SPOT-GUI to determine C-Values or evaluate critical facilities: (1) *Initialization: Population*, (2) *UpDownStreamNodes*, (3) *EPANET Simulations*, (4) *Health*

Impacts Analysis, and (5) *Infrastructure Impacts Analysis*. Table 3.0.1 provides an overview of the steps for determining C-Values.

Table 3.0.1: Overview of steps for determining C-Values

Step	Feature	Task
Steps 3.1.1 – Step 3.1.10	Opening and Input Generation	Opening TEVA-SPOT-GUI and setting up and running “Initialization: Population” and “Upstream & Downstream Nodes”.
Step 3.2.1 – Step 3.2.5	Scenarios <ul style="list-style-type: none"> • EPANET Simulations 	Setting up and running EPANET simulations.
Steps 3.3.1 – Step 3.3.2	Health Impacts Analysis (HIA)	Setting up and running HIA analyses.
Steps 3.4.1 – Step 3.4.2	Infrastructure Impacts Analysis (IIA)	Setting up and running IAA analyses.
Steps 3.5.1 – Step 3.5.11	Obtaining results <ul style="list-style-type: none"> • Map tab • Table tab 	Retrieving results and determining C-Values.

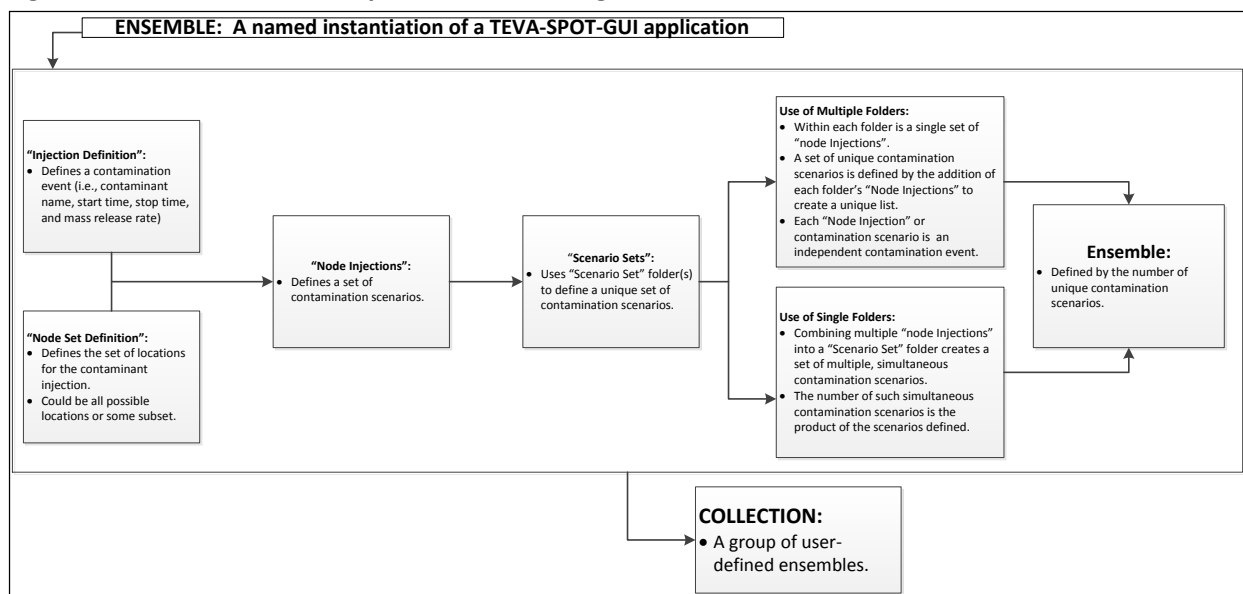
Utility facilities are selected by the user as a set of contamination scenarios and simulated in the “EPANET Simulations” module. Consequences are determined using the “Health Impacts Analysis” module or the “Infrastructure Impacts Analysis” module or both modules.

To demonstrate the use of TEVA-SPOT-GUI to examine public health and infrastructure consequences and determine C-Values, we use an example biotoxin. For our illustrative example, we use a real, but anonymous, distribution system model. First, we demonstrate how to create an “Ensemble” to determine C-Values for Utility Facilities (UF). For demonstration purposes only, we use the example network’s group of tanks as the UF contamination scenarios. After the creation of the ensemble, “Network_4_Utility_Facilities”, we demonstrate how to determine consequences.

3.1 Collections, Ensembles, Population: Initiation, and Upstream and Downstream Nodes

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 obtained from the network. 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). Figure 3.1.1 provides a schematic illustrating the TEVA-SPOT-GUI 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 3.1.1. TEVA-SPOT-GUI process for defining contamination scenarios



After a “Collection” and an “Ensemble” are created (steps 3.1.1-3.1.4), the next step is to import a distribution system model into the “Ensemble” (step 3.1.5). The distribution system model must be an EPANET model (EPANET formatted text file with the .inp extension) that is capable of running extended period simulations. Please refer to [TEVA-SPOT-GUI User’s Manual, Appendix A, Water Utility Requirements for Using EPA’s TEVA-SPOT](#) for a discussion of the requirements and steps that must be followed to use TEVA-SPOT appropriately [2]. Our model is named *Network 4*. Network 4 is a real, but anonymous, distribution system model. This model has been used elsewhere; see [7], [8], [9], and [10]. In step 3.1.6 the user clicks the “Edit” menu item and then chooses “Ensemble Options”. The “Ensemble Options” box enables the user to specify various simulation parameters. More discussion of these parameters is available in Section 5.

After the network model is imported and the simulation parameters are reviewed, the network population is initialized (step 3.1.7). TEVA-SPOT allows the user to specify the population distribution using either (1) a demand based method or (2) a census based method. The demand-based method requires a user to input of 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.

We assume that the population distribution (i.e., the number of people residing at each non-zero demand node) is based on demand or water usage and those 200 gallons per person per day is usage rate. Given this per capita water usage rate, the total population served by the water distribution system model is approximately 152,000 people.

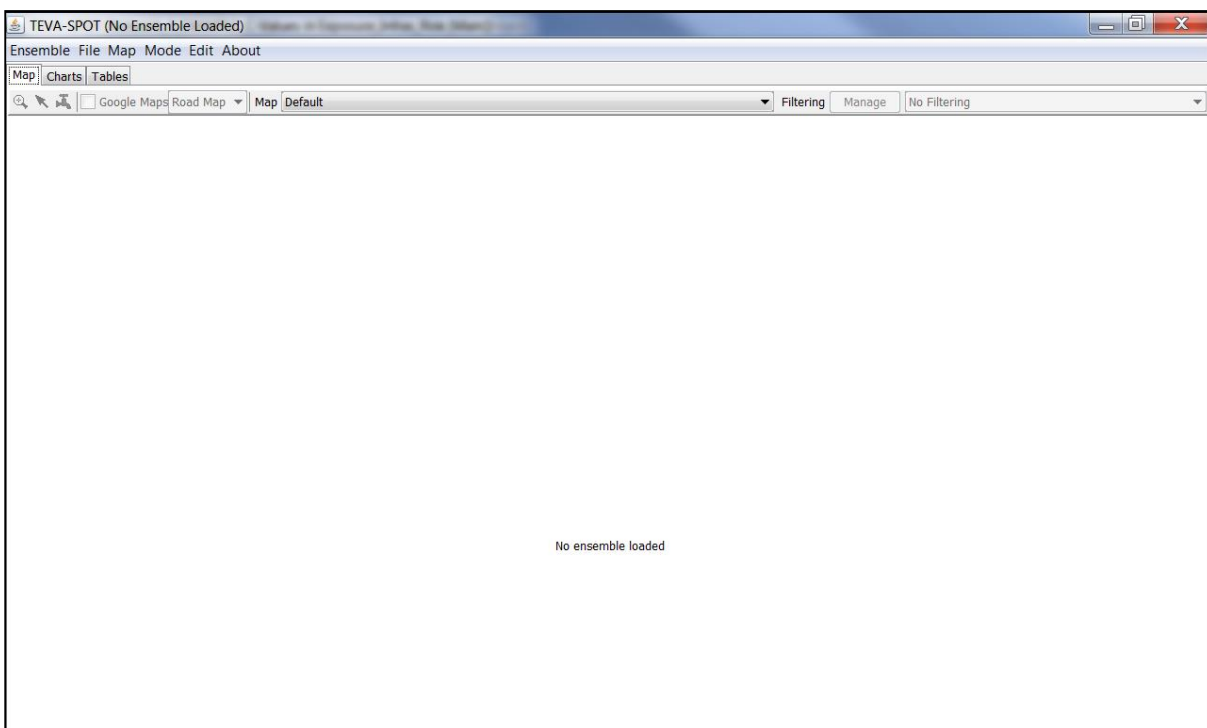
Step 3.1.8 describes the use of the “UpDownStreamNodes” module. This module determines the upstream and downstream nodes corresponding to a set of contamination scenarios or injection locations. The number of upstream or downstream nodes associated with a particular injection location (node) is a function 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 use the default simulation length.

Steps 3.1.9 and 3.1.10 demonstrate the execution and completion of the “Input Generation” modules.

Opening and Input Generation

STEP 3.1.1.

Open TEVA-SPOT-GUI by choosing START Menu and then clicking on the TEVA-SPOT folder and then TEVA-SPOT.

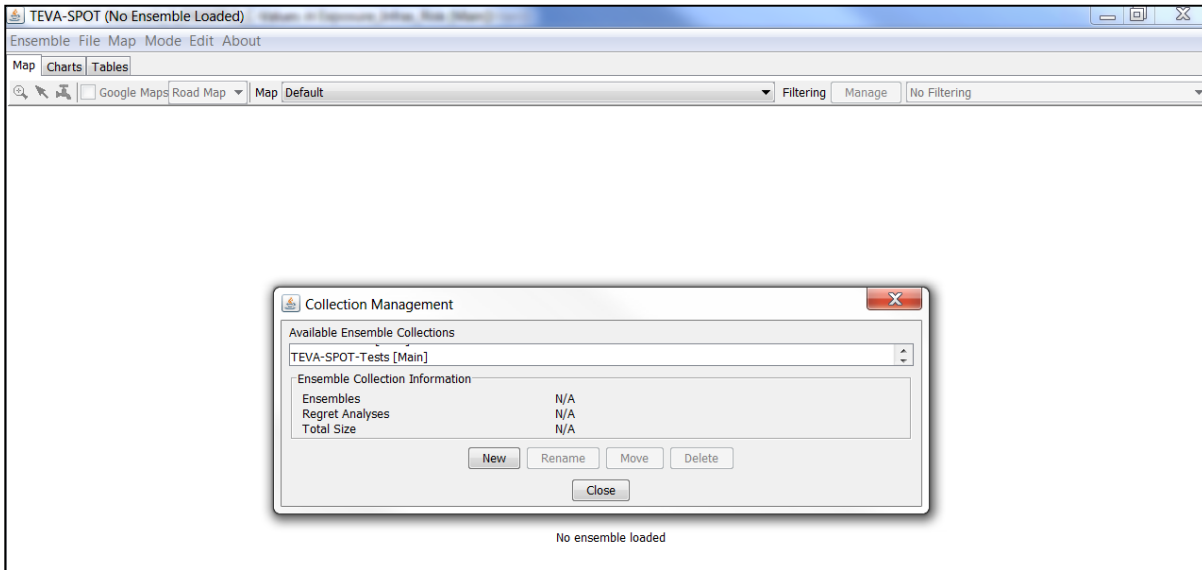


Initial screen – indicates “No Ensemble Loaded”.
For more explanation, see TEVA-SPOT-GUI User’s Manual.

Opening and Input Generation

Step 3.1.2.

Under Ensemble Menu, select “Collection Management”.



Collections are defined by the user and represent a set of ensembles.

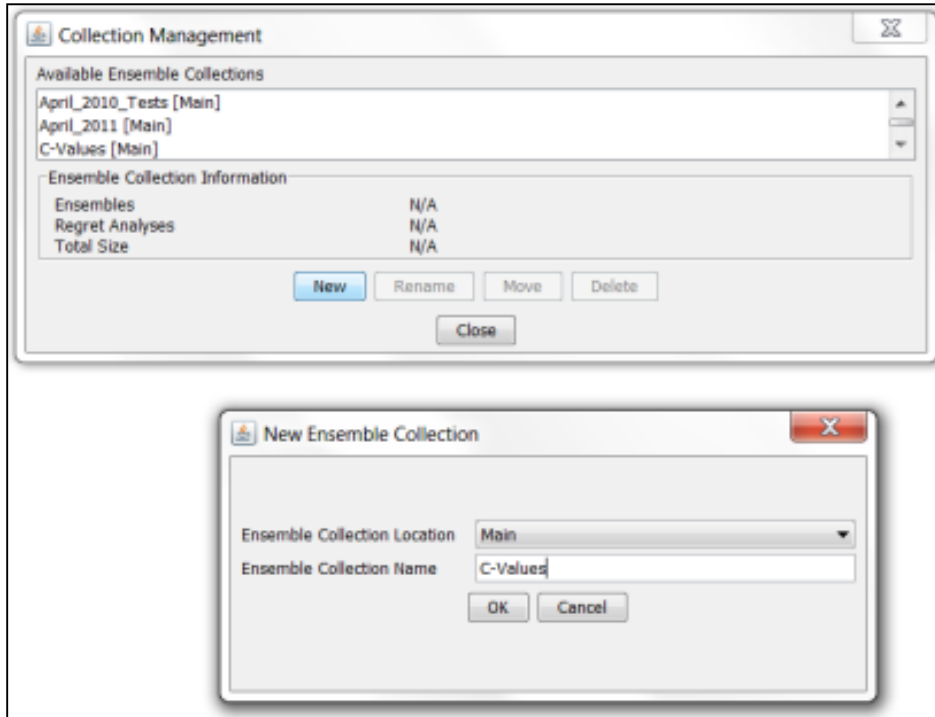
Collections and their associated **Ensembles** are located in the folder: **TEVA-SPOT-Database**.

Opening and Input Generation

Step 3.1.3

Click “New” and Name your “collection”. For instance, name your collection “C-Values”. Click “OK”.

Click “Close” to close the “Collection Management” box.

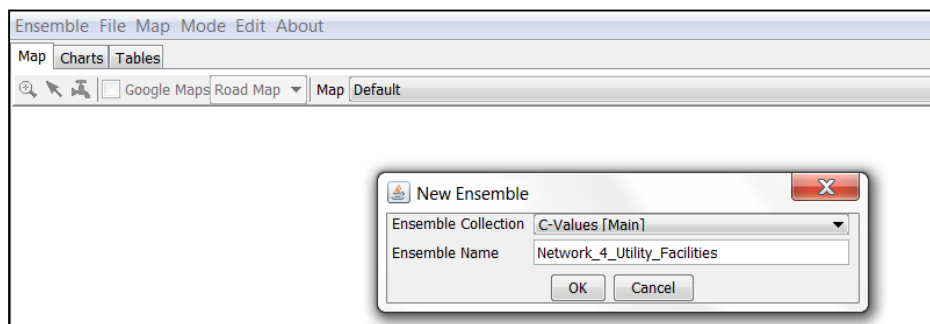


This is the “Collection” folder where “Ensembles” of contamination scenarios are located.

Step 3.1.4.

Under “Ensemble” menu, click “New”.

Name the “Ensemble” as “Network_4_Utility_Facilities”. Click “OK”.

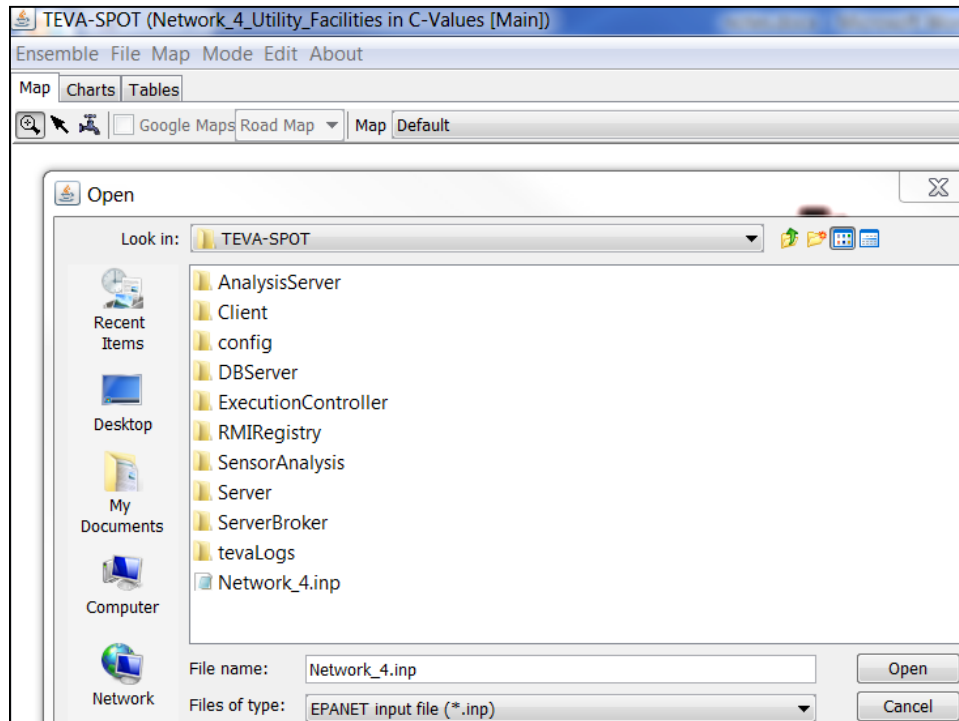


It is a good practice not to have spaces within the names.

Opening and Input Generation

Step 3.1.5.

Under “Ensemble Menu”, select “Import EPANET .inp File”. The dialogue box will appear and select or browse to the location for your model. Click “Open”.



If there are errors within the .inp file: TEVA-SPOT-GUI may indicate problems with loading the inp file and the file will not be loaded.

TEVA-SPOT-GUI will indicate where the problems are. The user should open their model using a text editor (e.g., Microsoft® Notepad) and try to fix the problem indicated.

Note for the discussion here, the “Network_4.inp” file was first copied to the C:\Program Files\TEVA-SPOT\Client directory. This is the directory that TEVA-SPOT-GUI first opens to.

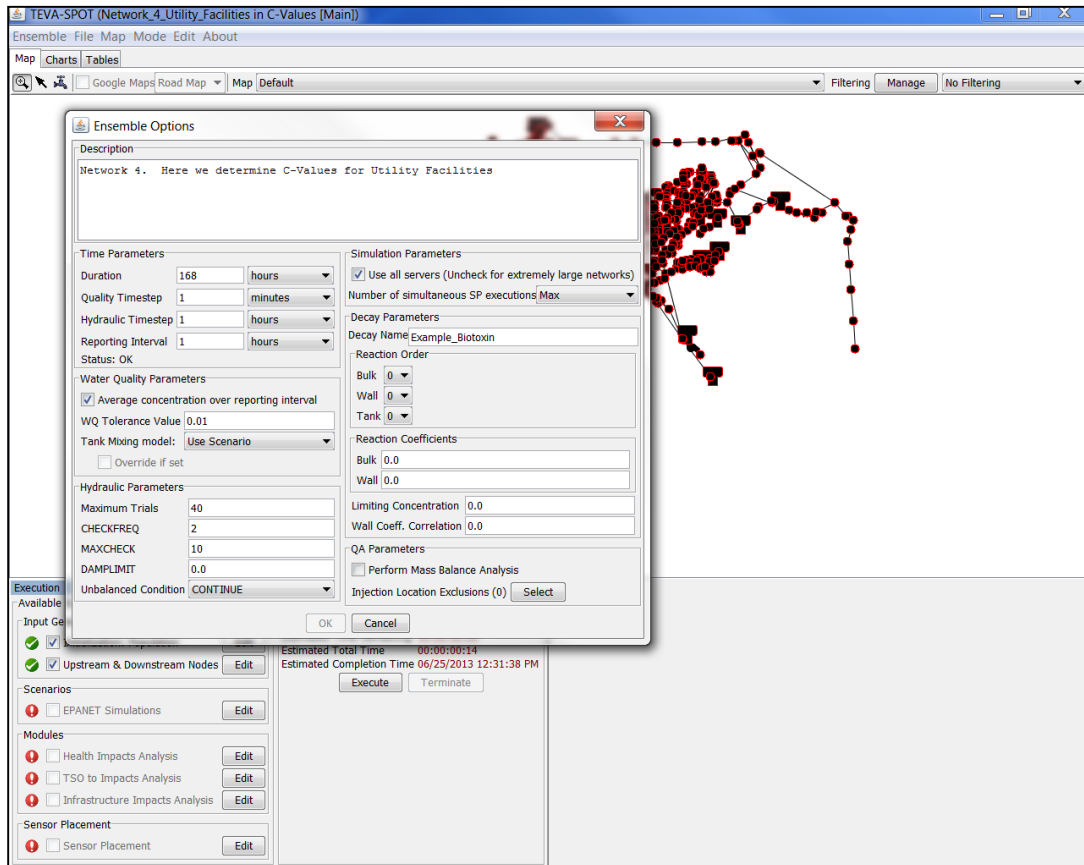
Opening and Input Generation

Step 3.1.6.

Under the “EDIT” Menu, select “Ensemble Options”. Use the default parameters shown below.

Type the text shown below into the description box. Also, type “Example Biotoxin” into the “Decay Name” box. Click “OK”.

Under the “Ensemble” menu, select “Execution Control” to display the “Execution” dialogue box.

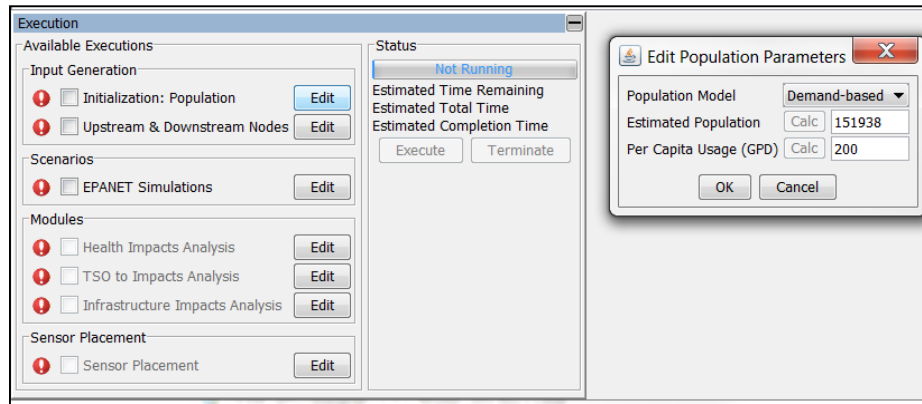


For more information, see TEVA-SPOT-GUI User's Manual.

Opening and Input Generation

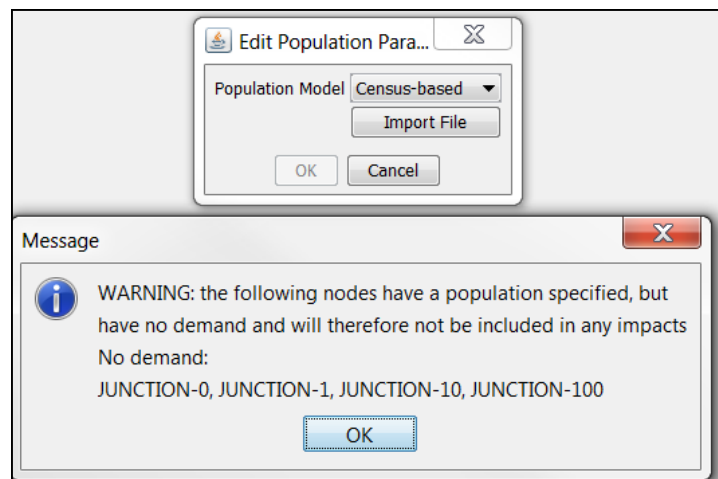
Step 3.1.7.

Click EDIT box for the “Initialization: Population” module. In the “Edit Population Parameters” dialogue box, for the “Population Model” parameter, choose “Demand-based” from the drop down menu. Within the “Per Capita Usage (GPD)” box, type “200” and then click the “Calc” button. Finally, Click “OK”.



Demand-based population assignment is demonstrated. A “Census” based approach could also be used by choosing “Census based” and then importing a text file that provides the number of people for each non-zero demand node.

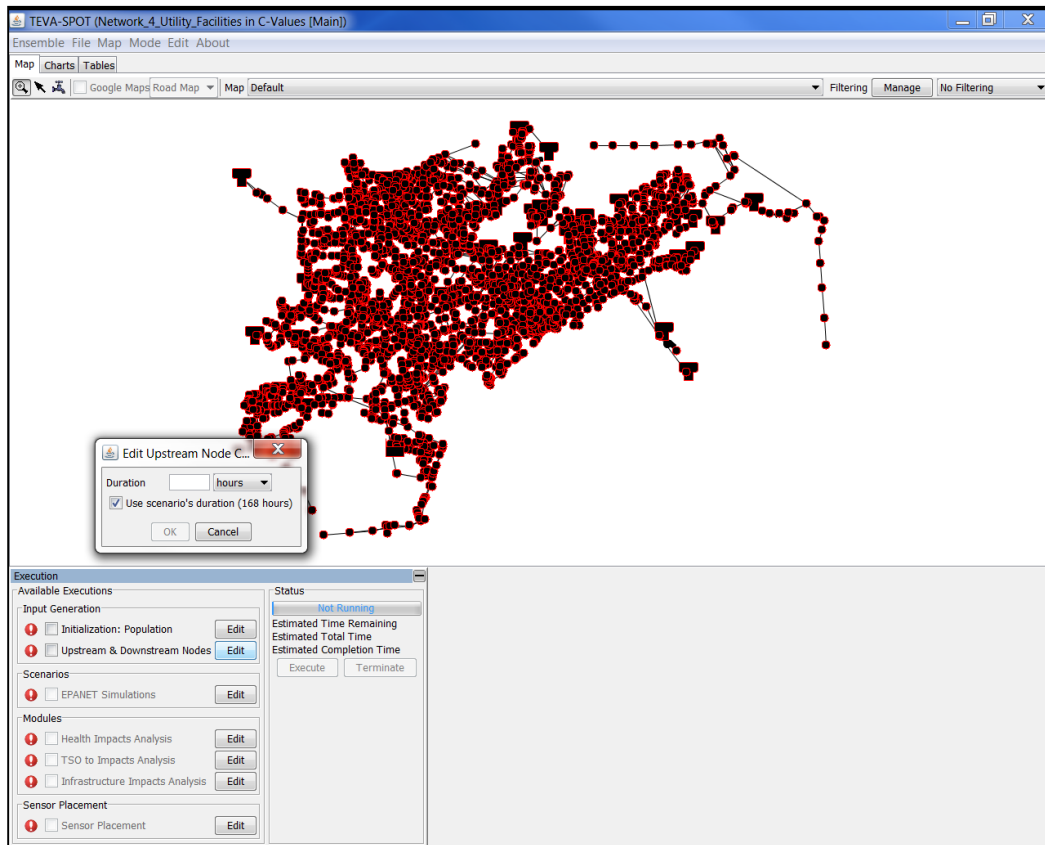
Note: TEVA-SPOT-GUI will check the user’s uploaded population file to determine if people are placed at nodes with zero demand. TEVA-SPOT-GUI will notify the user in a message box as shown below:



Opening and Input Generation

Step 3.1.8.

Click “EDIT” box for “UpDownStreamNodes” module. Notice that the box “Edit Upstream Node Calculation Parameters” appears. Click cancel, this uses the default simulation length specified in the “EDIT/Ensemble Options” menu.

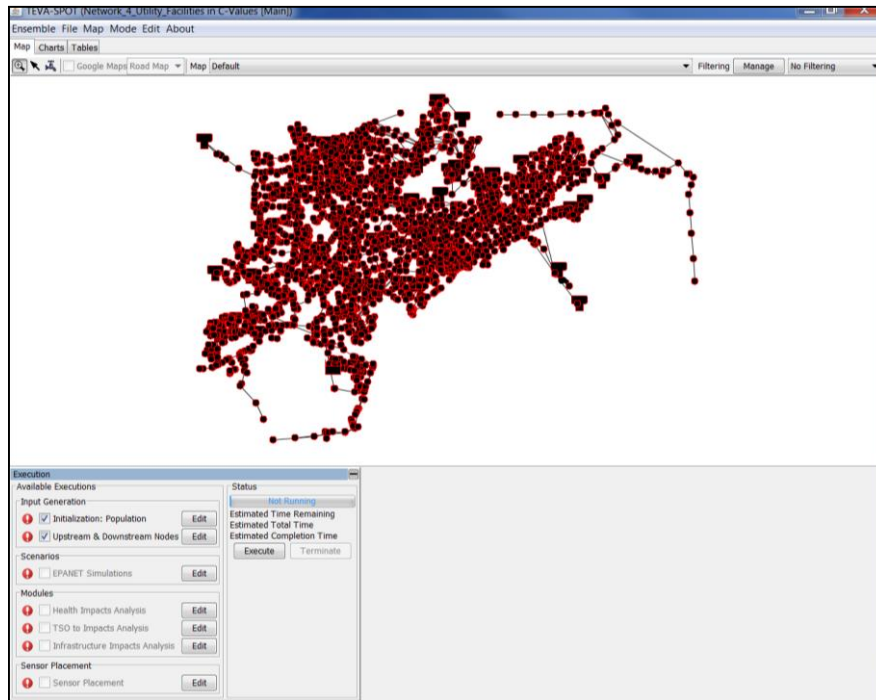


The default duration period (hrs) is used to capture the full extent of the exposure period, which is one wk or 168 hrs.

Opening and Input Generation

Step 3.1.9.

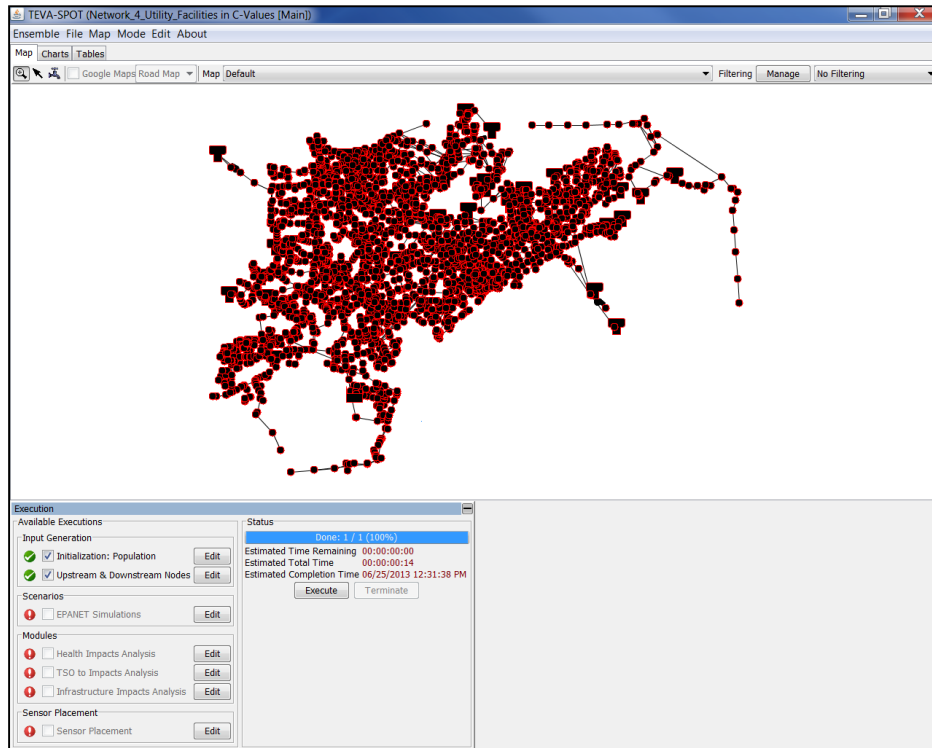
Click the two boxes associated with: “Initialization: Population” & “UpDownStreamNodes”. Check marks will appear, then click “EXECUTE”. Both modules should complete running, i.e., the RED Exclamation points will turn GREEN.



Opening and Input Generation

Step 3.1.10.

Observe the completion of the two modules. “Initialization: Population” should run quickly, i.e., take a few minutes. “Upstream & Downstream Nodes” may take a while (from a few minutes to an hour or more) depending on the size of the network model.



Now GREEN checkmarks appear indicating the successful completion of the Input Generation Modules.

3.2 Contamination Scenarios

TEVA-SPOT-GUI simulates contaminant injection or release into a drinking water distribution system and then performs the required hydraulic and water quality analysis using a modified version of EPANET to predict contaminant concentrations (mg/L) throughout the distribution system. A contamination scenario is defined by the contaminant, its injection specifications, and the locations where the contaminant is injected in the system. More specifically, the contamination scenario is given by: (1) contaminant mass release rate (mg/min), (2) contaminant release duration, given a start time and a stop time in units of seconds, minutes or hours, and (3) specification of the threat ensemble (node IDs) to represent contamination injection locations. For the purpose of determining C-Values, we define the locations for contamination injection as user-specified *Utility Facilities*.

The contamination source for the hypothetical biotoxin is described by the arbitrary mixture of 300 grams of the example biotoxin into 7,500 liters of water to result in a biotoxin bulk water concentration of 40 mg/L. It is assumed, for the purposes of this demonstration, that the example biotoxin is released

at the time of 12:00 AM and injected for a period of 480 minutes or 8 hours for a total mass of 300 grams. TEVA-SPOT simulates contamination injections in a water distribution system using mass per minute for the input quantity (e.g., mg/min), i.e., assuming no volume added. A total mass of 300 grams (300,000 mg) and an injection duration of 480 minutes results in a mass injection rate of 625 mg/min. For additional information on the design of a contamination scenario please refer to Section 5.3.

The creation of an ensemble of contamination scenarios is the coupling of an “Injection Definition” (steps 3.2.1 and 3.2.2) with a “Node Set Definition” (step 3.2.3) to create a “Node Injection” (See Figure 3.1.1). “Injection Definition” defines the contaminant injection parameters, namely the contaminant name, mass injection rate (mg/min, or organisms or cells/min), and the start and stop time of the injection (specified in the units of secs, mins, or hrs). “Node Set Definition” defines the locations where the contaminant will be injected.

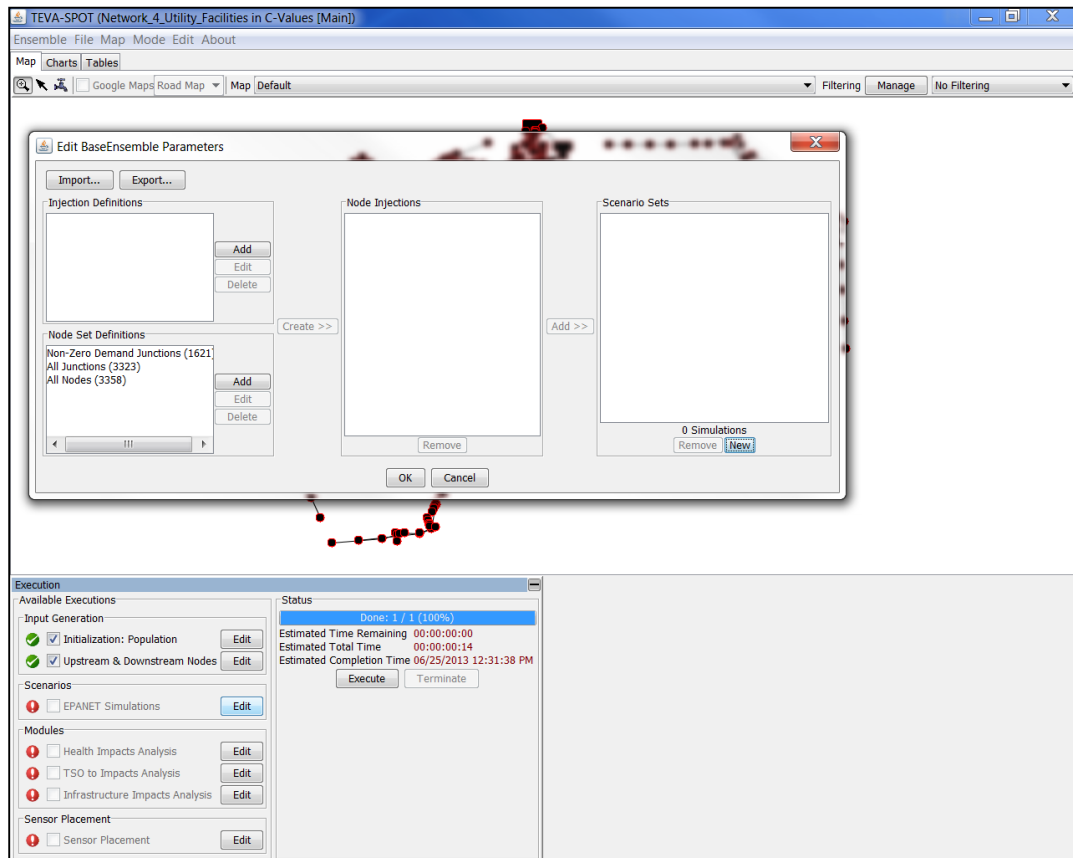
“Node Injections” is then added using “Add” to a folder called a “Scenario Set” (step 3.2.4). “Node Injections” represent the summation of the injection definition with the set of injection locations. Each “Scenario Set” represents a set of contamination scenarios. Multiple “Scenario Set[s]”, with each set containing one “Injection: Example_Biotoxin / Nodes: Tanks (34)” “Node Injections”, can be created and the number of simulations will be additive. 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 two instances of our “Injection: Example biotoxin/Nodes: Tanks (34)” will result in $34 * 33$ combinations of simultaneous contamination scenarios. This will result in 595 unique scenarios.

Once an ensemble of contamination scenarios are created within the “Edit” box associated with “EPANET Simulations”, the “EPANET Simulations” will be ready (i.e., not grayed out) to “Execute”. Step 3.2.5 shows the “Execution” and completion (green check mark) of the EPANET simulations.

Contamination Scenarios

Step 3.2.1.

In the “Scenarios” box, Click “EDIT” button next to “EPANET Simulations” and the dialogue box appear.

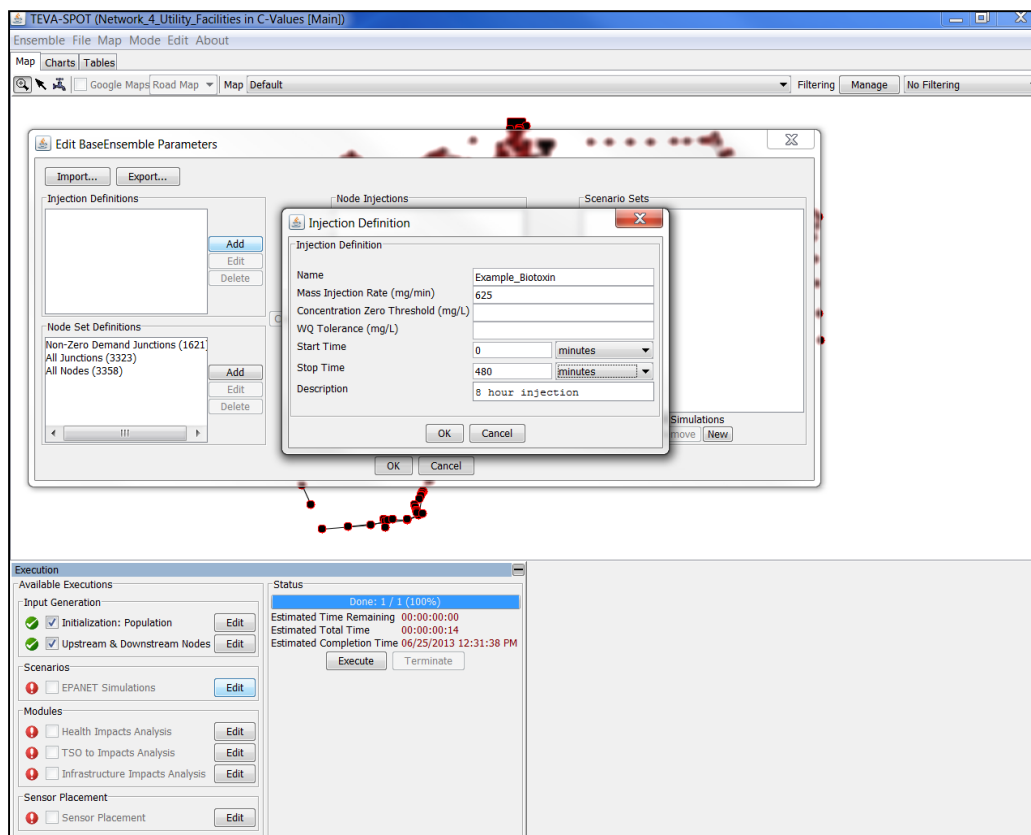


For more explanation, see TEVA-SPOT-GUI User's Manual.

Contamination Scenarios

Step 3.2.2.

Under the “Injection Definition”, click “Add”. Enter “Example_Biotoxin” for the NAME and the parameters: Mass Injection Rate of 625 mg/min and for the START and STOP Times of the injection, select “minutes from the drop down menu, and enter 0 and 480 minutes, respectively. In the description box, type “8 hour injection” since 480 minutes corresponds to an 8 hour injection. (For descriptions of the other parameters shown in this dialogue box, see below.) Click “OK”.



“Concentration Zero Threshold (mg/L)” is the concentration of contaminant in the distribution below which it will not be tracked. This feature behaves like a detection limit, that is, any concentration value below this value will be recorded as zero.

“WQ Tolerance (mg/L)” refers to the EPANET water quality tolerance parameter. 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]. The water quality tolerance determines whether the quality of one parcel of water is the same as that of another 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]. Generally, lowering the water quality tolerance will provide increased accuracy of the water quality modeling results at the expense of increased simulation time.

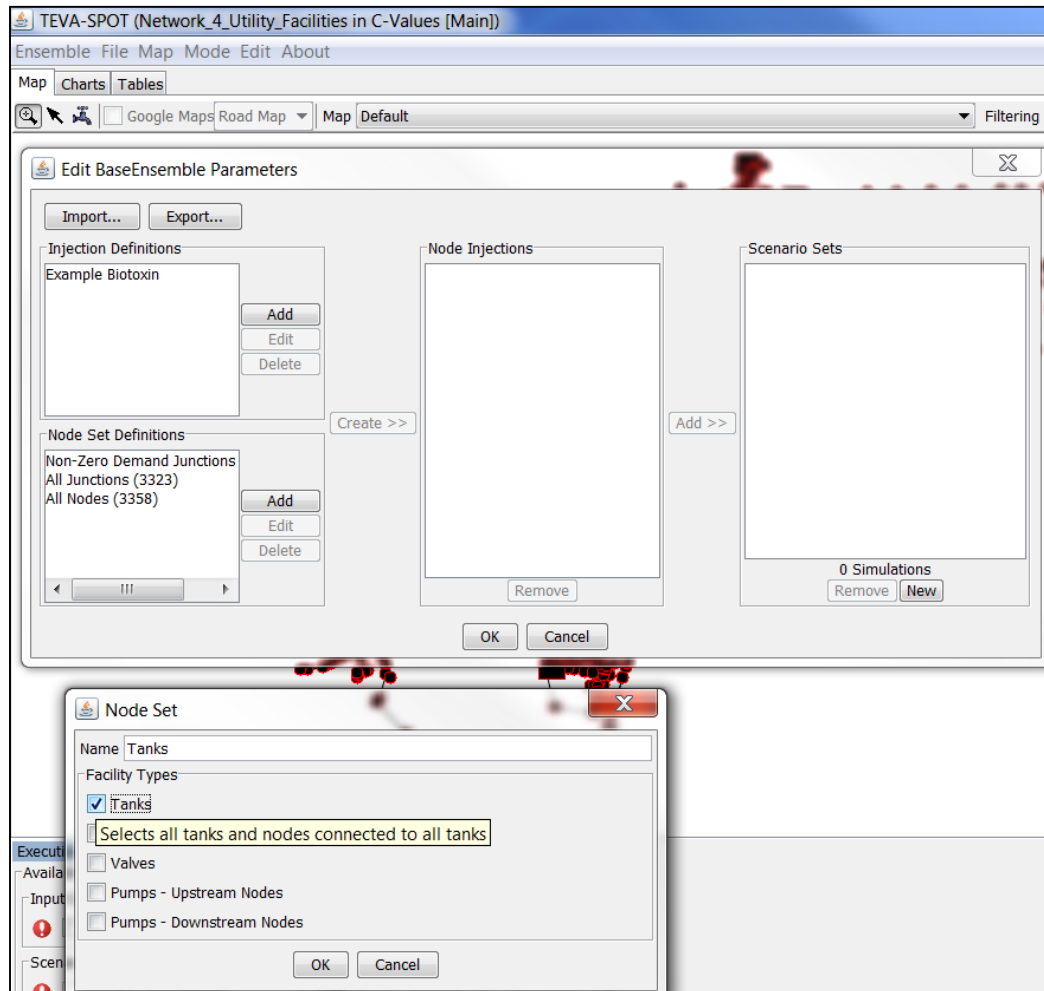
Inserting a WQ Tolerance (mg/L) value in this step (within the Injection Definition box pictured above) will override the WQ Tolerance specified in the EDIT/ Ensemble Options box; however no value need be specified here.

Note that the actual START time of the contaminant injection is defined in the .inp file, which for the example model being used here is 12:00 AM local time.

Contamination Scenarios

Step 3.2.3.

Click “Add” under the “Node Set Definitions” and select “Facility Nodes”. In the Name field, type “Tanks”. Check the “Tanks” component. Click “OK”. Note that in addition to all tanks, connected nodes are also included.

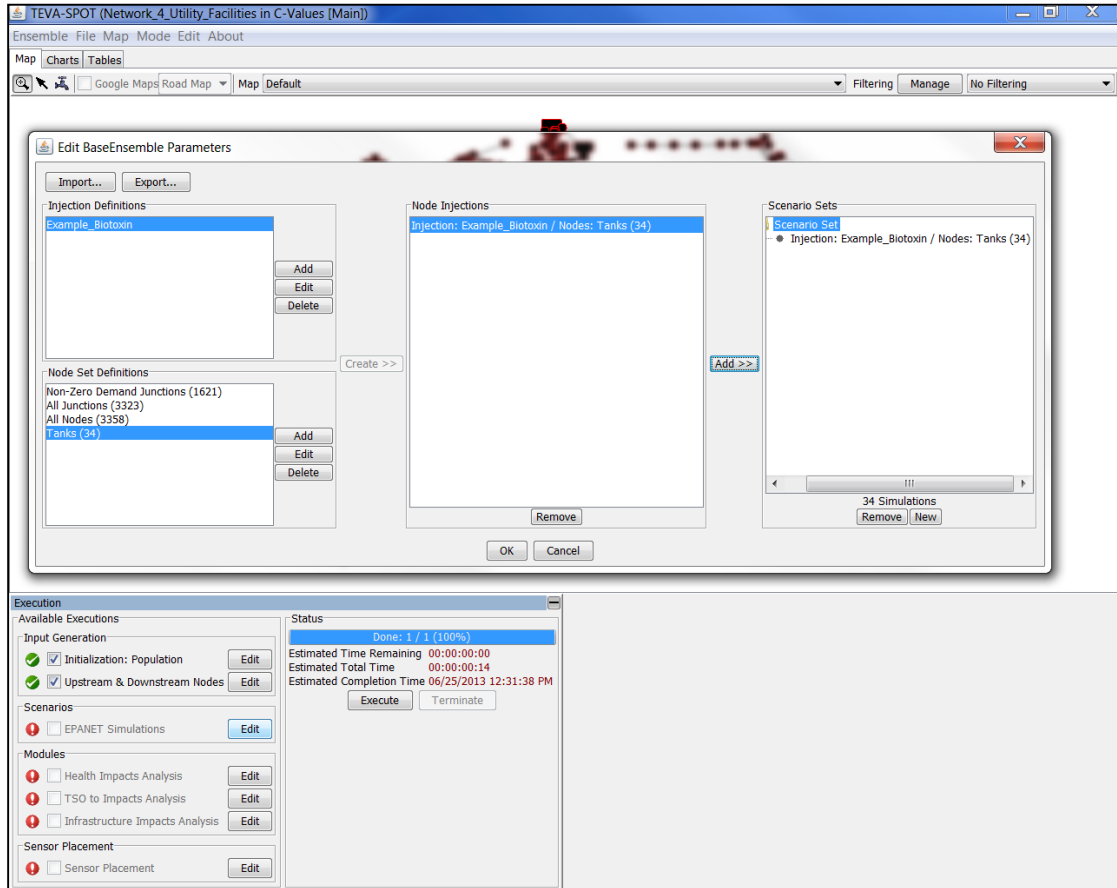


The example here demonstrates how a “Utility Facility” node set is created. The use of “Tanks” as the only component of the “Utility Facility” node set is arbitrary. All utility facilities could be selected to represent all the water system components as locations for injection.

Contamination Scenarios

Step 3.2.4.

Select “Example Biotoxin” & “Tanks”. Click “Create” “Node Injections”. Click “New” under “Scenario Sets”. A folder appears. In the Node Injections box, select: “Injection: Example Biotoxin/Nodes: Tanks (34)”. Below the Scenario Sets box, click “New”. The folder name “Scenario Set” will appear; click on “Scenario Set”. Click “Add” to add to “Scenario Sets” folder. Click “OK” and the “Edit BaseEnsemble Parameters” box disappears.

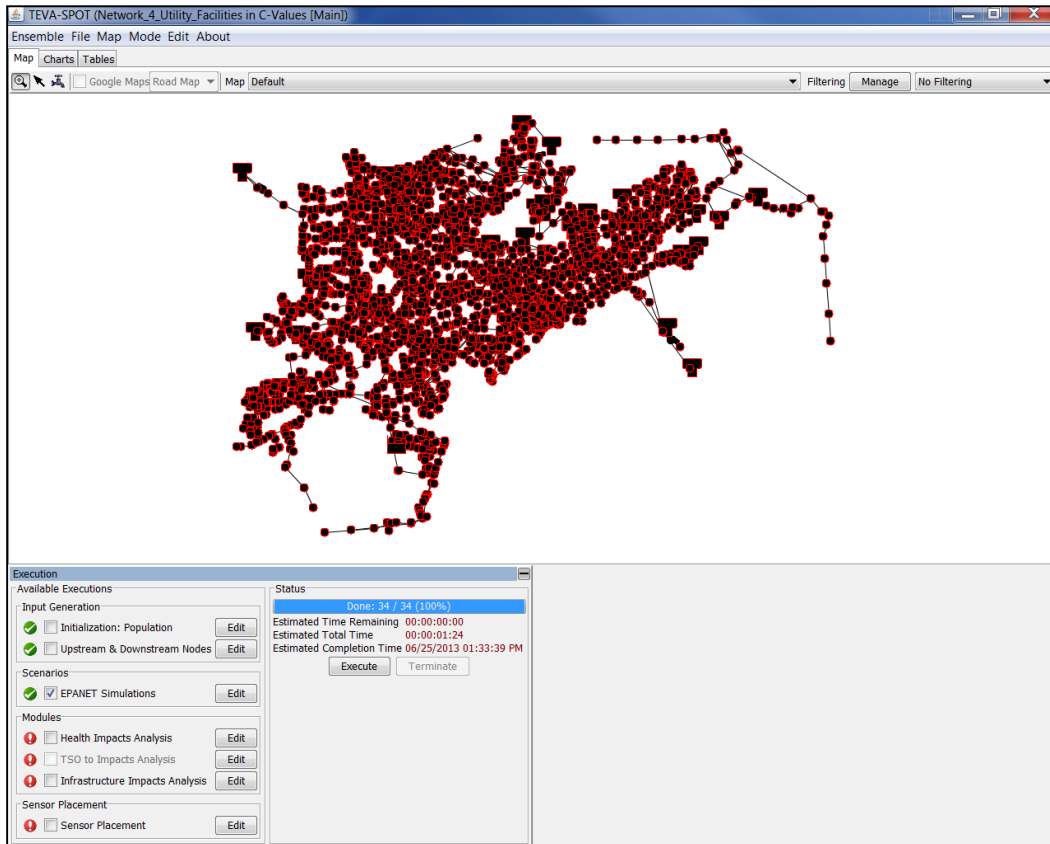


Example here demonstrates how a “Utility Facility” node set is combined with an “Injection Definition” to create an ensemble of contamination scenarios.

Contamination Scenarios

Step 3.2.5.

There is no need to re-run the “Initialization: Population” and the “Upstream & Downstream Nodes”, so unclick those boxes if they are still checked. Click the EPANET Simulation EDIT box and then click EXECUTE. Execution time could take a while (from a few minutes to many hours or even days) depending on the network model, the number of contamination scenarios being executed, and the computer that is being used. The simulation of contamination scenarios is running properly when the scenarios are being counted down, e.g., “running 2 of 34...”. EPANET Simulations are executed and completed. Green checkmark appears.



Note that multiple applications of TEVA-SPOT-GUI (each application is termed an “Ensemble”) can be opened at once and, if desired, executed together. Executing the desired modules within multiple ensembles will result in TEVA-SPOT-GUI running all the modules in a sequential fashion, i.e., one after another in the order they were started, until all are complete. After the Utility Facility ensemble is created, it will be executed. If modules are not executed together, each application should be *unchecked*, if needed, after it is run to avoid the time-consuming re-running of the application as other applications are selected for execution.

3.3 Health Impacts Analysis

Within the *Health Impacts Analysis* module, TEVA-SPOT-GUI provides for the selection and input of (1) dose calculation parameters and (2) dose response method and parameters, including disease progression parameters. TEVA-SPOT-GUI version 2.3.1 estimates public health consequences from the ingestion of contaminated tap water.

The health impacts analysis module provides the capability to assess public health consequences in terms of dose received or a health effects end point using contaminant-specific dose response information entered by the user. A check mark in the box “Calculate Dose-Response” will enable or, if absent, disables 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. We demonstrate the use of the probit slope method here. For “Chemical/Toxin” contaminants, health consequences are based on a lethal dose (LD). 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 (LD_{50}) given such a dose. For “Biological”, the user enters their contaminant-specific ID dose that would result in 50% of the population becoming diseased or infected (ID_{50}) 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 LD_{50} values are specified in terms of mg of chemical or toxin per kilogram of body weight.

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 “Contaminant 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 measure available will be “Dose Thresholds”. If the dose threshold-based approach is desired, 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].

Our example biotoxin has a lethal dose to 50 percent of the population (LD_{50}) of 6.00×10^{-6} mg/kg. We use a probit dose response model with a beta slope factor of 0.6711 to characterize health effects (i.e., fatalities) for a given dose of the biotoxin. The fatality rate is determined by the probit dose response

curve. For demonstration purposes, we consider the typical adult person's body mass to be 71.8 kg and their mean per capita water ingestion rate to be 1.41 liters per day. We assume a person's dose of the biotoxin is solely from the ingestion of contaminated tap. We use the "five fixed times" ingestion timing model in TEVA-SPOT [6]. The contaminant description and distribution system model used are for demonstration purposes.

The setup and execution of the health impacts analysis module requires two steps: (1) step 3.3.1, entering the needed parameters and (2) step 3.3.2.

Health Impacts Analysis

Step 3.3.1.

In the “Execution” dialogue box, in the “Modules” box, click “EDIT” button next to the “Health Impacts Analysis” or HIA module. Input the parameters shown in the screen capture to the right to complete the data inputs for the HIA module. Click “OK”.

Edit Health Impacts Analysis Parameters

Contaminant Name: Example_Biotoxin

Dose Calculation Parameters

Dose Calculation Method: Ingestion of Tap Water

Ingestion Timing Model: ATUS

Ingestion Volume Model: Fixed Volume

Mean Volume (liters/person/day): 1.41

Dose Thresholds

Dose Thresholds: [] Edit

Response Thresholds: [] Edit

Miscellaneous

Number of worst-case fatality scenarios to save: 0

Number of worst-case dosage scenarios to save: 0

☐ Use one server per node

☒ Calculate Dose-Response

Dose Response Options

Contaminant Defaults: Select...

Contaminant Type: Chemical/Toxin

Average Body Mass (kg): 71.8

Dose Response Method

Dose-Response calculation method: Probit

LD50 (mg/kg): 6.00E-6

Beta: 0.6711

Disease Progression Parameters

Latency Time (hrs): 1

Fatality Time (hrs): 48

OK Cancel

Miscellaneous: Placing a number (integer only) in the boxes in the Miscellaneous section, i.e., next to either “Number of worst-case fatality scenarios to save” or “Number of worst-case dosage scenarios to save” will save contaminant concentration data per time step of the simulation (fatality scenarios) and/or dosage data per time step of the simulation (dosage scenarios) for the number of highest ranked scenarios indicated.

The purpose of “fatality scenarios” and “dosage scenarios” in TEVA-SPOT-GUI and, as described here, is only for the purpose of saving and retrieving contaminant concentration data or dosage data for high percentile consequence contamination scenarios.

The resulting “fatality scenarios” and “dosage scenarios” based text files, one for each scenario saved, will be saved to the C:\TEVA-SPOT-Database\C-Values\Network_4_Utility_Facilities\Health Impacts Analysis folder. For large networks (>10K nodes), each file saved can be large; therefore, the storage requirement to save many such files maybe very large. It is important that a relatively small number be placed in these boxes box, i.e., typically on the order of 10 or less.

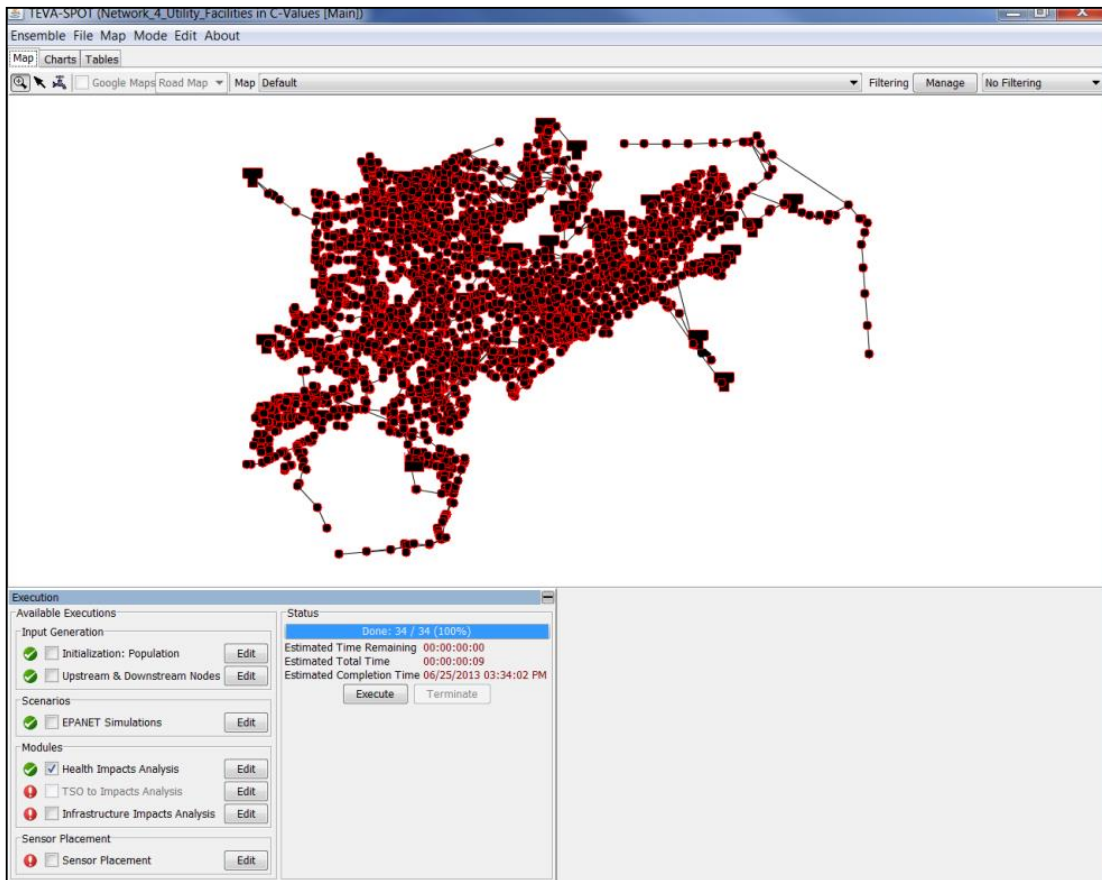
Use one server per node: Check this box only if your computer’s resources (processing speed, number of computer cores and memory are very limited).

Dose Thresholds: An alternate method for determining public health consequences.

Health Impacts Analysis

Step 3.3.2.

If checked, unclick the EPANET Simulations as there is no need to execute this scenario again. Click the “Health Impacts Analysis” module and then click “EXECUTE”. Execution time could take a while (from a few minutes to a number of hours) depending on the size of the network model, the number of contamination scenarios being run, and the computer that is being used. Green checkmark will appear when the Health Impacts Analysis module completes successfully.



The Health Impacts Analysis (HIA) module completes.

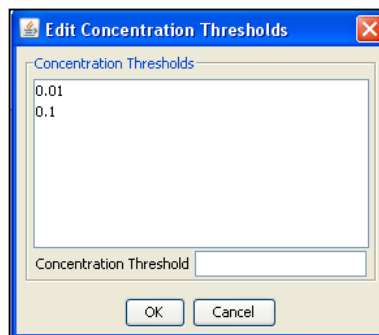
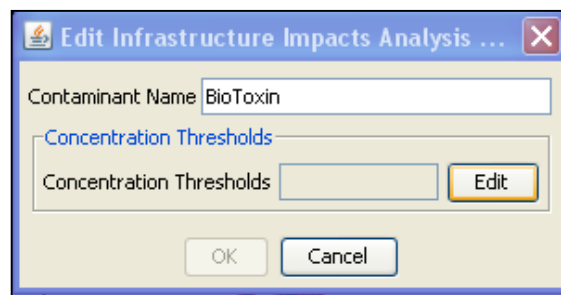
Note: It is faster (more computationally efficient) to run the EPANET Simulations along with the “Impacts Analysis Modules”, i.e., HIA and IIA.

3.4 Input of Infrastructure Impacts Analysis Data

TEVA-SPOT-GUI provides for the analysis of infrastructure consequences as determined by the length of pipe (ft) that witnesses contaminant concentrations above a user specified concentration threshold. Steps 3.4.1 and 3.4.2 demonstrate this module.

Step 3.4.1.

In the “Execution” dialogue box, under the “Modules” box, select EDIT next to the *Infrastructure Impacts Analysis* Module. Place cursor in box labeled “Concentration Threshold” and type “0.01”; press ENTER. Next, type “0.1” and press ENTER. Click “OK” to close the “Edit Concentration Thresholds” dialogue box and again to close the “Edit Infrastructure Impacts...” dialogue box.

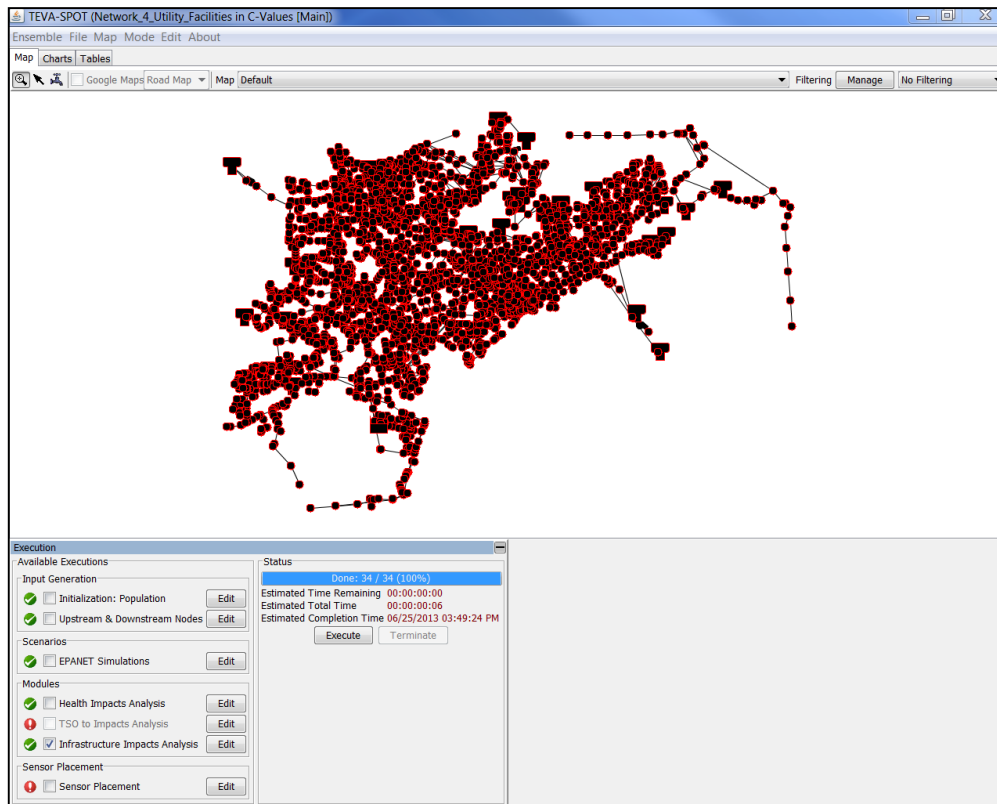


Multiple contaminant concentration thresholds can be specified. Enter the value and press ENTER. The values specified above are only for demonstration purposes.

Infrastructure Impacts Analysis

Step 3.4.2.

Unclick all boxes. Then click the “Infrastructure Impacts Analysis” module to check it and then click “EXECUTE”.



GREEN CHECK MARKS denote that the Infrastructure Impacts Analysis (HIA) module has completed running.

3.5 Determining Utility Facility C-Values

Public health and/or infrastructure consequences can result from the injection of a contaminant at a particular utility facility. Through the analysis of the example biotoxin threat (Sections 3.1 to 3.4) TEVA-SPOT-GUI enables the user to estimate public health and infrastructure consequences that could result from the intentional injection of the contaminant at each of the utility facilities selected. The consequences that are estimated to result from the injection at each utility facility represent each particular facility's C-Value.

Once the utility facility C-Values are determined they can be used to rank the utility facilities that represent the greatest concern for intentional contamination given the injection of the example biotoxin. Ranking of utility facilities can be based on public health C-Value and infrastructure damage (e.g., extent of pipe feet witnessing contamination) C-Value.

The C-Value associated with each facility can be obtained in a variety of ways, e.g., tables or maps, available from within the TEVA-SPOT graphical user interface or, depending on the data, within the TEVA-SPOT-Database for the particular ensemble.

We demonstrate the retrieval of utility facility C-Values from TEVA-SPOT-GUI and the ranking of utility facilities by their public health C-Value that could result if contamination were introduced at the particular facility. We also demonstrate how to retrieve utility facility C-Values based on infrastructure contamination and show how to use the information to rank the utility facilities based on infrastructure consequences. For any given ensemble of contamination events, the n th percentile injection node is the injection node that yields the n th percentile consequence or C-Value. TEVA-SPOT-GUI ranks contamination injection locations by public health consequences, e.g., fatalities, and by infrastructure consequences, e.g., feet of pipe that witness contamination above a certain level. TEVA-SPOT-GUI ranks a given ensemble's contamination injection locations according to six percentile scenarios, namely 10th, 25th, 50th, 75th, 90th and 100th. More detailed information is provided for this ranked contamination injection locations. Table 3.5.1 provides a tabular description of some of the TEVA-SPOT-GUI outputs that can be used for retrieving and evaluating utility facility C-Values. Table 3.5.1 also provides a roadmap to the TEVA-SPOT-GUI illustrative screen shots presented in this section.

Table 3.5.1: Description of Selected TEVA-SPOT-GUI Outputs to Determine, Rank, and Evaluate C-Values

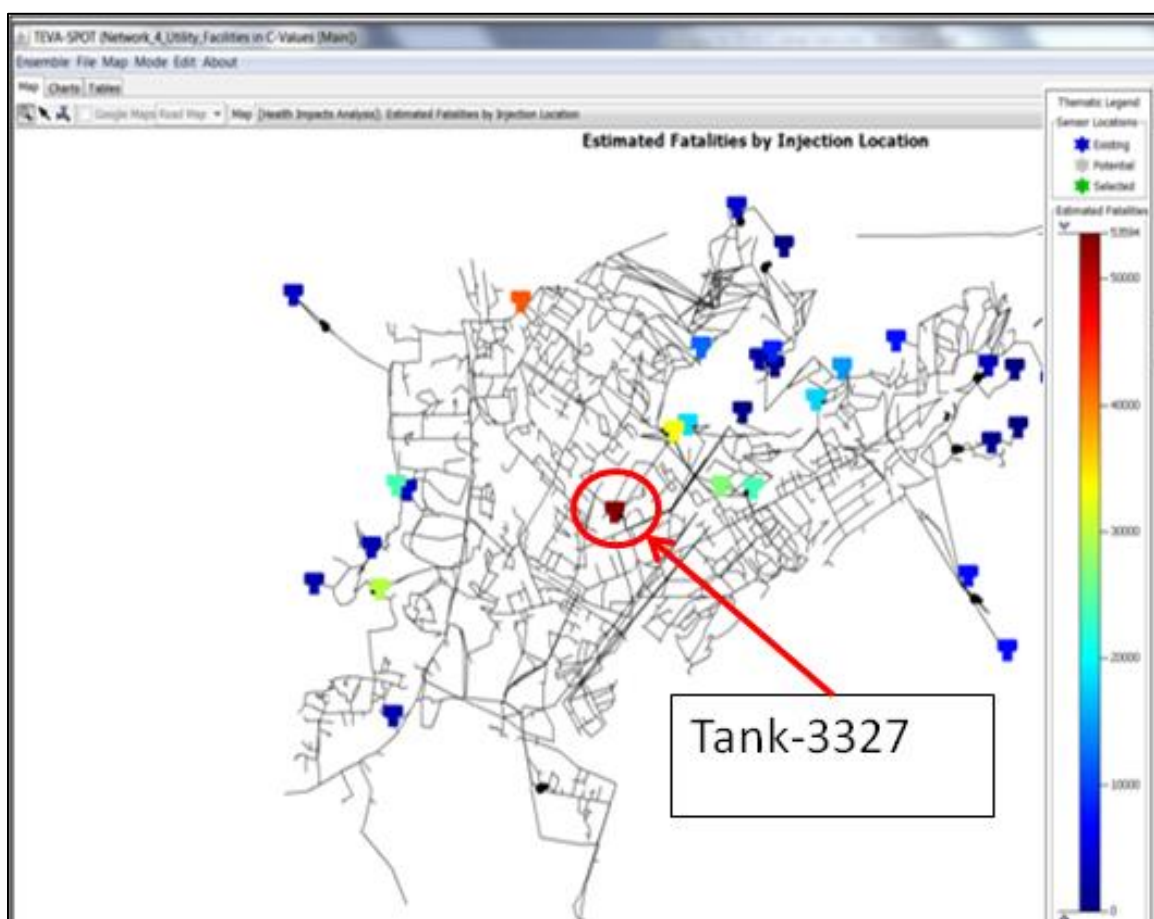
Step	Map or Table	Use
3.5.1	Map: Estimated Fatalities by Injection Location	Obtain a map of utility facility C-Values. Map provides a visual ranking of utility facilities, color-coded by largest public health C-Value.
3.5.2	Maps: Estimated Fatalities by Receptor Location – various percentile (25, 50, 75, 90, and 100 th) maps.	Obtain detailed information about where public health consequences occur in the network given contaminant injection at a particular utility facility.
3.5.3/3.5.4	Table: Injection Impacts Table: Summary Table	Obtain tabular utility facility C-Values results. Use these results to rank utility facilities by largest C-Value.
3.5.5	Table: Estimated Fatalities Receptor Nodes Table	Examine ranking of utility facilities by C-Value (e.g., examine number of fatalities by receptor locations for six, ranked percentile scenarios ranging from 10 th to 100 th percentile). Use data to evaluate highest ranked utility facilities.
3.5.6/3.5.7	Map: Infrastructure Impacts Analysis: Feet of Pipe with Concentrations Over 0.01 by Injection Location. Although two IIA analysis concentration thresholds were specified, we illustrate only the case of 0.01 mg/L here.	Obtain a map of utility facility C-Values based on infrastructure impacts. Map provides a visual ranking of utility facilities by the contaminant injection location that results in the largest feet of pipe that witnesses contamination above 0.01 mg/L.

Step	Map or Table	Use
3.5.8	Map: Infrastructure Impacts Analysis: Pipes with Contamination Over 0.01 – 90 th Percentile	Obtain detailed information about which pipes witness contamination over a user-specified concentration for a particular contamination injection (utility facility) scenario.
3.5.9 to 3.5.11	Table: Upstream and Downstream Nodes: 3 tables. (1) Downstream Node Counts, (2) Downstream Population, and (3) Upstream Node Counts	Obtain additional information about the water distribution system network. Rank utility facilities by their upstream or downstream connectivity.

Retrieving and Using C-Values

Step 3.5.1.

If the “Execution” panel at bottom remains open, you should close the “Execution” dialogue box to begin this section to provide more space to viewing the maps and tables. Click on the MAP tab. Using the drop down menu next to the “Map” field bar, select the map titled, “Estimated Fatalities by Injection Location”. Note that injection locations (nodes) are color coded by the number of fatalities. Tank-3327 represents the tank that if contaminated could result in the largest public health consequences.



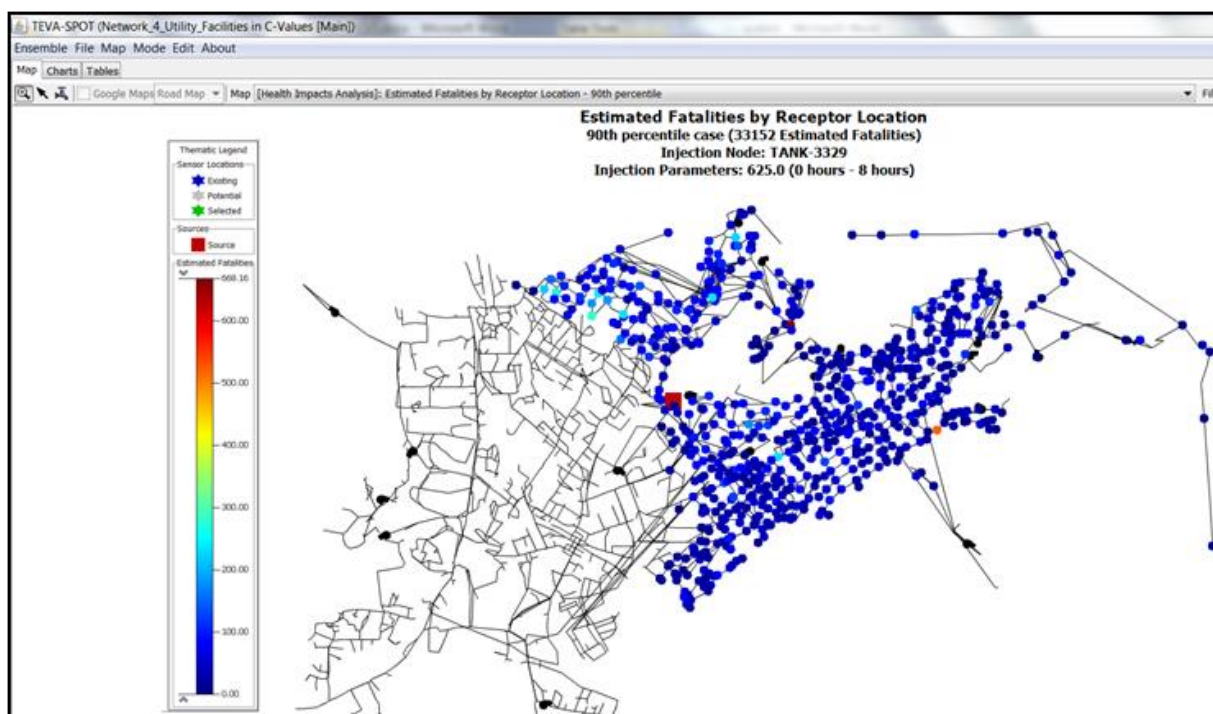
These results can be exported from TEVA-SPOT-GUI to a dbase IV file and then incorporated into a geographical information system (GIS). See “ENSEMBLE MANAGEMENT”, “EXPORT MAP DATA”.

Retrieving and Using C-Values

Step 3.5.2.

Scrolling down through the drop down menu next to the “Map” field bar, select the map titled, “Estimated Fatalities by Receptor Location - 90th percentile”. The RED SQUARE corresponds to the injection location, Tank-3329. Note that this map details estimated receptor information for a specific scenario, i.e., the estimated 90th percentile scenario based fatalities. The legend corresponds to the number of fatalities by receptor location. The map below has been altered for better viewing here, i.e., the legend has been placed on the left.

On the slider bar associated with the legend, using your mouse right click and then choose “Set min/max”. Enter the number “1” in the “min” box. This will restrict the view of fatalities by receptor location to just those locations that experienced one or more estimated fatalities. This will not be necessary with later versions of TEVA-SPOT-GUI (i.e., 8-07-13 and later).



These results can be exported from TEVA-SPOT-GUI to a dbase IV file and then incorporated into a geographical information system (GIS). See “ENSEMBLE MANAGEMENT”, “EXPORT MA DATA”.

Retrieving and Using C-Values

Step 3.5.3.

Select the TABLES tab. Then, using the drop down menu next to the table field bar, select the “Injection Impacts Table”. This table provides each contamination scenario’s (i.e., each tank) consequences in terms of “Estimated Fatalities” (see RED CIRCLE). Other information is available, but we restrict our attention to the public health based C-Values.

This table can be used to determine the utility-based locations (node IDs) that would result in the greatest consequences if contaminated.

TEVA-SPOT (Network_4_Utility_Facilities in C-Values [Main])									
Ensemble File Table Mode Edit About									
Map Charts Tables									
Table [Health Impacts Analysis]: Injection Impacts Table									
Summary Table									
Injection Node	Injection	Node Type	Max Con...	Max Indi...	Number	Number of Estimated Fatalities	Nodes for 90% Estimated Fatalities		Nodes with Fatalities
TANK-3327	625.0 (0 hours - 8 hours)	T	0.01	6.149	59,597.133	22,997.133	598		1327
TANK-3357	625.0 (0 hours - 8 hours)	T	0.147	6.623	42,399.352	42,399.352	558		886
TANK-3328	625.0 (0 hours - 8 hours)	T	0.076	2.488	33,147.598	33,147.598	486		725
TANK-3329	625.0 (0 hours - 8 hours)	T	0.076	2.488	33,147.176	33,147.176	486		725
TANK-3325	625.0 (0 hours - 8 hours)	T	0.028	38.116	29,633.979	29,633.979	623		1327
TANK-3332	625.0 (0 hours - 8 hours)	T	0.065	13.63	27,127.219	27,127.219	366		531
TANK-3330	625.0 (0 hours - 8 hours)	T	0.013	7.327	24,047.053	24,047.053	547		1212
TANK-3331	625.0 (0 hours - 8 hours)	T	0.015	8.529	23,894.68	23,894.68	263		371
TANK-3337	625.0 (0 hours - 8 hours)	T	0.059	22.647	18,274.752	18,274.752	249		371
TANK-3339	625.0 (0 hours - 8 hours)	T	0.043	19.353	17,835.127	17,835.127	209		371
TANK-3338	625.0 (0 hours - 8 hours)	T	0.043	19.353	17,835.127	17,835.127	209		371
TANK-3343	625.0 (0 hours - 8 hours)	T	0.075	13.974	14,888.881	14,888.881	166		245
TANK-3344	625.0 (0 hours - 8 hours)	T	0.074	13.69	14,866.35	14,866.35	166		245
TANK-3333	625.0 (0 hours - 8 hours)	T	0.03	32.188	12,133.798	12,133.798	95		148
TANK-3351	625.0 (0 hours - 8 hours)	T	0.145	39.481	8,351.237	8,351.237	99		189
TANK-3349	625.0 (0 hours - 8 hours)	T	0.056	47.957	7,490.456	7,490.456	83		194
TANK-3348	625.0 (0 hours - 8 hours)	T	0.036	95.429	7,075.059	7,075.059	72		197
TANK-3345	625.0 (0 hours - 8 hours)	T	0.027	56.918	6,948.981	6,948.981	77		221
TANK-3334	625.0 (0 hours - 8 hours)	T	0.039	22.259	3,813.321	3,813.321	37		104
TANK-3326	625.0 (0 hours - 8 hours)	T	0.21	20.603	3,491.969	3,491.969	115		1116
TANK-3324	625.0 (0 hours - 8 hours)	T	0.039	70.186	3,335.921	3,335.921	25		40
TANK-3350	625.0 (0 hours - 8 hours)	T	0.156	54.874	2,931.155	2,931.155	33		155
TANK-3335	625.0 (0 hours - 8 hours)	T	0.07	120.256	2,857.106	2,857.106	18		40
TANK-3336	625.0 (0 hours - 8 hours)	T	0.052	113.999	2,577.351	2,577.351	29		44
TANK-3340	625.0 (0 hours - 8 hours)	T	0.048	277.003	2,121.043	2,121.043	12		22
TANK-3342	625.0 (0 hours - 8 hours)	T	0.137	143.915	1,863.13	1,863.13	15		26
TANK-3352	625.0 (0 hours - 8 hours)	T	0.189	85.242	1,685.662	1,685.662	17		31
TANK-3354	625.0 (0 hours - 8 hours)	T	0.165	104.067	1,415.245	1,415.245	14		22
TANK-3353	625.0 (0 hours - 8 hours)	T	0.112	54.621	936.31	936.31	12		16
TANK-3347	625.0 (0 hours - 8 hours)	T	0.057	44.961	421.749	421.749	4		6
TANK-3341	625.0 (0 hours - 8 hours)	T	0.157	49.131	254.818	254.818	5		6
TANK-3356	625.0 (0 hours - 8 hours)	T	0.176	130.401	161.03	161.03	2		2
TANK-3355	625.0 (0 hours - 8 hours)	T	0.142	151.513	133.522	133.522	1		1
TANK-3346	625.0 (0 hours - 8 hours)	T	0.21	18.229	112.474	112.474	4		6

Injection Node: Contamination scenario associated with each tank.

Injection: Defines the injection definition.

Node Type: Identifies node as either T (Tank), J (Junction), R (Reservoir), Pi (Pump In, Suction side), Po (Pump Out, Delivery side), and Tc (Tank Connection, node connected directly to tank).

Max Concentration: Maximum contaminant concentration that appears at receptor node and time step during the simulation.

Max Individual Dose: Maximum individual dose that any person would receive during the simulation.

Number of Estimated Infected/Fatalities: Number of people expected to die given the specified dose response model and parameters.

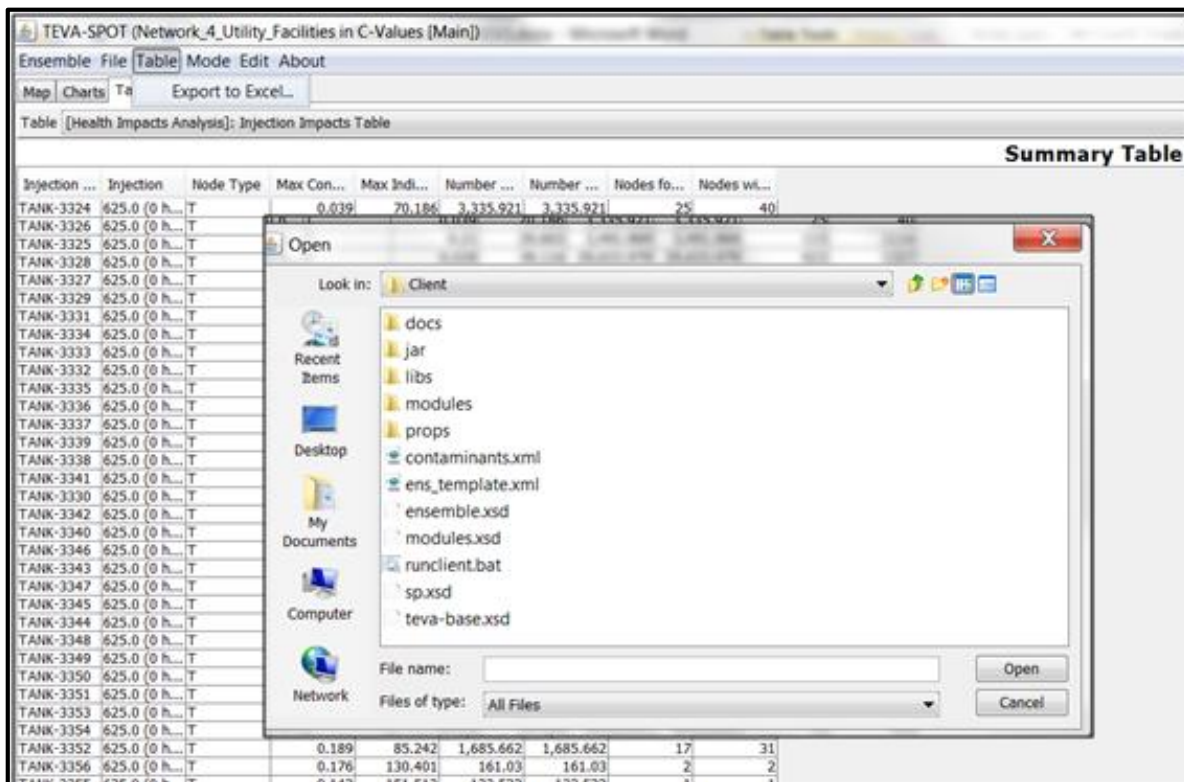
Nodes for 90% Estimated Fatalities: Number of receptor nodes that represent 90% of the estimated fatalities.

Nodes with Fatalities: Number of receptor nodes that exhibit fatalities.

Retrieving and Using C-Values

Step 3.5.4.

The results in Step 3.5.3. can be exported to EXCEL by SELECTING MENU TABLE and then choosing "EXPORT TO EXCEL...". A dialogue box appears to indicate where the .xls file should be saved.



Note: Typically under Windows 7 operating system TEVA-SPOT-GUI IS NOT ALLOWED to export an output table to the directory: C:\Program Files\TEVA-SPOT\Client. Therefore, the user should browse to an accessible location.

Retrieving and Using C-Values

Step 3.5.5.

Select the TABLE drop down menu. Next, select the “Estimated Fatalities Receptor Nodes Table”.

This table provides the number of fatalities at each receptor location for six, ranked percentile scenarios ranging from 10th to 100th (ONLY 75th PERCENTILE SHOWN).

LEVA-SPOT (Network of Utility Facilities in C-values [main])

Ensemble File Table Mode Edit About

Map | Charts | Tables

Table [Health Impacts Analysis]: Estimated Fatalities Receptor Nodes Table Filtering Manage No Filtering

Receptor Node	10th (TANK-3341 [625.0 (0 hours - 8 hours)])	25th (TANK-3342 [625.0 (0 hours - 8 hours)])	50th (TANK-3345 [625.0 (0 hours - 8 hours)])	75th (TANK-3337 [625.0 (0 hours - 8 hours)])	90th (TANK-3329 [625.0 (0 hours - 8 hours)])
JUNCTION-3212	0	0	0	1,045.386	758.986
JUNCTION-2828	0	913.189	0	0	0
JUNCTION-2609	0	0	0	0	32.88
JUNCTION-1913	0	0	0	0	0
JUNCTION-1880	0	0	0	0	0
JUNCTION-2573	0	0	0	0	278.943
JUNCTION-1855	0	0	0	0	0
JUNCTION-2222	0	0	0	0	0
JUNCTION-3075	0	0	0	0.155	181.944
JUNCTION-1856	0	0	0	0	0
JUNCTION-2310	0	0	0	0	0
JUNCTION-1873	0	0	0	0	0
JUNCTION-1969	0	0	0	0	0
JUNCTION-2647	0	0	0	0	61.85
JUNCTION-1619	0	0	0	0	0
JUNCTION-1638	0	0	0	0	0
JUNCTION-1948	0	0	0	0	0
JUNCTION-3098	0	0	0	220.835	162.724
JUNCTION-2092	0	0	0	0	0
JUNCTION-2097	0	0	0	0	0

Note that the table above has been truncated for viewing here.

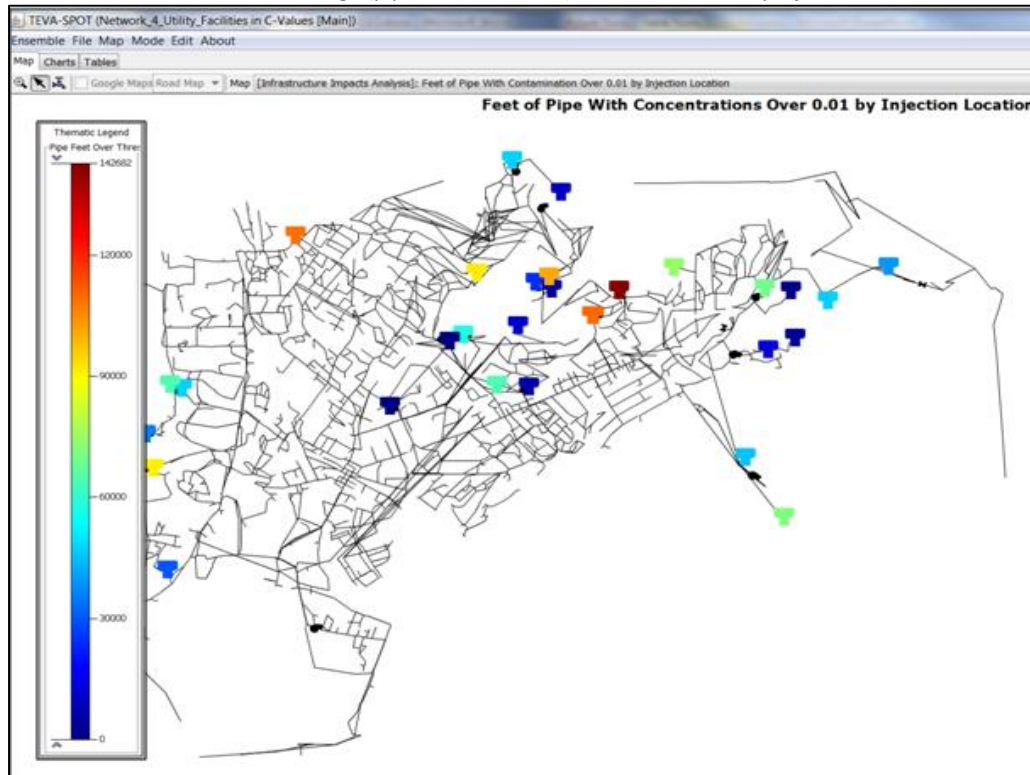
Columns (except first column) represent the percentile (ranked utility facilities). Rows represent the receptor locations for each utility facility contamination injection location. Each cell in the table represents the number of people expected to die (fatalities).

These results can be exported to EXCEL (.xls) file using the approach described in Step 3.5.4.

Retrieving and Using C-Values

Step 3.5.6.

Select the MAP tab. Next, select the “Infrastructure Impacts Analysis” map titled “Feet of Pipe with Contamination Over 0.01 by Injection Location”. Infrastructure damage (pipe contamination) can be examined by Injection Location.



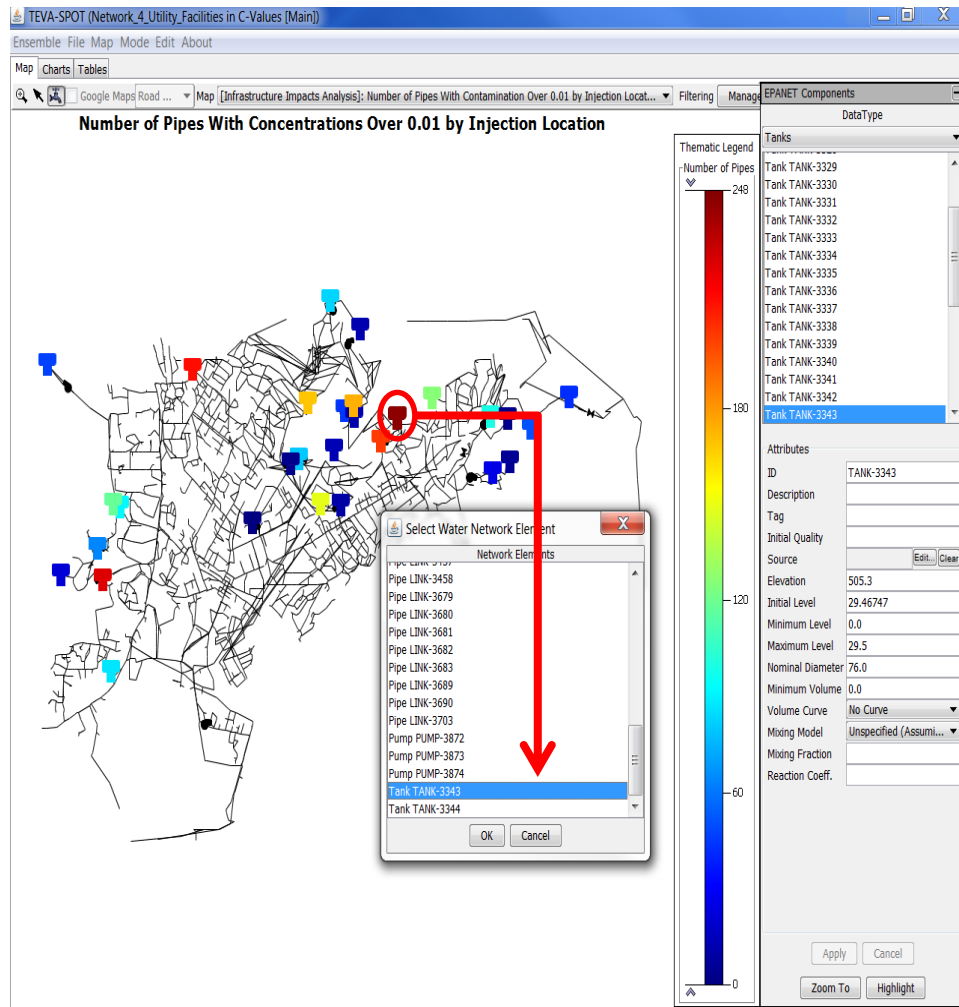
Note: For viewing purposes, this screen shot has been modified to fit this format. All MAP data can be exported for incorporation into GIS using ENSEMBLE MANAGEMENT and EXPORT MAP DATA.

Note: Recall that the contaminant concentration value of 0.01 mg/L was specified in Step 3.4.1. The values used are for demonstration purposes only.

Retrieving and Using C-Values

Step 3.5.7

Click on the water faucet icon within the MAP TAB and the “EPANET Components” panel will appear. Next, with the water faucet icon SELECTED, click on the darkest red tank and notice the panel “Select Water Network Element” appears. The arrow icon, in between the magnifier glass and the faucet, can be used to move the map. Within the “Select Water Network Element” box, use scroll bar to maneuver to bottom to see that this color-code Tank could be Tank-3343 or Tank-3344. Use the magnifier glass to ZOOM in to see the two tanks (not illustrated here).



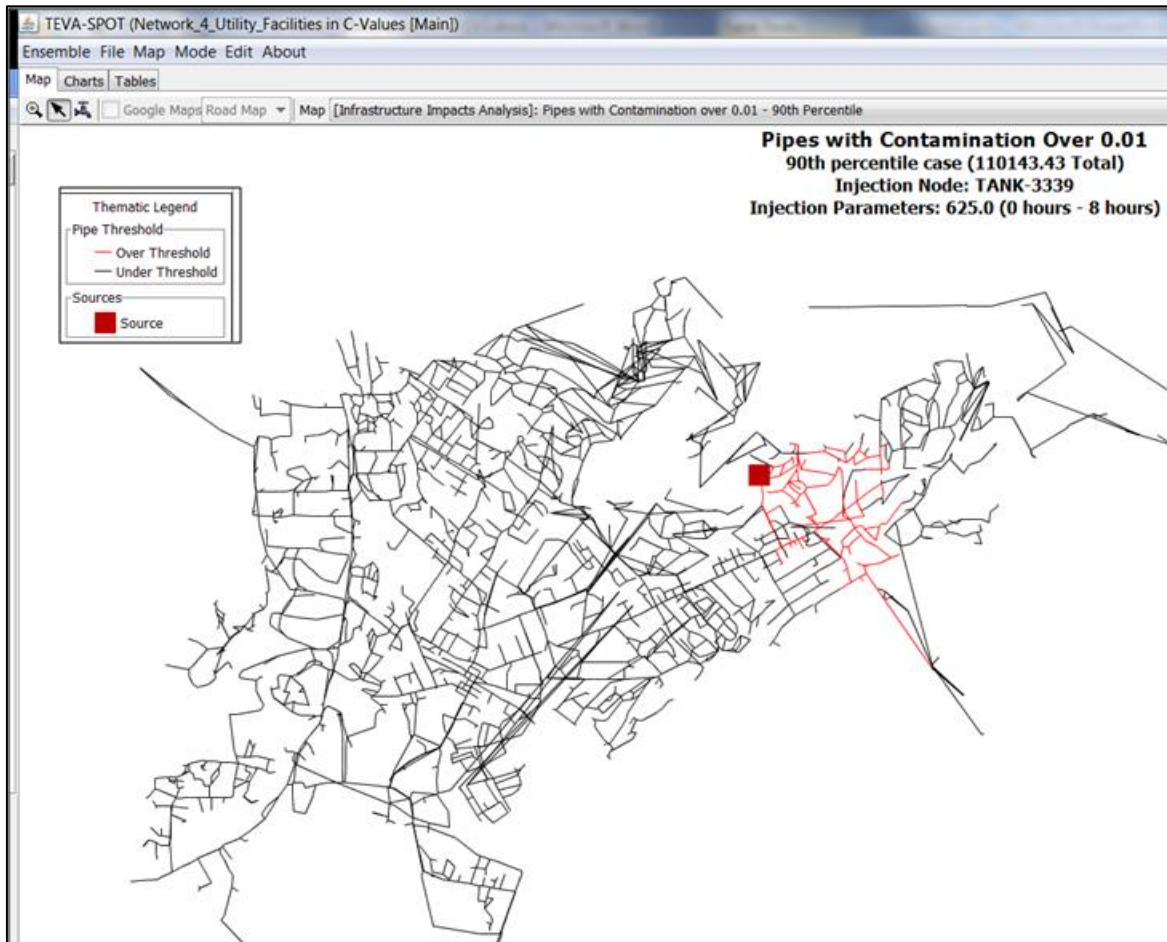
Use the “Water Faucet” icon to examine model elements in more detail. Notice that the map above is for “Number of Pipes with Concentrations Over 0.01 Injection Location”; whereas, the map in the previous step was “Feet of Pipe...”. Both versions of maps are available.

Note: Recall that the contaminant concentration value of 0.01 mg/L was specified in Step 3.4.1. The values used are for demonstration purposes only.

Retrieving and Using C-Values

Step 3.5.8.

Select the MAP tab. Next, select the “Infrastructure Impacts Analysis” map titled “Pipes with Contamination over 0.01 – 90th Percentile”. Infrastructure damage (pipe contamination) can be examined for specific, percentile ranked facilities, such as the 90th percentile scenario highlighted here.



All MAP data can be exported for incorporation into GIS using ENSEMBLE MANAGEMENT and EXPORT MAP DATA.

Retrieving and Using C-Values

Step 3.5.9.

Select the TABLES tab. Next, select the table “Upstream & Downstream Nodes: Downstream Population Table”. The table below is available as a result of executing the first two modules: “Initialization: Population” and “Upstream & Downstream Nodes”.

TEVA-SPOT (Network_4_Utility_Facilities in C-Values [Main])				
Ensemble File Table Mode Edit About				
Map Charts Tables				
Table [Upstream & Downstream Nodes (UpDownStreamNodes)]: Downstream Population Table				
Downstream Population Simulation Length: 168 hours Total Population: 151938				
Injection Node	# of Downstream Nodes	Dead End?	Downstream Population	Downstream Population %
TANK-3357	3357	N	151938	100.0%
TANK-3356	6	N	163	0.1%
TANK-3355	7	N	136	0.1%
TANK-3354	48	N	1459	1.0%
TANK-3353	30	N	1063	0.7%
TANK-3352	71	N	2034	1.3%
TANK-3351	464	N	18031	11.9%
TANK-3350	464	N	18031	11.9%
TANK-3349	464	N	18031	11.9%
TANK-3348	464	N	18031	11.9%
TANK-3347	18	N	766	0.5%
TANK-3346	12	N	122	0.1%
TANK-3345	464	N	18031	11.9%
TANK-3344	464	N	18031	11.9%
TANK-3343	464	N	18031	11.9%
TANK-3342	43	N	2085	1.4%
TANK-3341	15	N	266	0.2%
TANK-3340	50	N	2723	1.8%
TANK-3339	701	N	30339	20.0%
TANK-3338	701	N	30339	20.0%
TANK-3337	701	N	30339	20.0%
TANK-3336	157	N	3966	2.6%
TANK-3335	83	N	3543	2.3%
TANK-3334	3357	N	151938	100.0%
TANK-3333	3357	N	151938	100.0%
TANK-3332	3357	N	151938	100.0%
TANK-3331	3357	N	151938	100.0%
TANK-3330	3357	N	151938	100.0%
TANK-3329	3357	N	151938	100.0%
TANK-3328	3357	N	151938	100.0%
TANK-3327	3357	N	151938	100.0%
TANK-3326	3357	N	151938	100.0%
TANK-3325	3357	N	151938	100.0%
TANK-3324	86	N	3543	2.3%
RESERVOIR-3323	3357	N	151938	100.0%

This table provides for each node: (1) number of downstream nodes, (2) whether the injection node is a dead-end node – yes (Y) or no (N), (3) downstream population, and (4) downstream population as a percentage of the total population. A dead-end node is any node that does not have a downstream node. In TEVA-SPOT-GUI it is determined hydraulically and, therefore, is dependent on the simulation time.

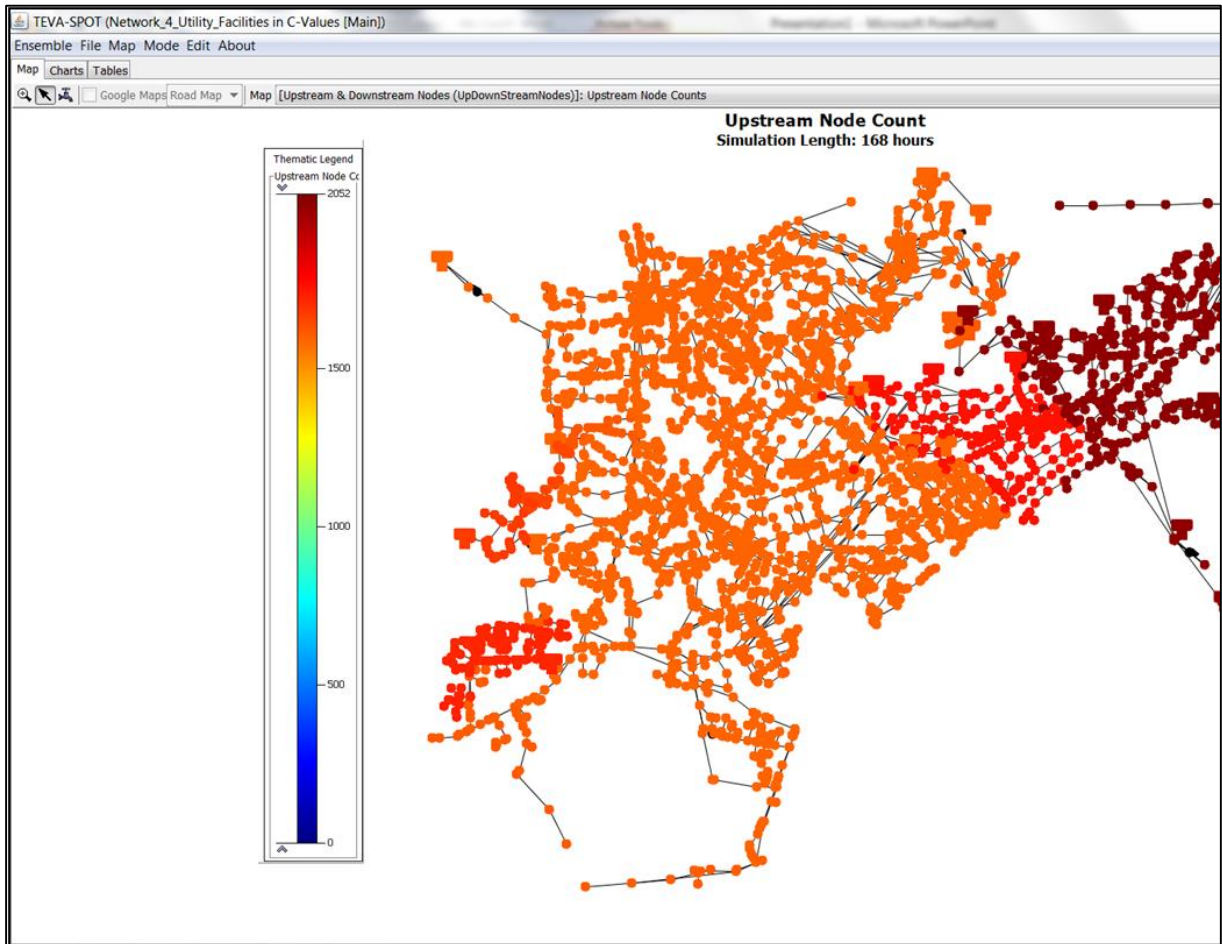
Here injection node is every node in the model NOT just the injection nodes described by the ENSEMBLE definition.

These results can be exported to EXCEL by SELECTING MENU TABLE and then choosing “EXPORT TO EXCEL...”. A dialogue box appears to indicate where the Excel.xls file should be saved.

Retrieving and Using C-Values

Step 3.5.10.

Select the MAP tab. Select “Upstream Node Counts”.

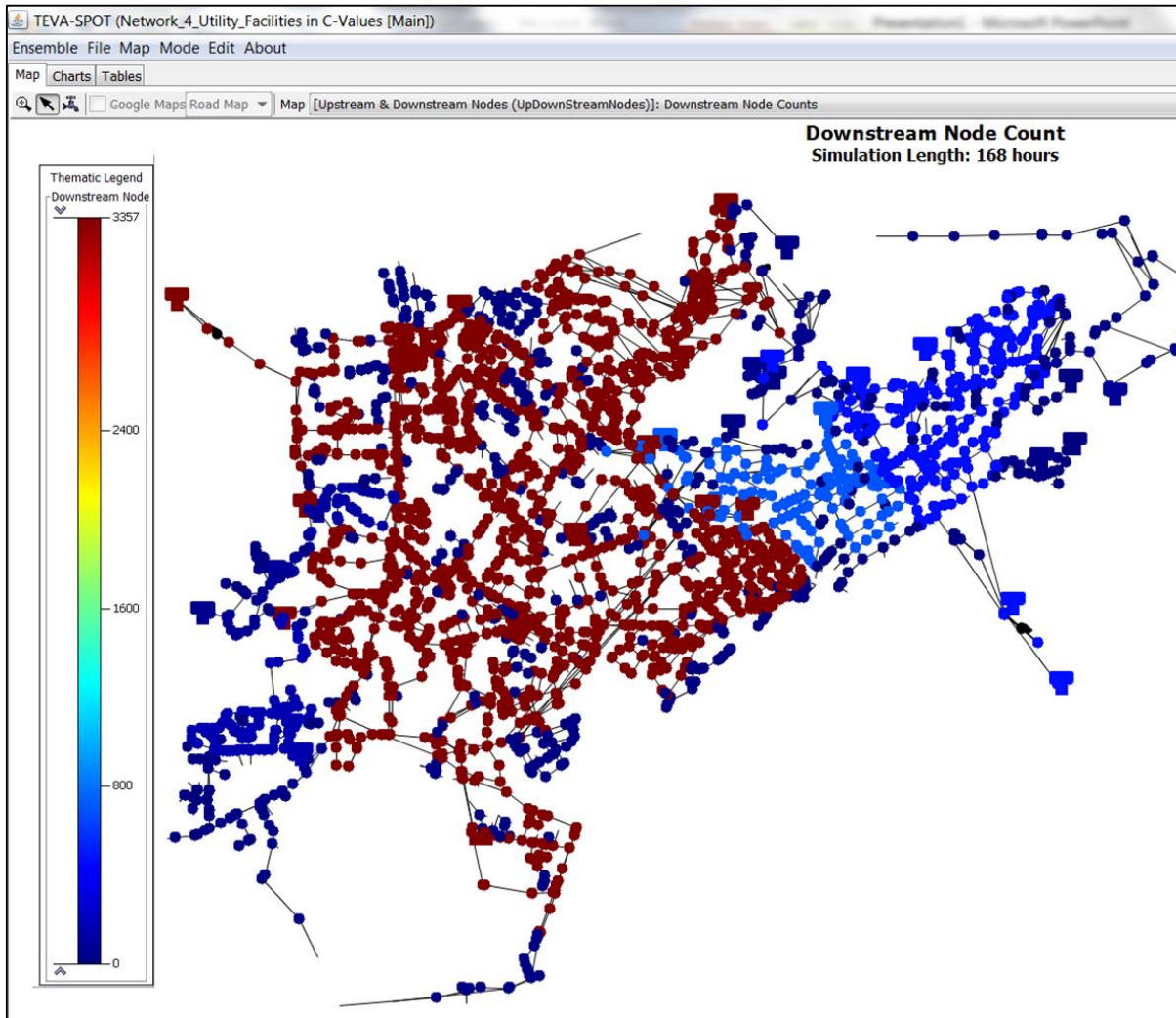


Note: For viewing purposes, this screen shot has been modified to fit this format. This map illustrates the areas of the network (color coded) that are fed by the largest number of upstream nodes. For example, the dark red nodes are fed by the largest number of upstream nodes. All MAP data can be exported for incorporation into GIS using ENSEMBLE MANAGEMENT and EXPORT MAP DATA.

Retrieving and Using C-Values

Step 3.5.11.

Select the MAP tab. Select “Downstream Node Counts”.



Note: For viewing purposes, this screen shot has been modified to fit this format. This map illustrates the areas of the network (color coded) that feed the largest number of downstream nodes. For example, the dark red nodes feed the largest number of downstream nodes. All MAP data can be exported for incorporation into GIS using ENSEMBLE MANAGEMENT and EXPORT MAP DATA.

4 PROTECTING CRITICAL FACILITIES.

In this section we describe the process for using TEVA-SPOT-GUI to evaluate a set of user-defined critical facilities for their upstream vulnerability to contamination. Specifically, a user can identify a set of locations as critical facilities and TEVA-SPOT-GUI will determine the set of upstream network locations that supply water and, therefore, could potentially contaminate a critical facility. For example, hospitals, schools, or other critical infrastructure can be identified and TEVA-SPOT-GUI can be used to help protect them. Since utility facilities are separately identified by TEVA-SPOT-GUI, they are not considered critical facilities. By determining the upstream locations that could most affect the critical facilities, TEVA-SPOT-GUI helps the user to prioritize SRS efforts and resources to protect critical facilities. This feature can also be used to help determine the best locations to place monitoring stations to protect the critical facilities. Here, again, we define critical facilities to not include utility facilities in order to avoid confusion. Utility facilities were examined in Section 3.0.

Critical Facilities can be evaluated after executing the module “UpDownStreamNodes”. The “UpDownStreamNodes” module must be run prior to the “EPANET Simulations” module in order for the critical facilities capability to be available. In Step 3.1.8 we demonstrated how to run this module. Here, we demonstrate how to select or upload a list of critical facilities into TEVA-SPOT-GUI and then use the consequence assessment modules to evaluate the ensemble of contamination scenarios. The user selects or inputs a list of critical facility nodes, which TEVA-SPOT-GUI then determines the ensemble of associated contamination scenarios that could affect the critical facilities identified. The contamination scenarios are then simulated in the “EPANET Simulations” module. Consequences are determined using the public health and infrastructure modules described earlier. Similarly, consequence results can be retrieved from TEVA-SPOT-GUI as described in Section 3.5 and Table 3.5.1.

The user identifies critical facilities by node ID. The node identifier for a particular critical facility could be obtained from the geographical information system (GIS) database for the water distribution system model. Alternatively, the user could identify the model node for each critical facility by using the available mapping features with TEVA-SPOT-GUI. The mapping features are described in Section 5.0.

We also demonstrate how to use the sensor placement module to identify the preferred locations for monitoring a group of critical facilities. The goal in designing such a monitoring strategy is to minimize, subject to a constraint on the number of sensors, the consequences associated with contamination event(s) directed at the critical facilities.

The process described will base the selection of the monitoring locations on minimizing public health consequences (fatalities). The process described assumes that all the upstream locations identified are equally likely locations for intentional contamination and, therefore, the monitoring locations selected will seek to minimize the expected or mean consequences across the network. This means that sensor monitoring locations are selected to minimize the mean public health consequences given the ensemble of contamination events simulated.

Additionally, we demonstrate how to *fix* a sensor at a critical facility to ensure that a monitoring sensor is placed at each critical facility to prevent consequences from occurring at the critical facility. Without

fixing a sensor at each critical facility TEVA-SPOT optimizes the placement of sensors upstream of the critical facility to minimize the mean consequences determined from the group of upstream contamination scenarios. In other words, each critical facility would be protected only from the extent of minimizing the mean consequences associated with the upstream contamination scenario locations. Therefore, without fixing a sensor at each critical facility, consequences could still occur at the critical facility. For a given set of sensor monitoring stations, TEVA-SPOT will optimize the placement of sensors for the number of sensors that remain after fixing at identified critical facilities. For example, if a user sets a sensor set size in TEVA-SPOT to be 15 sensors and the water system being evaluated has 10 critical facilities with a sensor monitoring station fixed at each critical facility, TEVA-SPOT will optimize the placement of the remaining 5 sensors.

Sensor placement optimization involves a two-step process: (1) generation of threat simulator output tso-to-impact (tso-2-impact) files and (2) optimization of sensor locations. The generation of tso-2-impact files (one for each combination of consequence measure, response time, and detection limit) is the precursor to the sensor placement optimization step. 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, we refer the reader to the User Manual for TEVA-SPOT-Toolkit [2]. For more information on sensor network design using TEVA-SPOT [13].

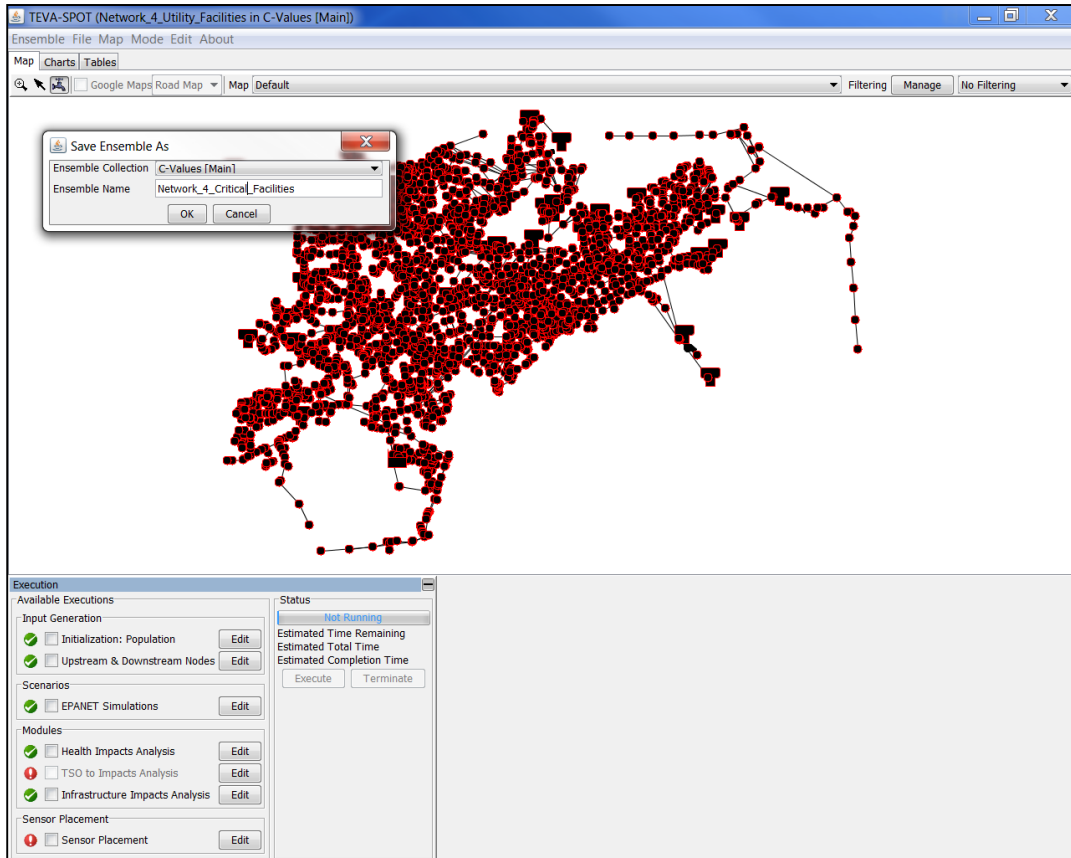
Table 4.0.1: Overview of TEVA-SPOT-GUI Procedure to Identify Critical Facilities, Determine and Evaluate Possible Upstream Contamination Events, Design A Sensor Network to Protect Critical Facilities, and Retrieve the Sensor Placement Results.

Step	Feature	Task
Steps 4.0.1 - Step 4.0.2	Ensemble Menu <ul style="list-style-type: none"> • Save As • Load 	Creating a “Critical_Facilities” ensemble using the “Save As” feature to save an existing ensemble under a new name, and then loading the newly created ensemble.
Step 4.0.3	Input Generation <ul style="list-style-type: none"> • Initialization: Population • Upstream & Downstream Nodes 	Running the Input Generation modules on the “Critical_Facilities” ensemble.
Steps 4.0.4 – 4.0.8	Scenarios <ul style="list-style-type: none"> • EPANET Simulations 	Setting up the EPANET Simulation module for the “Critical_Facilities” ensemble.
Steps 4.0.9 – 4.0.10	Modules <ul style="list-style-type: none"> • Health Impacts Analysis • Infrastructure Impacts Analysis 	Setting up the Health Impacts Analysis and Infrastructure Impacts Analysis modules for the “Critical_Facilities” ensemble.
Steps 4.0.11 – 4.0.16	Sensor Placement	Setting up the Sensor Placement module for the “Critical_Facilities” ensemble.
Step 4.0.17	Execution <ul style="list-style-type: none"> • EPANET Simulations • HIA • IIA • Sensor Placement 	Executing the EPANET simulations, HIA, IIA, and Sensor Placement modules.
Steps 4.0.18 – 4.0.19	Obtaining Results <ul style="list-style-type: none"> • Map tab 	Retrieving a sensor network design map: “Sensor Locations”. Retrieving a sensor network design map: “Sensor Event Detection: Links and Nodes”.
Steps 4.0.20 – 4.0.22	Obtaining Results <ul style="list-style-type: none"> • Table tab 	Retrieving sensor placement performance results: “Trade-Off Analysis Data” & “Sensor Placement Summary”, “Impacts and Detection Time”, “Sensor Ranking” tables.
Step 4.0.23	Obtaining Results <ul style="list-style-type: none"> • Table tab 	Retrieving sensor placement results: “All Sensors” table & “Sensor Counts” tables.

Protecting Critical Facilities

Step 4.0.1.

Under the ENSEMBLE MENU, select “Save As” while in the “Network_4_Utility_Facilities” Ensemble. In the “Ensemble Name” box, type “Network_4_Critical_Facilities”. Click “OK”.

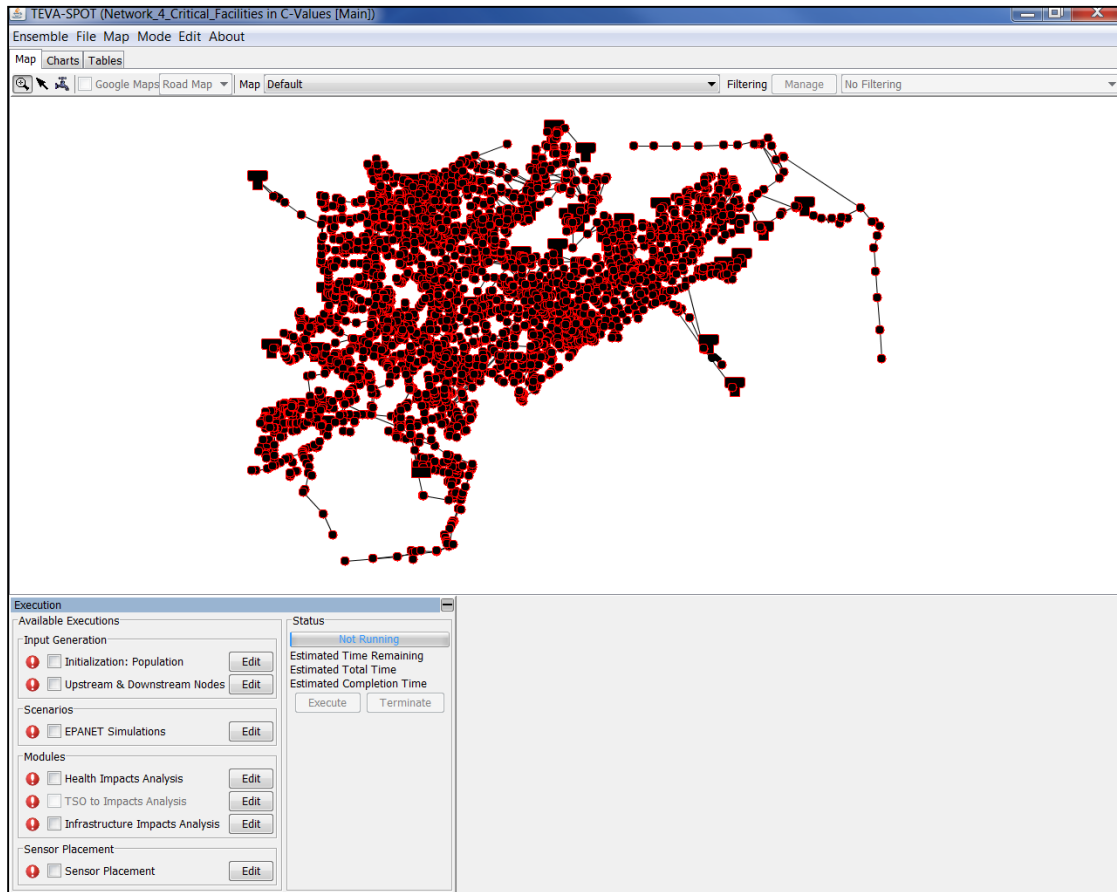


Use the “Save As” feature to replicate an ensemble. Using the “Save As” feature does NOT replace the current ensemble but instead only saves the current or loaded ensemble with a new name. It does not save or replicate any results – only the complete description of the ensemble.

Protecting Critical Facilities

Step 4.0.2.

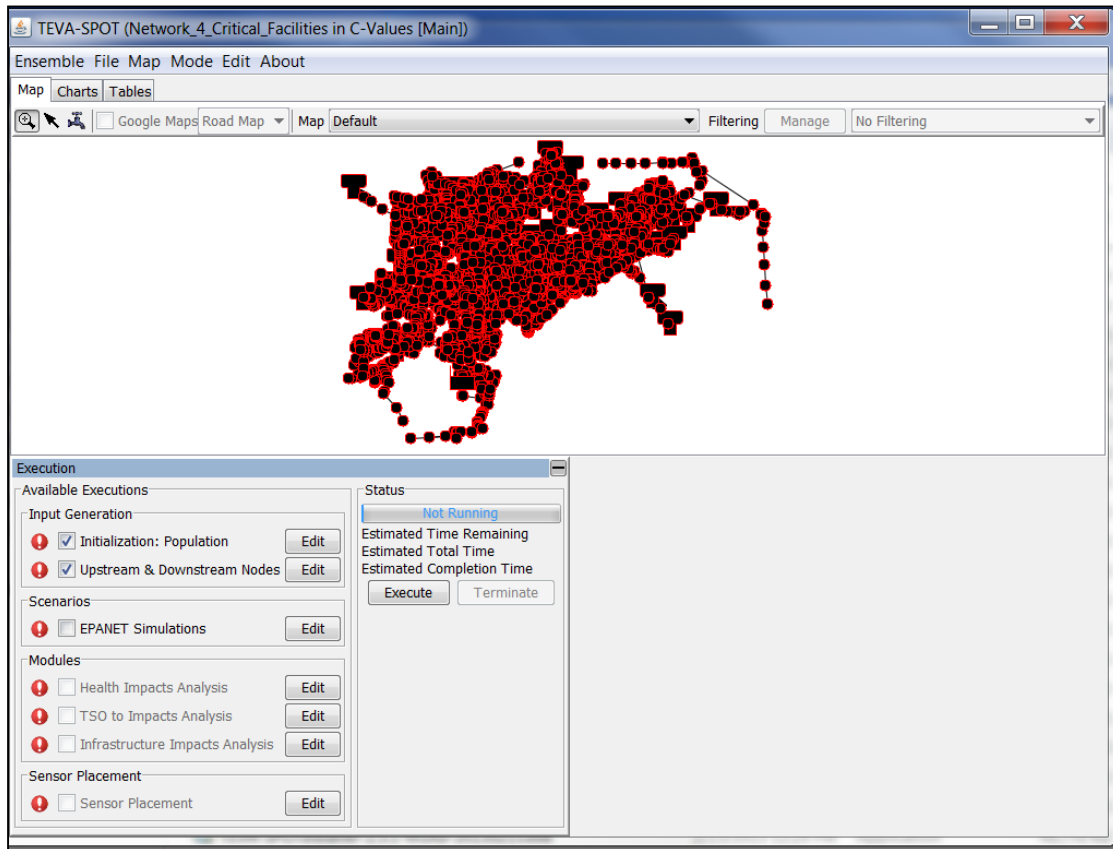
Under the ENSEMBLE MENU, select “LOAD” and load the just saved ensemble to examine critical facilities. Next, choose “Execution Control” under the ENSEMBLE MENU. Alternatively type the keys: Ctrl+E.



Protecting Critical Facilities

Step 4.0.3.

Click the two boxes associated with: “Initialization: Population” and “Upstream & Downstream Nodes” and execute the modules.

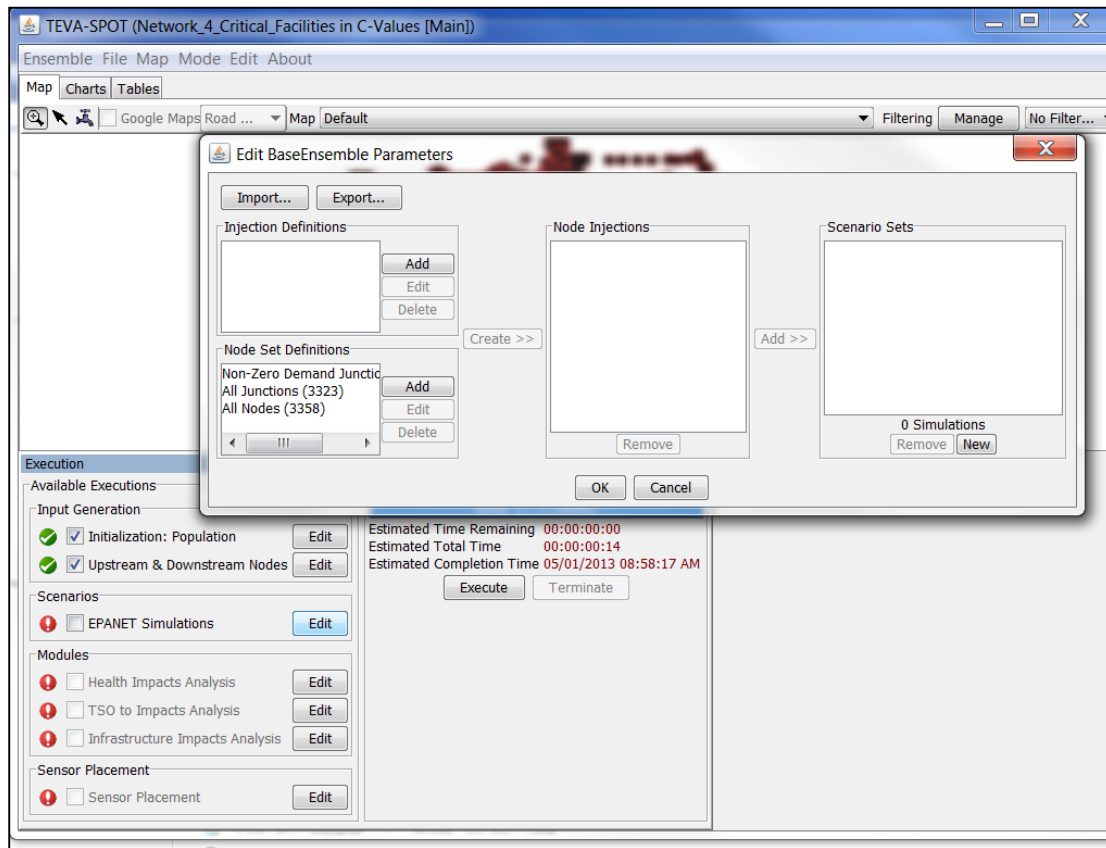


This step was demonstrated earlier for the “Utility_Facilities” ensemble.

Protecting Critical Facilities

Step 4.0.4.

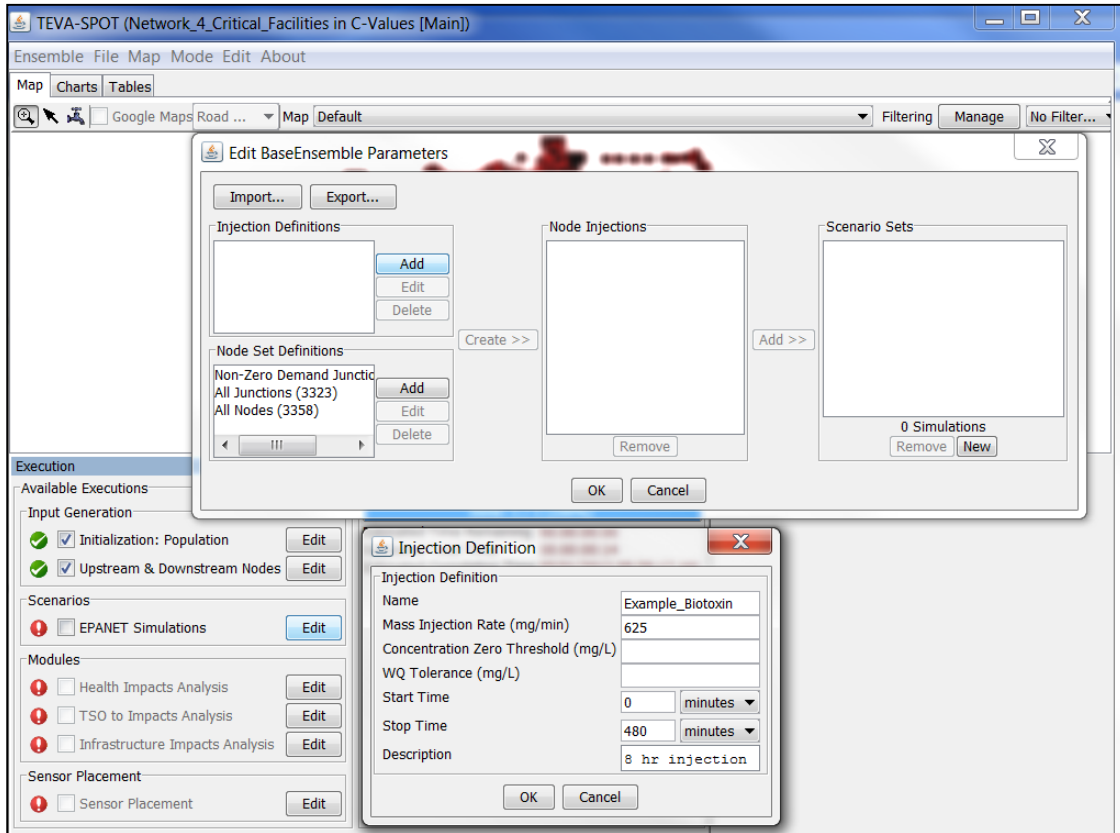
Click “EDIT” button next to “EPANET Simulations” and the dialogue box appears.



Protecting Critical Facilities

Step 4.0.5.

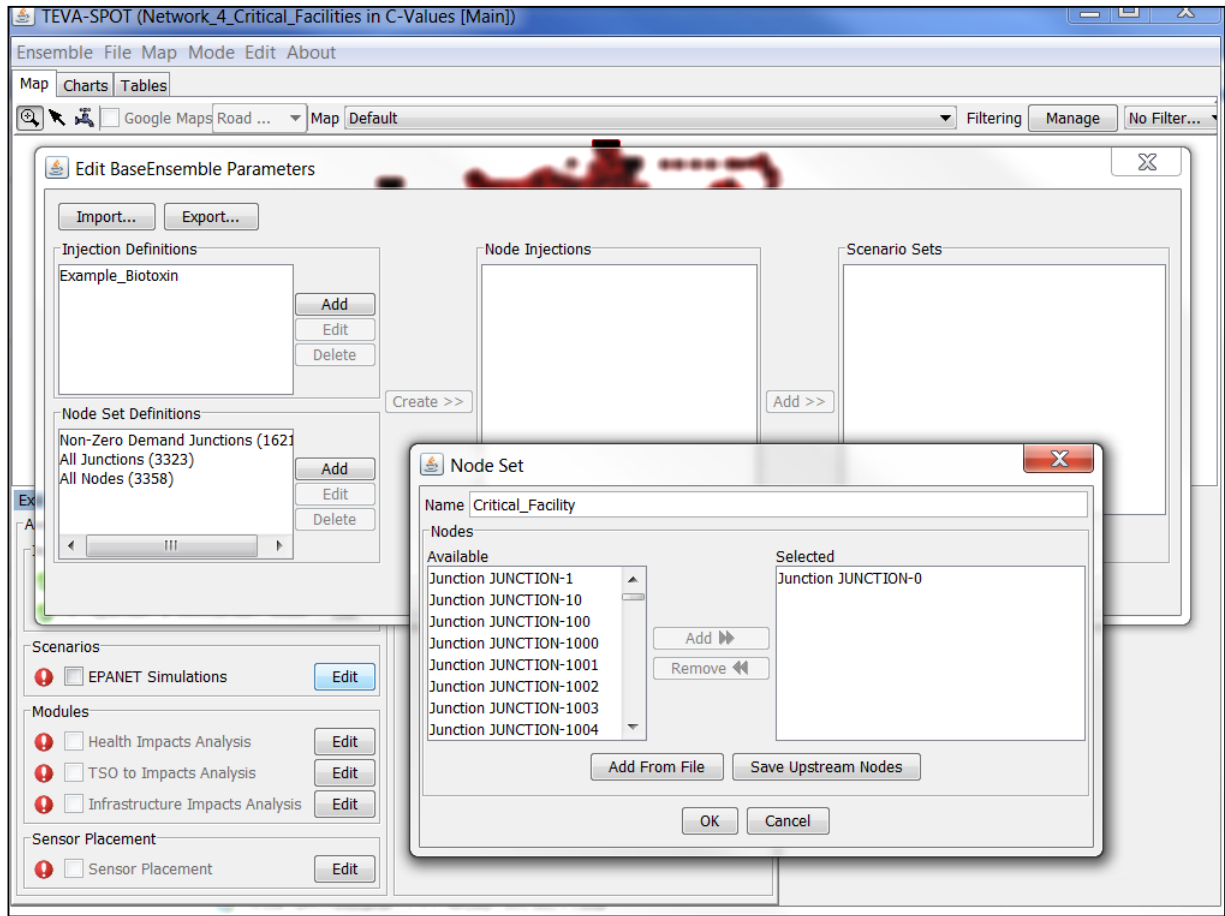
Under the “Injection Definition”, click “Add”. Enter “Example_Biotoxin” for the NAME and the parameters and information specified. For “Start Time” and “Stop Time”, select “minutes” from the drop down menu. Click “OK”.



Protecting Critical Facilities

Step 4.0.6.

Under “Node Set Definitions”, click “Add”. Next, click “Critical Facilities”. To demonstrate we arbitrarily select the first node, JUNCTION-0 and click “Add”. Type in the “Name” of the Node Set as “Critical_Facility”. Click “OK”.

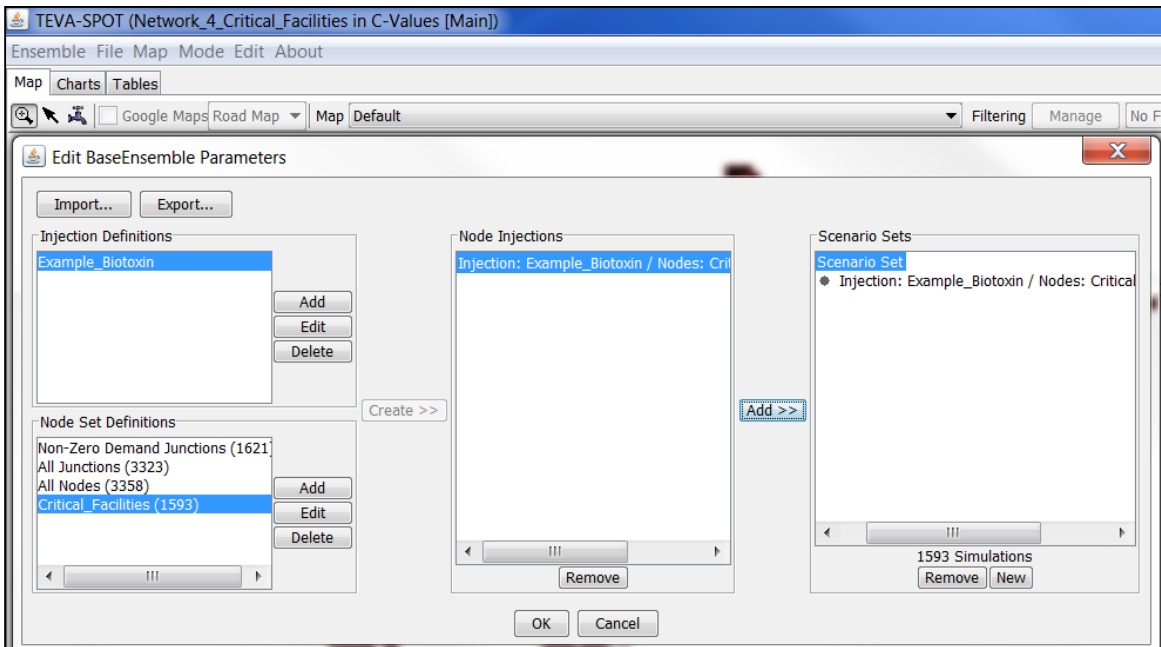


Protecting Critical Facilities

Step 4.0.7.

(All loaded "Scenario Sets" will run. So, when beginning a new exercise, it may be less confusing to first delete the previous entries, e.g., the "Injection Definition". Therefore, if you have previously completed the Utility Facilities portion of this tutorial, please "Delete" the "Injection Definitions" entry, the "Node Injections" entry, and the "Scenario Set" entry from the boxes. Then, proceed with the Critical Facilities exercise.)

Select "Example Biotoxin" & "Critical Facilities". Click "Create" "Node Injections". Under "Scenario Sets", click "New". A new Folder appears. (If you have previously run the Scenario Set for Utilities, those folders will also show in the "Node Injections" and "Scenario Sets" list of folders.) Select Node Injections: "Example Biotoxin/Nodes: Critical_Facilities (1593)" and the new "Scenario Set" folder. Click "Add" to add to "Scenario Sets" folder. Click "OK".

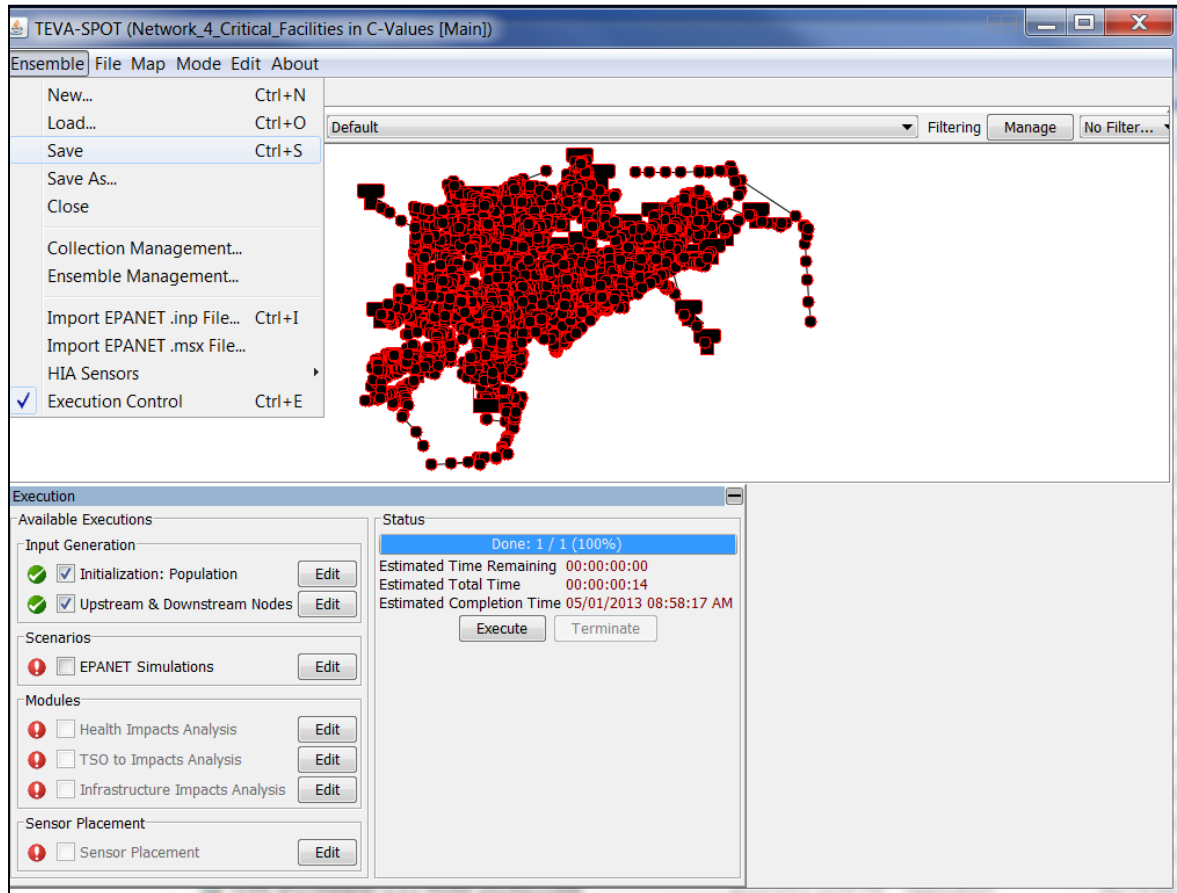


Note: The above box is truncated. Note too that all such boxes in TEVA-SPOT-GUI can be enlarged if needed by clicking the left mouse button at a corner and dragging the box to enlarge.

Protecting Critical Facilities

Step 4.0.8.

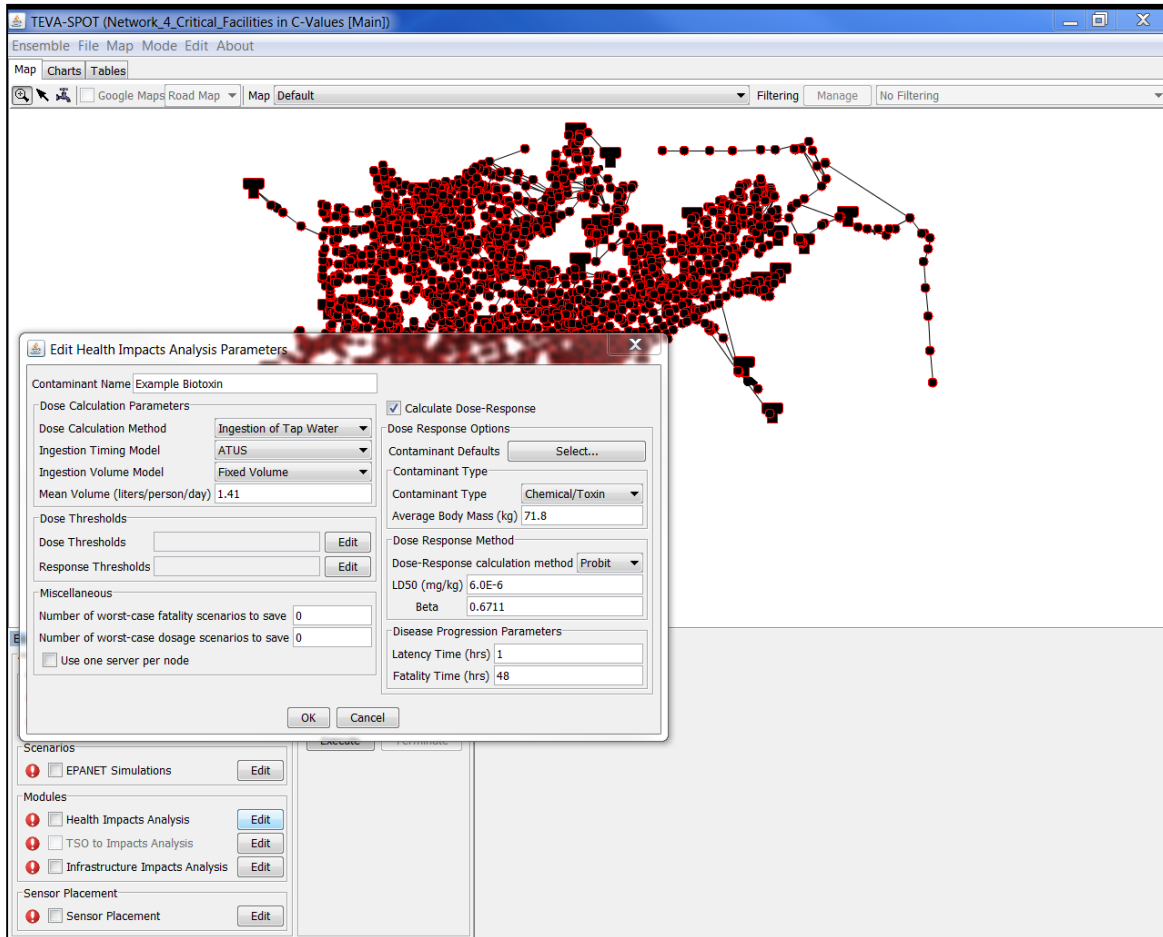
Select “Ensemble” from the Menu and Click “Save”.



Protecting Critical Facilities

Step 4.0.9.

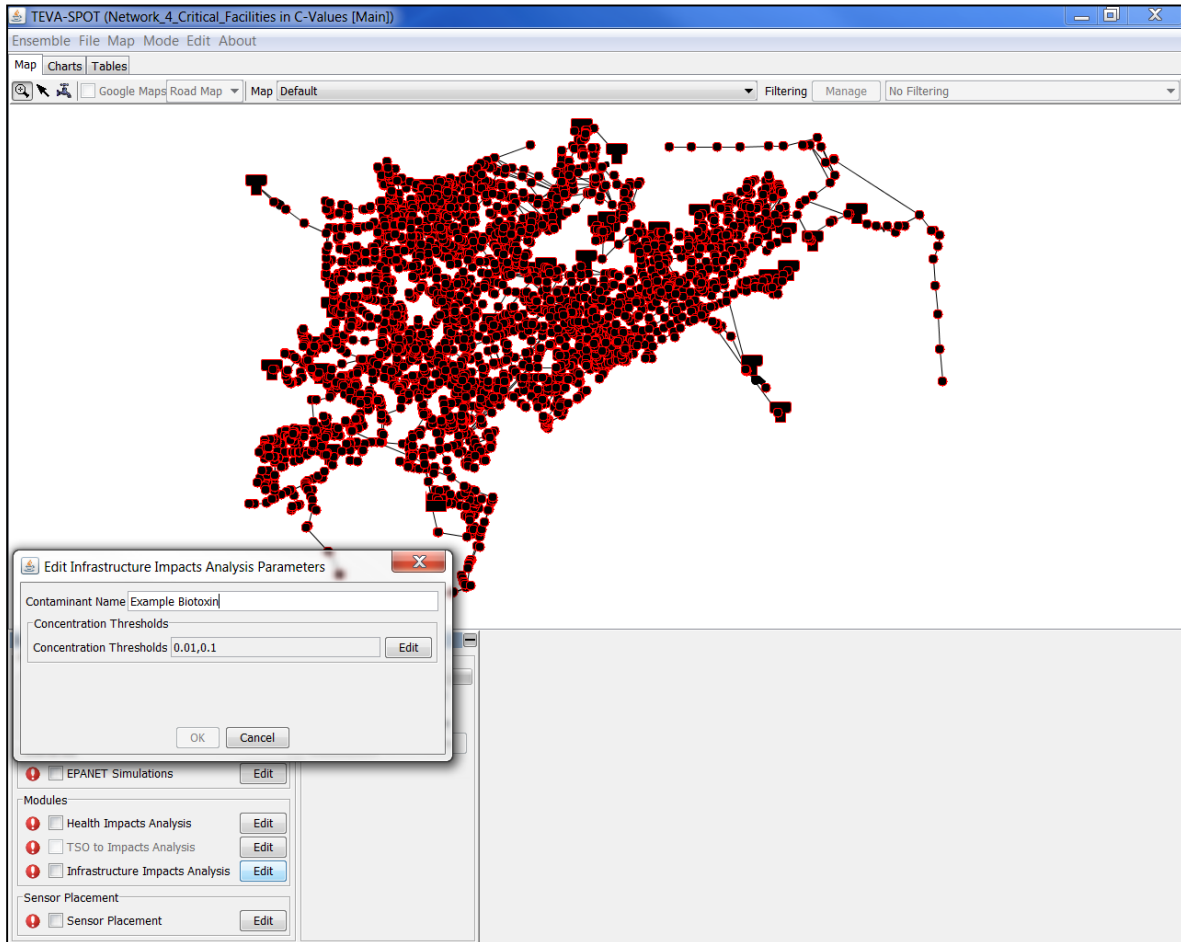
See Section 3.3 and Step 3.3.1 for setting up the Health Impacts Analysis Module. In the “Execution” dialogue box, under “Modules”, select “Edit” for “Health Impacts Analysis”. Verify that entries match and close the “Edit” box.



Protecting Critical Facilities

Step 4.0.10.

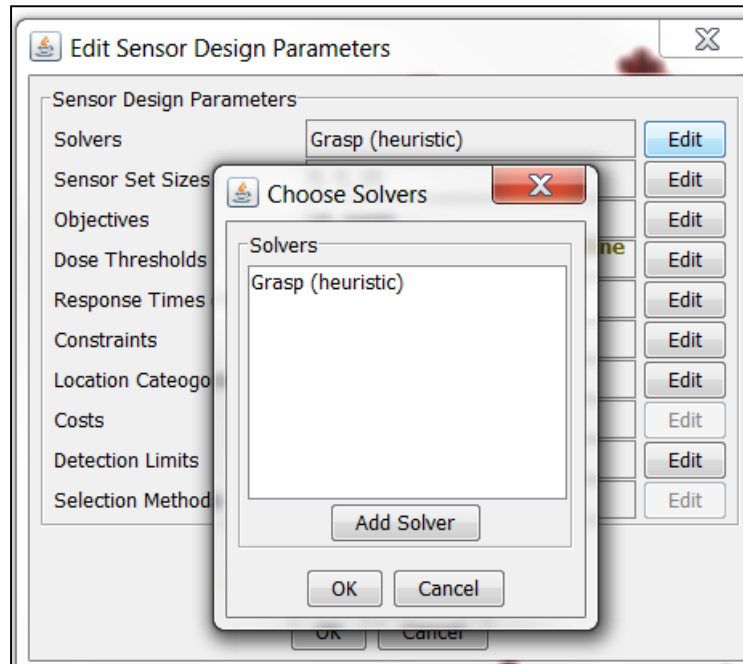
See Section 3.4 and Step 3.4.1 for setting up the Infrastructure Impacts Analysis module. In the “Execution” dialogue box, under “Modules”, select “Edit” for “Infrastructure Impacts Analysis”. Verify the entries and close the “Edit” box.



Protecting Critical Facilities

Step 4.0.11.

In the “Execution” dialogue box, next to “Sensor Placement”, click the EDIT button. The panel “Edit Sensor Design Parameters” will appear. Starting with “Solvers” Click the “EDIT” button and then Click “Add Solver”. Two options: “GRASP (heuristic)” and “Lagrangian” will be able to be selected. Select “GRASP (heuristic)” and click “OK”.



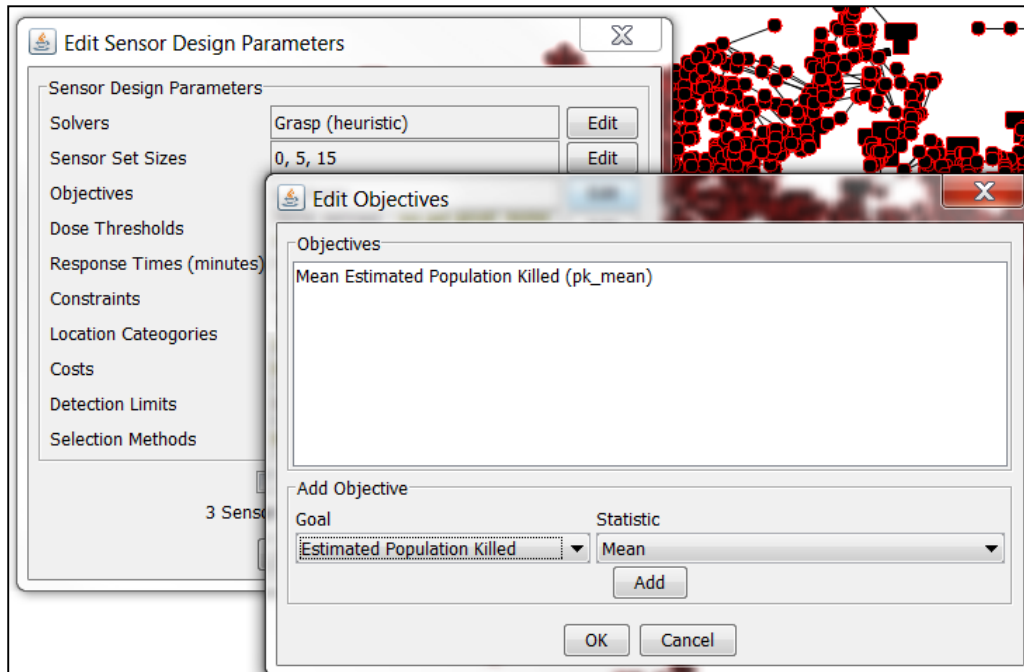
Lagrangian: This solver can be used for very large models that cannot be easily solved using the GRASP algorithm. Although the lagrangian’s performance is less accurate (i.e., the sensor locations chosen will not perform as well at reducing the chosen consequence measure) than that of the GRASP it requires less computer memory.

PICO: Parallel Integer and Combinatorial Optimizer (PICO). PICO is a mixed integer linear program (MILP) based optimization solver and is the only TEVA-SPOT solver that can provide guaranteed optimization. PICO is currently not available in TEVA-SPOT-GUI but is available in the TEVA-SPOT toolkit. Please refer to the TEVA-SPOT Toolkit Users Manual for more information [2] and “Sensor Network Design for Drinking Water Contamination Warning Systems: A Compendium of Research Results and Case Studies Using TEVA-SPOT Software” [13].

Protecting Critical Facilities

Step 4.0.12.

Click the EDIT button next to “Objectives” and the “Edit Objectives” box appears. From the list appearing under “Goal” select each of the indicated “Objectives” one at a time and clicking “Add” with each one to populate the panel as shown. Ensure the “Statistic” selected is “Mean”.



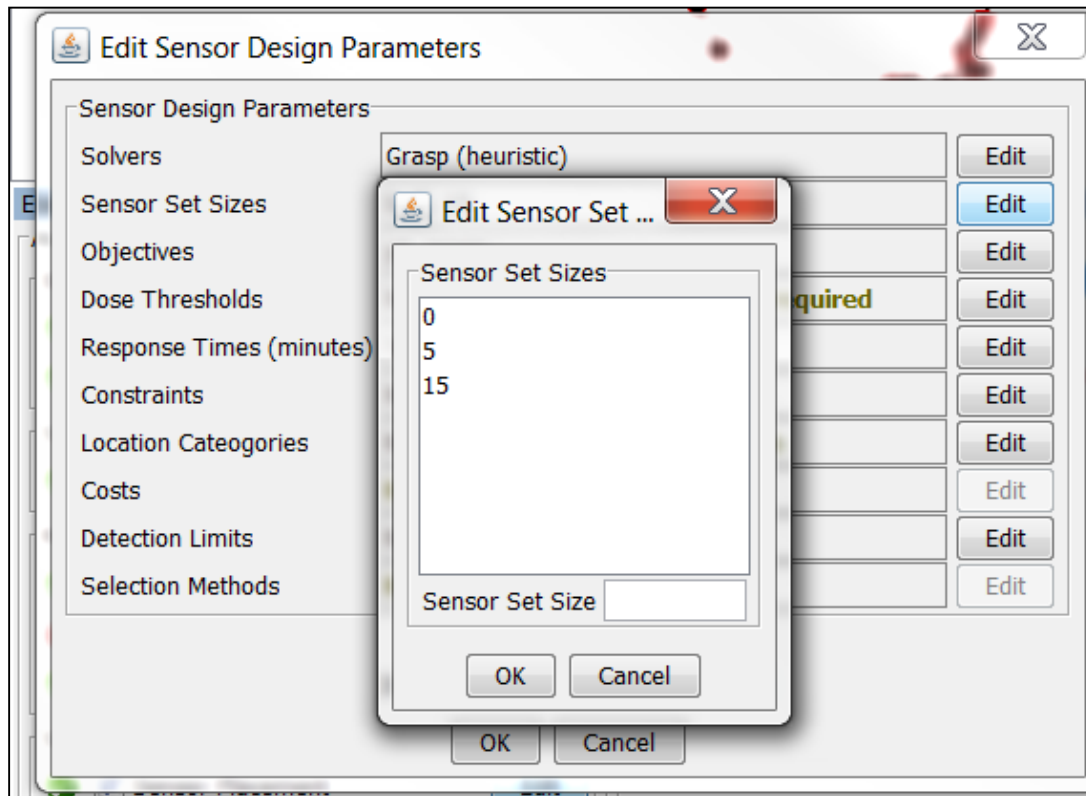
After adding an objective, the objective can be removed by double clicking on the objective.

Constraints: This capability allows the user to define a side constraint on the objective. For example, population killed (pk) could be constrained to minimize the extent of contamination (ec) objective subject to an upper bound on extent of contamination. The user would insert an upper bound for ec in units of pipe feet. The user is referred to the TEVA-SPOT Toolkit Users Manual for more information [2].

Protecting Critical Facilities

Step 4.0.13.

Click the EDIT button next to "Sensor Set Sizes" and the "Edit Sensor Set Sizes" box appears. In the "Sensor Set Size" box type the number "5" and press ENTER on the keyboard. Next, type the number "15" and press ENTER on the keyboard. The "0" sensor set size appears automatically. Click "OK".

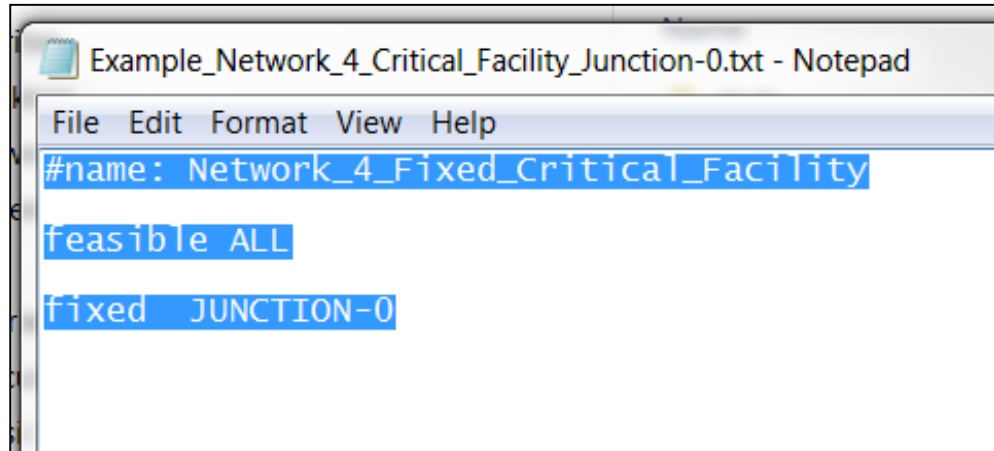


"Sensor Set Size" defines the number of sensors being considered in the monitoring strategy to protect the critical facilities. Multiple "Sensor Set Sizes" (as shown above) can be considered together.

Protecting Critical Facilities

Step 4.0.14.

To “Edit” the “Location Categories” parameter requires the creation of an “Existing Sensor(s) Location File”. Open Windows “Notepad” or a suitable text editor and create the text file shown below.



Please name the file: “Example_Network_4_Critical_Facility_Junction-0.txt” and save the file to: **C:\Program Files\TEVA-SPOT\Client (or to a location from which you will be able to upload the file).**

Notice the format of the contents of the file and the key words: #name:”, “feasible ALL”, and “fixed [Node ID]”. Word separations are SPACE or TAB. 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. The keyword “#name:” is ignored by the TEVA-SPOT Toolkit [2].

For the key words “feasible ALL” TEVA-SPOT-GUI identifies all nodes in the model as being feasible for the placement of sensors.

TEVA-SPOT-GUI executes the key word “fixed” and the associated location(s) that are to be fixed. Multiple node IDs can be placed on the same line and/or multiple rows can be used. For each row, the keyword “fixed” must precede the node ID(s).

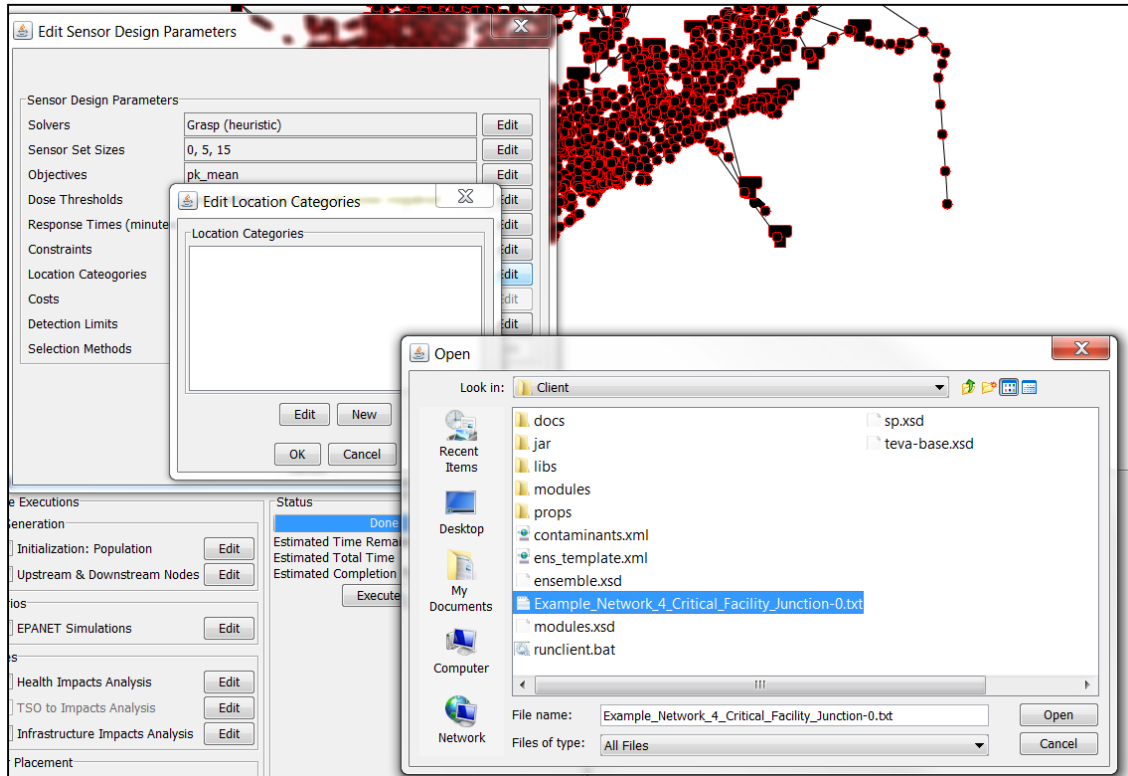
Notice that capitalization is important: TEVA-SPOT-GUI will not recognize the fixed location if the node “Junction-0” is NOT capitalized exactly as it is in the model.

A keyword NOT used here is “infeasible”. The keyword “infeasible” specifies those node ID(s) that can NOT be considered in sensor placement. The “All” in “feasible All” or “infeasible All” can be replaced with node IDs. For more information, refer to the TEVA-SPOT Toolkit Users Manual [2].

Protecting Critical Facilities

Step 4.0.15.

Click the “EDIT” button next to the “Location Categories”. Then click “New” and “SP Format”. The “Open” dialogue box will appear allowing the upload of an “existing sensor(s)” text file.



This step uploads the critical facility location file. Fixing a sensor at each critical facility will ensure that each sensor network design includes a sensor monitoring location at the critical facility. For example, if you identified five critical facilities, you would start with five fixed sensors.

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. Choosing “All Locations” will result in the best overall performance (i.e., selection of sensor locations which best reduce the chosen consequence measure(s)) across the contamination scenarios ensemble. However, choosing “All Locations” may substantially increase computation time and computer memory requirements to complete.

Protecting Critical Facilities

Step 4.0.16.

The “Sensor Design Parameters” consisting of “Response Times” (minutes) and “Detection Limits” (e.g., mg/L) can be modified as described by Step 4.0.13. For information on these remaining “Sensor Design Parameters”, users should consult the TEVA-SPOT Toolkit Users Manual [2].

Sensor Design Parameters		
Solvers	Grasp (heuristic)	Edit
Sensor Set Sizes	0, 5, 15	Edit
Objectives	pk_mean	Edit
Dose Thresholds	None defined - no pd goal: none required	Edit
Response Times (minutes)	None defined - using 0	Edit
Constraints	None defined - Optional	Edit
Location Categories	Example_Network_4_Critical_Facility_Junction-0.txt	Edit
Costs	N/A	Edit
Detection Limits	None defined - using 0	Edit
Selection Methods	N/A	Edit

☐ Create All Impacts

3 Sensor Designs will be generated

OK Cancel

“Response Time (minutes)”: Refers to 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.

“Detection Limits”: Refers to a minimum water concentration (e.g., mg/L or organisms/L) that will be required for sensor detection at a particular sensor monitoring location.

“Create All Impacts” should not be checked if fast runtimes are needed. Checking the box results in the generation of additional tso-2-impact files (located in the TEVA-SPOT-Database) for any objective not already selected, which can be then used for Regret Analyses.

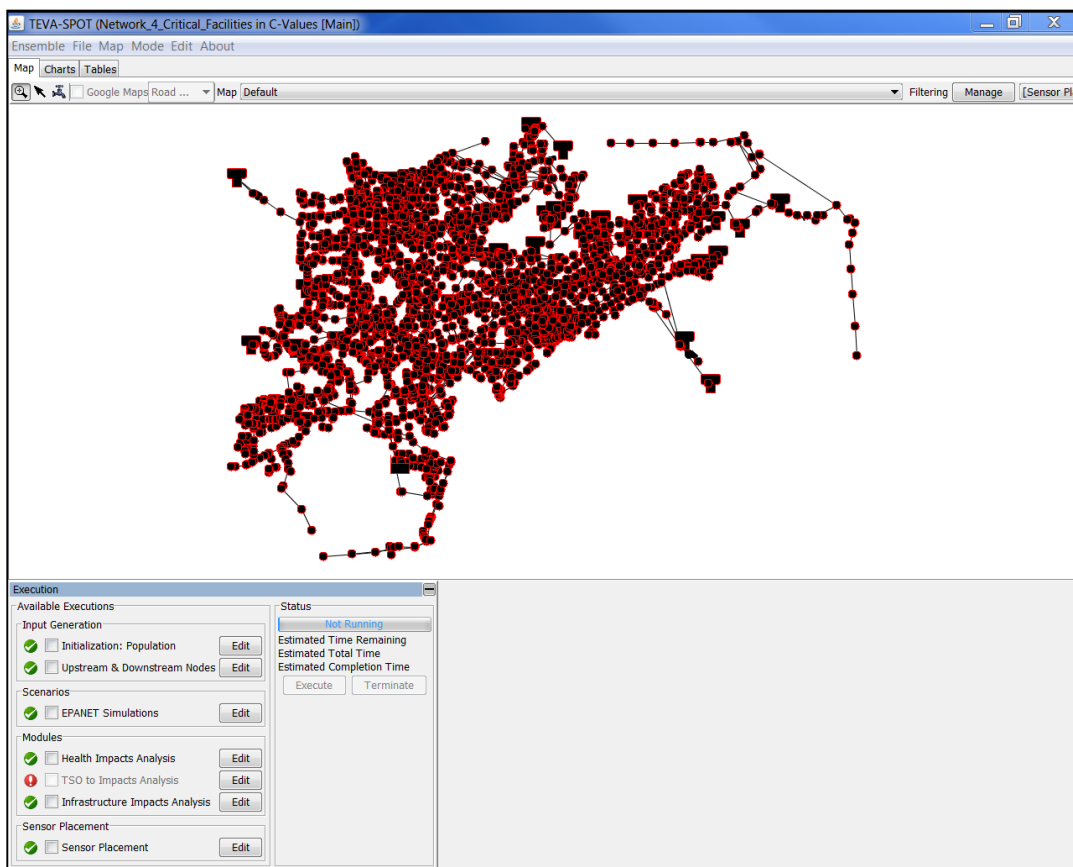
Regret Analysis (Menu item “Mode”, choose “Switch to Regret Analysis”) provides a means to select the best sensor design among many. For example, multiple ensembles can be created, e.g., different contaminants, release times, mass release rates, response delays, detection limits, and with each of these ensembles sensor designs are created. The impact files and sensor designs can be loaded into TEVA-SPOT-GUI Regret Analysis and evaluated to compute a matrix of consequences. Every sensor design chosen is evaluated against every impact. The performance measures (*Preferred Overall Design and Preferred Design to Minimize Maximum Deviation*) are used to compute the difference between the best design (which is the design created for the particular consequence measure) and all the other designs. There are no parameters to enter like there is in the “Ensemble Analysis Mode”. Please refer to the TEVA-SPOT-GUI Users Manual for more information [2].

Step 4.0.17.

Verify entries into the “Edit Sensor Design Parameters” dialogue box and click “OK”. Modules are now ready for execution. Check the “EPANET Simulations” scenario, the “Health Impacts Analysis” module, and the “Infrastructure Impacts Analysis”. Click “Execute”. Execution could take some time (hours or even days) to complete. The execution of all the modules concurrently on the Example Network_4 demonstrated here takes approximately 40 minutes using a 64-bit, Windows 7, quad-core, 2.6 gigahertz laptop computer with 32 gigabytes of random access memory.

Once complete, the exclamation points in red circles should become check marks in green circles. (Troubleshooting tip: If the marks fail to change upon completion of the execution, go to the “Ensemble” menu and select “Load” to reload the data.)

Execution of “Sensor Placement”. First, make sure that the completed executions are unchecked so that they do not run again. Now click the “Sensor Placement” box with a check mark and click EXECUTE. Two processes will be executed. First, the precursor to sensor placement will run called “tso-2-impacts”. Next sensor placement will run. Once both processes are complete the screen below will be displayed. In order to view the results, minimize the “Execution” dialogue box.



Precursor to sensor placement – “tso-2-impacts” will be run for each combination of objective, response time, and detection limit.

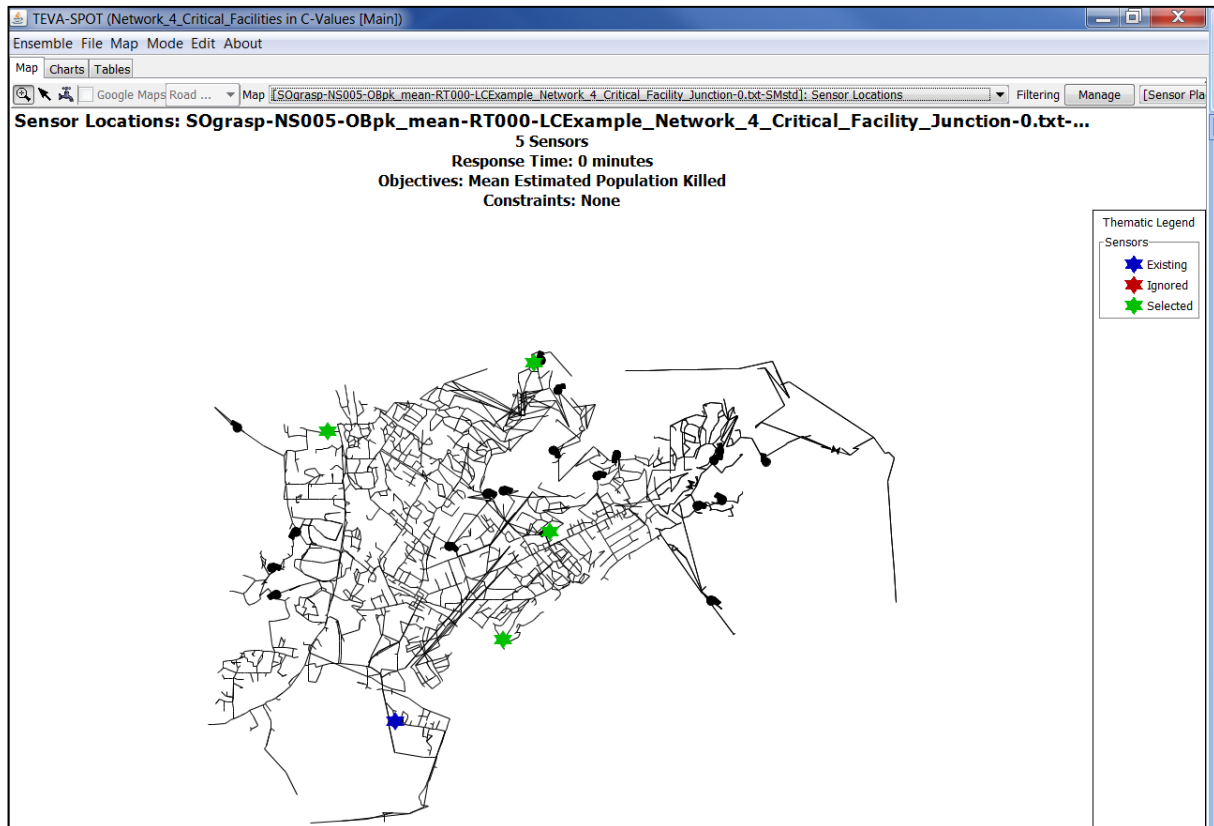
For sensor placements, the total number includes the null or zero sensors case.

Notice in the screen shot above that the “TSO to Impacts Analysis” module under the “Modules” section is grayed out and RED. This module for running “TSO to Impacts Analysis” is only for generating stand-alone impact files that could then be used with the TEVA-SPOT Toolkit or for other purposes. “TSO-to-Impact” analyses are also performed within the “Sensor Placement” module.

Protecting Critical Facilities

Step 4.0.18.

Retrieving sensor placement results: 5 sensor location design. Click MAP tab, next choose the “Sograsp-NS005-Obpk_mean...Sensor Locations”.



Notice the naming convention for sensor network designs:

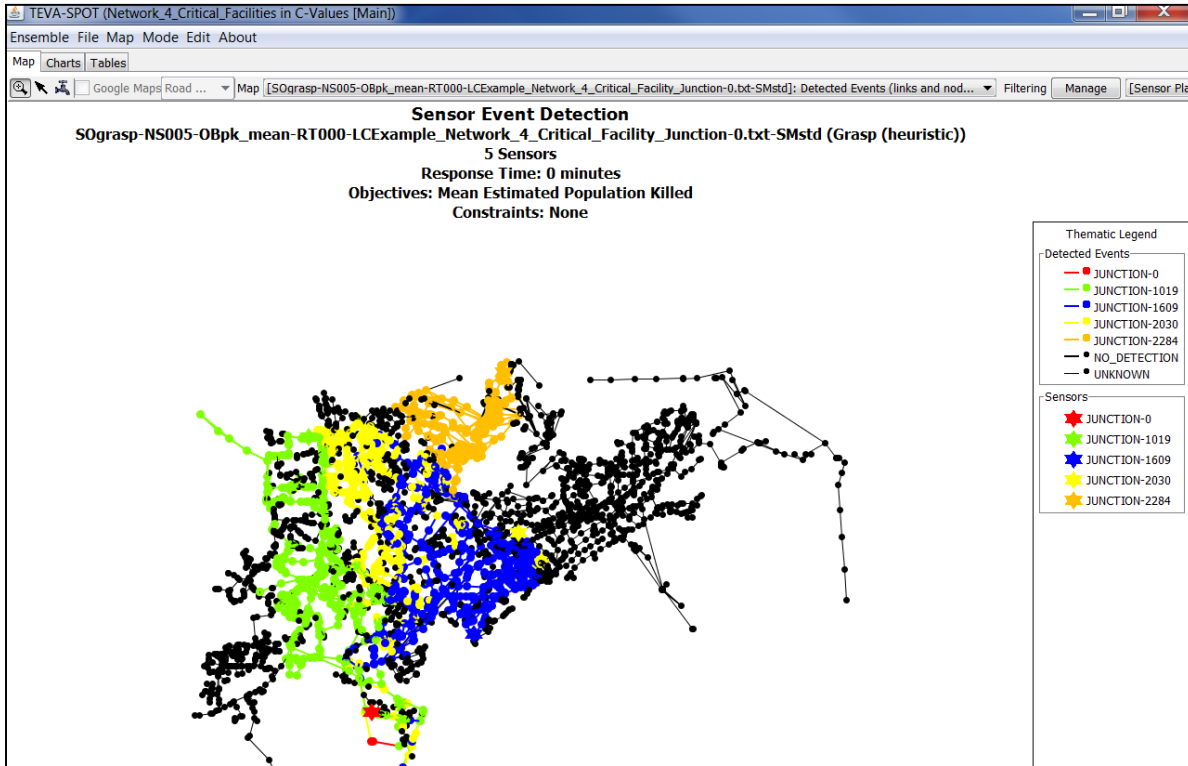
- SOgrasp: Sensor Objective – grasp
- NS005: 5 locations sensor network design
- OBpk: Objective – population killed (pk)
- Mean: Mean objective statistic.
- RT000: Response time of zero minutes
- LC: Location Category(s). The name that appears after LC is the file name of the uploaded “SP formatted” text file
- GREEN STARS designate optimally selected locations. BLUE STARS designate “fixed” location(s). RED STARS would designate “infeasible” locations (if used, not shown here).

Notice that scrolling within the MAP, TABLE, and CHART menus of TEVA-SPOT-GUI can be tedious due to the many output products generated. Use the “MANAGE” feature within each tab to create filtered sets of results. Results can be filtered for either Health Impacts or Sensor Placement. Please refer to the TEVA-SPOT-GUI Users Manual for more information [2].

Protecting Critical Facilities

Step 4.0.19.

Retrieving sensor placement results. Next, choose the map below (NS = 5 and Detected Events, Links and Nodes) from under the MAP TAB.



This MAP provides sensor event detection information associated with each sensor location.

RED STAR shows the location of the *Critical Facility*. Multiple critical facilities will be displayed using different colors.

Although it is difficult to see each COLORED STAR, these sensor locations are depicted in Step 4.0.18. Associated with each STAR (Sensor Location) are similarly colored pipes and nodes. The correspondingly colored pipes and nodes represent the event detection information associated with the particular sensor location.

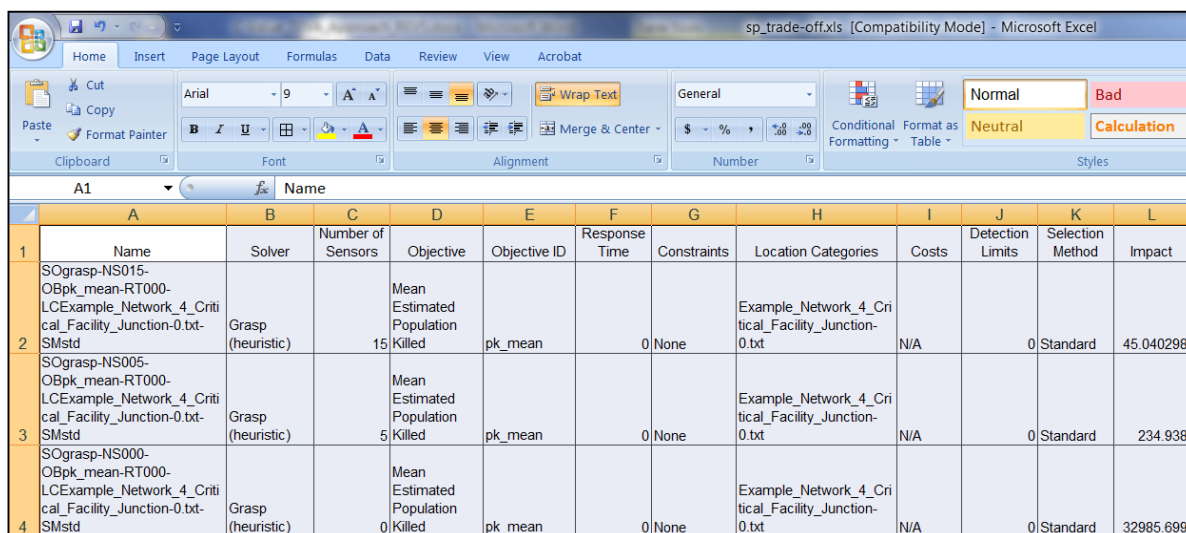
Right clicking on the legend (see RED circles), "Detected Events" or "Sensors" allows the removal from view of selected information. The data is only removed from view.

Note: Event Detection Maps are also available for "Nodes Only" and "Pipes Only".

Protecting Critical Facilities

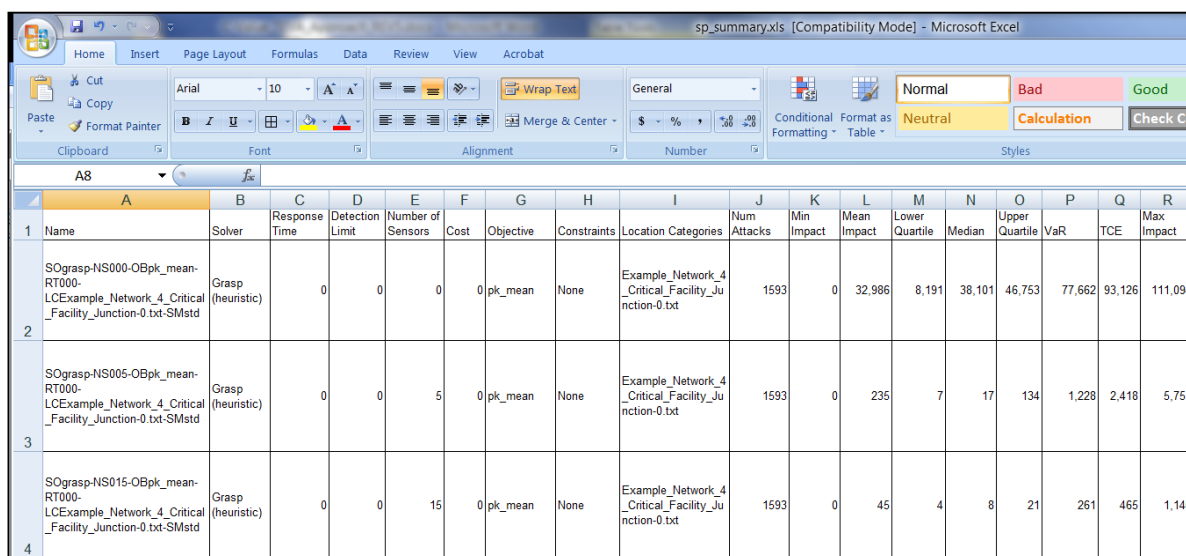
Step 4.0.20.

Retrieving sensor placement performance results: TRADE-OFF ANALYSIS DATA & SENSOR PLACEMENT SUMMARY tables.



	A	B	C	D	E	F	G	H	I	J	K	L
	Name	Solver	Number of Sensors	Objective	Objective ID	Response Time	Constraints	Location Categories	Costs	Detection Limits	Selection Method	Impact
1	SOgrasp-NS015-OBpk_mean-RT000-LCExample_Network_4_Critical_Facility_Junction-0.txt-SMstd	Grasp (heuristic)	15	Mean Estimated Population Killed	pk_mean	0	None	Example_Network_4_Critical_Facility_Junction-0.txt	N/A	0	Standard	45.040298
2	SOgrasp-NS005-OBpk_mean-RT000-LCExample_Network_4_Critical_Facility_Junction-0.txt-SMstd	Grasp (heuristic)	5	Mean Estimated Population Killed	pk_mean	0	None	Example_Network_4_Critical_Facility_Junction-0.txt	N/A	0	Standard	234.938
3	SOgrasp-NS000-OBpk_mean-RT000-LCExample_Network_4_Critical_Facility_Junction-0.txt-SMstd	Grasp (heuristic)	0	Mean Estimated Population Killed	pk_mean	0	None	Example_Network_4_Critical_Facility_Junction-0.txt	N/A	0	Standard	32985.699
4												

Table Above: “Trade-Off Analysis”, EXPORTED TO Microsoft EXCEL and then formatted.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
	Name	Solver	Response Time	Detection Limit	Number of Sensors	Cost	Objective	Constraints	Location Categories	Num Attacks	Min Impact	Mean Impact	Lower Quartile	Median	Upper Quartile	VaR	TCE	Max Impact
1	SOgrasp-NS000-OBpk_mean-RT000-LCExample_Network_4_Critical_Facility_Junction-0.txt-SMstd	Grasp (heuristic)	0	0	0	0	pk_mean	None	Example_Network_4_Critical_Facility_Junction-0.txt	1593	0	32,986	8,191	38,101	46,753	77,662	93,126	111,094
2	SOgrasp-NS005-OBpk_mean-RT000-LCExample_Network_4_Critical_Facility_Junction-0.txt-SMstd	Grasp (heuristic)	0	0	5	0	pk_mean	None	Example_Network_4_Critical_Facility_Junction-0.txt	1593	0	235	7	17	134	1,228	2,418	5,751
3	SOgrasp-NS015-OBpk_mean-RT000-LCExample_Network_4_Critical_Facility_Junction-0.txt-SMstd	Grasp (heuristic)	0	0	15	0	pk_mean	None	Example_Network_4_Critical_Facility_Junction-0.txt	1593	0	45	4	8	21	261	465	1,146
4																		

Table above is titled: “Sensor Placement Summary”. It has been EXPORTED TO Microsoft EXCEL and then formatted.

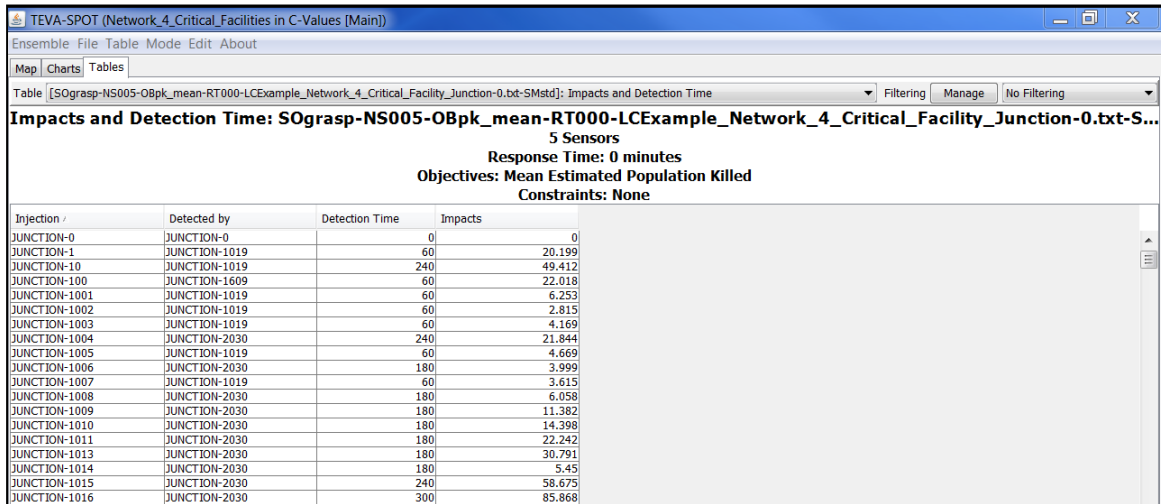
EXPORTING Tabular results to EXCEL: Click “TABLE” on top MENU and then select “Export to Excel...”.

Although the minimization objective statistic was MEAN, notice that fatalities are also reported for other percentile contamination scenarios, e.g., VaR, TCE, and Max. Please refers to the TEVA-SPOT Toolkit Users Manual [2] or [10] for more information on these objective statistics.

Protecting Critical Facilities

Step 4.0.21.

Retrieving sensor placement results: “Impacts and Detection Time” tables. Click on the TABLE TAB. Scroll to the table titled: “SO...NS005-...OBpk... Impacts and Detection Time”.



The screenshot shows the TEVA-SPOT GUI with the 'TABLE' tab selected. The table title is 'SOgrasp-NS005-OBpk_mean-RT000-LCExample_Network_4_Critical_Facility_Junction-0.txt-S...'. The table contains 4 columns: Injection, Detected by, Detection Time, and Impacts. The data is sorted by Injection node.

Injection	Detected by	Detection Time	Impacts
JUNCTION-0	JUNCTION-0	0	0
JUNCTION-1	JUNCTION-1019	60	20.199
JUNCTION-10	JUNCTION-1019	240	49.412
JUNCTION-100	JUNCTION-1609	60	22.018
JUNCTION-1001	JUNCTION-1019	60	6.253
JUNCTION-1002	JUNCTION-1019	60	2.815
JUNCTION-1003	JUNCTION-1019	60	4.169
JUNCTION-1004	JUNCTION-2030	240	21.844
JUNCTION-1005	JUNCTION-1019	60	4.669
JUNCTION-1006	JUNCTION-2030	180	3.999
JUNCTION-1007	JUNCTION-1019	60	3.615
JUNCTION-1008	JUNCTION-2030	180	6.058
JUNCTION-1009	JUNCTION-2030	180	11.382
JUNCTION-1010	JUNCTION-2030	180	14.398
JUNCTION-1011	JUNCTION-2030	180	22.242
JUNCTION-1013	JUNCTION-2030	180	30.791
JUNCTION-1014	JUNCTION-2030	180	5.45
JUNCTION-1015	JUNCTION-2030	240	58.675
JUNCTION-1016	JUNCTION-2030	300	85.868

Note that this table provides information on the 5-sensor network design that was optimized for minimizing the mean population killed objective. The four columns are:

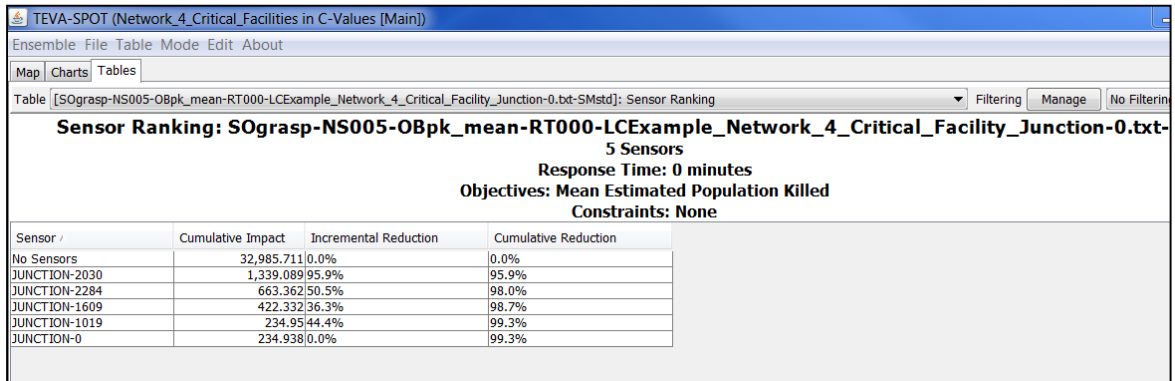
- Column 1 “Injection” provides the injection node
- Column 2 “Detected by” details which sensor (node ID) detected in the event in Column #1
- Column 3 “Detection Time” details the time (minutes) before the scenario (Column #1) was detected by the sensor at the node ID specified in Column #2
- Column 4 “Impacts” provides the number of people killed (pk) up to the detection and, therefore, cessation of public health consequences for the scenario specified in Column #1

Note that this table has been sorted in TEVA-SPOT-GUI by clicking on the first column, “Injection” to order alphabetically. Therefore, note that the Critical Facility, JUNCTION-0, has zero impacts. In TEVA-SPOT, fixing a sensor at each Critical Facility ensures there will be no impacts at the facility.

Protecting Critical Facilities

Step 4.0.22.

Retrieving sensor placement results: “Sensor Ranking” tables.



TEVA-SPOT (Network_4_Critical_Facilities in C-Values [Main])

Ensemble File Table Mode Edit About

Map Charts Tables

Table [SOgrasp-NS005-OBpk_mean-RT000-LCExample_Network_4_Critical_Facility_Junction-0.txt-SMstd]: Sensor Ranking

Filtering Manage No Filtering

Sensor Ranking: SOgrasp-NS005-OBpk_mean-RT000-LCExample_Network_4_Critical_Facility_Junction-0.txt-5 Sensors

Response Time: 0 minutes

Objectives: Mean Estimated Population Killed

Constraints: None

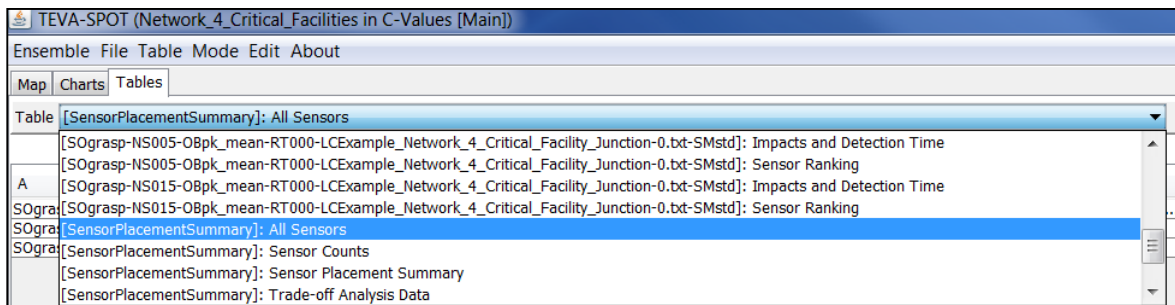
Sensor /	Cumulative Impact	Incremental Reduction	Cumulative Reduction
No Sensors	32,985.711	0.0%	0.0%
JUNCTION-2030	1,339.089	95.9%	95.9%
JUNCTION-2284	663.362	50.5%	98.0%
JUNCTION-1609	422.332	36.3%	98.7%
JUNCTION-1019	234.95	44.4%	99.3%
JUNCTION-0	234.938	0.0%	99.3%

Sensor Ranking tables provide sensor-by-sensor performance information. If no sensors were placed, the cumulative impact (Column #2) would be approximately 33,000 people. The majority of benefit provided occurs due to the sensor at location JUNCTION-2030.

Note that while 4 of the 5 sensors provided measurable benefit, the fixed sensor at JUNCTION-0 did not seem to provide any meaningful benefit. This, of course, is just an illustrative example of a critical facility.

Step 4.0.23.

Retrieving sensor placement results: OTHER TABLES. See “All Sensors” table and “Sensor Counts” table.



TEVA-SPOT (Network_4_Critical_Facilities in C-Values [Main])

Ensemble File Table Mode Edit About

Map Charts Tables

Table [SensorPlacementSummary]: All Sensors

- [SOgrasp-NS005-OBpk_mean-RT000-LCExample_Network_4_Critical_Facility_Junction-0.txt-SMstd]: Impacts and Detection Time
- [SOgrasp-NS005-OBpk_mean-RT000-LCExample_Network_4_Critical_Facility_Junction-0.txt-SMstd]: Sensor Ranking
- [SOgrasp-NS015-OBpk_mean-RT000-LCExample_Network_4_Critical_Facility_Junction-0.txt-SMstd]: Impacts and Detection Time
- [SOgrasp-NS015-OBpk_mean-RT000-LCExample_Network_4_Critical_Facility_Junction-0.txt-SMstd]: Sensor Ranking
- [SensorPlacementSummary]: All Sensors
- [SensorPlacementSummary]: Sensor Counts
- [SensorPlacementSummary]: Sensor Placement Summary
- [SensorPlacementSummary]: Trade-off Analysis Data

The table “All Sensors” provides node IDs for all sensor designs created.

The table “Sensor Counts” provides a two-column table: Column #1 (Node ID) and Column #2 (Times Selected). This table provides a count how many times each node was selected in a sensor design.

5 SUPPLEMENTAL GUIDANCE AND INFORMATION FOR USING TEVA-SPOT-GUI

We provide some additional discussion to help the user setup, run, analyze, and interpret results from TEVA-SPOT-GUI. This section is separated into five subsections as follows:

- 5.1 EPANET Simulation Parameters
- 5.2 TEVA-SPOT-GUI Simulation Parameters
- 5.3 Contamination Scenario
- 5.4 Quality Assurance Features within TEVA-SPOT-GUI
- 5.5 Using Google Maps within TEVA-SPOT-GUI
- 5.6 Trouble-shooting TEVA-SPOT-GUI Applications

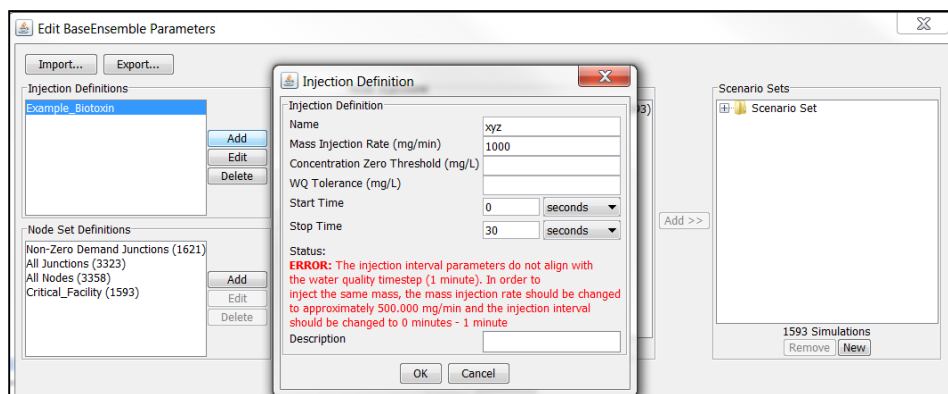
5.1 EPANET Simulation Parameters

The EPANET simulation parameters are generally specified in the Menu item “EDIT” and then by selecting “Ensemble Options”. The simulation length (hrs or min) should be sufficiently long for consequences to stabilize. This is generally a week (168 hrs) or longer.

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 is preferred. If injection duration shorter than 1 minute is needed, a shorter water quality time step may be needed. See Figure 5.1.1 below. 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 resources (memory requirements).

Figure 5.1.1. Injection definition error message.



The hydraulic time step must be less than or equal to the reporting interval, otherwise an error message will be given. 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.

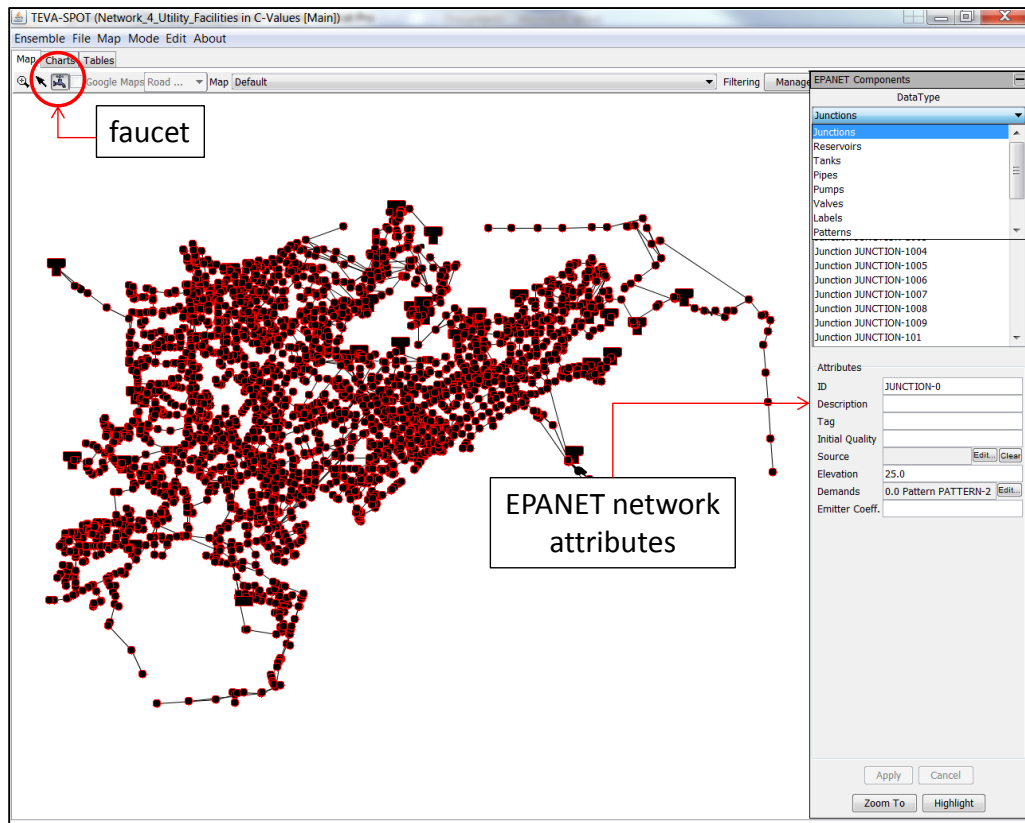
Generally a reporting time step of 1 hr is used. A warning will be given if the hydraulic/reporting interval parameters generate an exceedingly large number of time steps. Proceeding without change can result in long computation time and/or exhaustion of computer resources, including processing capabilities, 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 (Rossman 2000). 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 (Rossman 2000). 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 0.001 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 water quality tolerance can also be specified in the INJECTION DEFINITION. Inserting a WQ 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.

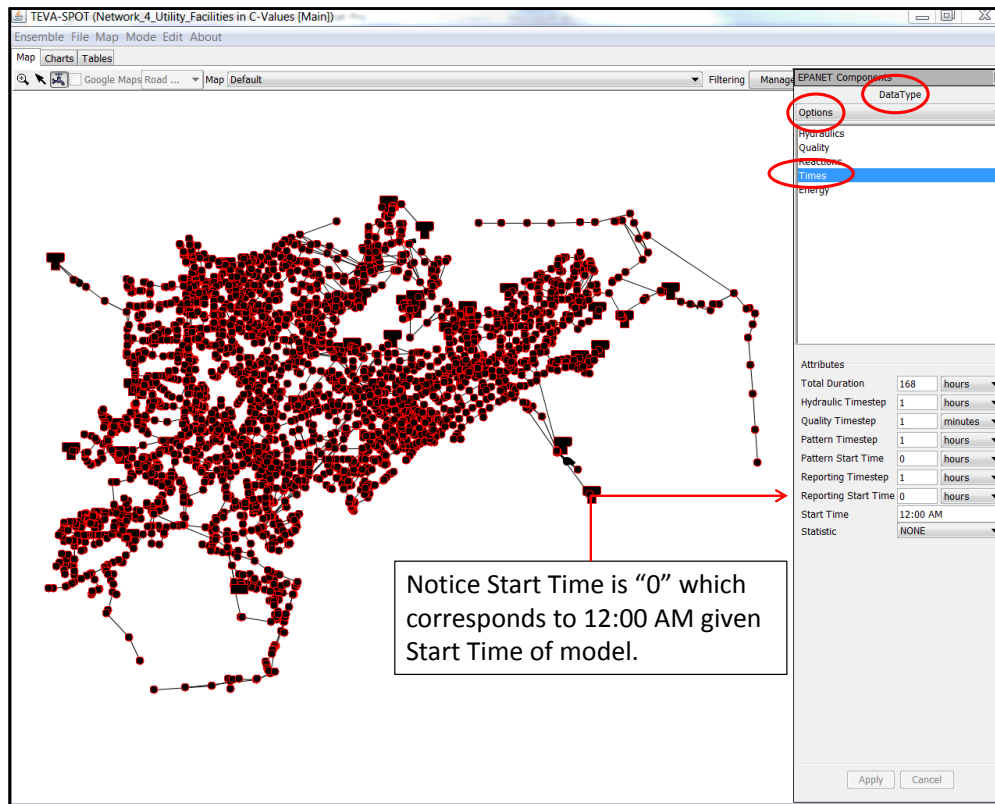
Clicking the *faucet* icon while in the MAP tab will bring up the majority of the INP file in a side panel on the right of the screen. See Figure 5.1.2 below. The “faucet” functionality can be used to explore the water system model. While in the default map, different network attributes can be highlighted. 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.

Figure 5.1.2. Accessing EPANET components: using the faucet icon.



The START TIME of the model is specified in the *.inp file and can be accessed via the *faucet* icon. Under “Data Type” scroll to “Options”, and next “Times” (see Figure 5.1.3).

Figure 5.1.3. Accessing EPANET component: start time.



The START TIME specifies the start of the simulation. TEVA-SPOT-GUI recognizes the START TIME as local time. For the example Network_4, 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 may 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.

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. EPANET's reaction and decay parameters are also specified in the "Ensemble Options" box.

EPANET multispecies (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].

It is highly recommended that initial model testing be performed in EPANET and then once the preferred hydraulic and water quality parameters are identified, tested, and evaluated the revised model be incorporated into TEVA-SPOT-GUI for analysis.

5.2 TEVA-SPOT-GUI Simulation Parameters

Most of the TEVA-SPOT-GUI simulation parameters are specified in each execution module. Others are specified within the Ensemble Options box. Most of the TEVA-SPOT-GUI simulation parameters were discussed with the discussion of each module. Here, we provide an overview of some additional TEVA-SPOT-GUI simulation parameters.

Within the “Ensemble Options” box under “Simulation Parameters” are 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. For the check box, this generally should always be checked. For the number of simultaneous “SP executions”, some thought is warranted depending on the size (# of nodes) of the model, 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 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.

Also within the “Ensemble Options” box but under the “QA Parameters” are two features: (1) check box for performing “mass balance analysis” and (2) “SELECT” button for selecting or uploading 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 will be discussed in the Quality Assurance section, 5.4.

5.3 Contamination Scenario

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 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 factor (1) 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 Users 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]. Recall that the mass injection rate and the start and stop times for a contamination scenario are specified within the *Injection Definition* which is under the *EPANET Simulations* module.

A contamination scenario together with the possible locations within the water distribution system where the contaminant could be injected describes a threat. Recall that the contamination injection locations are specified as a *Node Set Definition* within the *EPANET Simulations* Module.

Users of TEVA-SPOT 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 to support SRS efforts). Unfortunately, the interpretation of threat information is imperfect, and there is no single definition of a threat to the water sector. Thus, judgement 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 Water ISAC does track and report 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.

In Sections 5.3.1 through 5.3.4 we provide information 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 to meet their needs in the most computationally efficient manner. In Section 5.3.5 we provide a table with three example contamination scenarios for possible use in TEVA-SPOT. We also provide some supporting information about how TEVA-SPOT simulates contaminant releases into tanks and pressurized back flow of contaminants at nodes. Finally, we provide some thoughts on designing robust sensor monitoring networks using TEVA-SPOT.

5.3.1 Contaminant

The potential for adverse public health consequences increases as contaminant toxicity increases. Potential public health consequences for highly toxic contaminants can vary substantially between networks but contaminants with lower toxicities potential public health consequences have been shown to be similar for most 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] show 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].

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. define 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.

5.3.2 Contaminant Quantity

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 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 show 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, 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 under 5.3.1. 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).

Unless localized consequences are of concern, the injection mass for a sensor monitoring network design should be as large as feasible with no losses assumed to occur in the system [10]. Sensor monitoring networks generally perform best when the actual injection mass is smaller than that used in the sensor network design [10].

In Davis et al. [9], the authors outline 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):

$$M_i = q * M / Q \quad (1)$$

Where M_i 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):

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

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 at which 50% of the population who receives such a dose dies defines the LD_{50} for a contaminant. LD_{50} values for chemicals and toxins are usually expressed in units of mg of contaminant per Kg of body mass. Using contaminant-specific LD_{50} information and an average body mass for the population (N), a target dose for a contaminant can be determined as shown in Equation (3):

$$\text{Target Dose for Contaminant} = LD_{50} \text{ (mg/Kg)} * \text{Body Mass (Kg)} \quad (3)$$

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

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

As an example, consider a target contaminant's LD_{50} is 0.001 mg/Kg, the population served by the water system is 1,000,000, average body mass of the population served is 70 Kg, Q is 677.6 L/d, and q is 1 L/d

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.
- There are no losses 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.

5.3.3 Contaminant Injection Start Time

The sensitivity of the performance of a water quality sensor monitoring network to the time of contaminant injection depends on the network. The performance can be affected substantially if a contaminant injection occurs at a time different from that used for the design [10]. Although an example contamination scenario described here uses an injection time of 12:00 AM, research has shown that a water quality sensor monitoring network based on contaminant injection at 6:00 AM may be least sensitive to changes in injection time [10].

5.3.4 Contaminant Injection Duration

Generally speaking, considering a large ensemble of injection locations, adverse public health consequences resulting from 24-h injections are larger than those for 1-h injections because there is an increased opportunity for exposure. The difference between the magnitude of consequences from 24-h and 1-hr injections tends to increase with the decreasing toxicity of the contaminant, especially as the importance of the injection location decreases [8]. However, there are considerable differences among water distribution system networks [8]. The magnitude of adverse consequences which result for a given contamination scenario is due to the complex relationship between the contaminant's toxicity, mass injected, and injection rate as well as the hydraulic and water quality dynamics associated with a particular injection location.

Overall, the performance of a sensor network design based on a 24-h injection appears less sensitive to decreases in injection duration than the performance of a 1-h design to duration increases [10]. However, relative sensitivity to contaminant injection duration is network dependent [10].

Once the injection duration, D , is determined, the target contaminant mass derived in Section 5.3.2 can be used to determine a corresponding mass release rate, M_R (mg/min), which is used by TEVA-SPOT-GUI. The mass release rate is shown in Equation (5):

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

5.3.5 Supporting Information

In TEVA-SPOT, the direct addition of a contaminant (mass) to a tank is simulated utilizing a modified version of EPANET. The current version of EPANET does not allow the direct addition of contaminant mass to a tank.

EPANET simulates the pressurized back flow 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 back flow of contaminants will contaminate water used at the injection node and also any water flowing downstream from the node. EPANET, and therefore TEVA-SPOT, 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.

If a water distribution system model is sufficiently detailed that all non-zero demand (NZD) nodes represent terminal nodes in the water distribution system or individual service connections, people located at these nodes will only receive water from the water distribution system. As a result, injection of a contaminant at such nodes will only affect people at the injection node. Using TEVA-SPOT to simulate contaminant injections at terminal nodes or nodes that only receive water will likely under-predict consequences for two reasons [8]. First, not everyone at such nodes who would likely ingest contaminated water would be exposed due to the removal of all contaminated water by demand at the node before ingestion occurs. Second, in the water distribution system model, contaminants injected at terminal nodes have no means for conveyance back into the distribution system. Any ingestion of the contaminant can only occur at the injection node.

The performance of a water quality sensor monitoring network is sensitive to factors such as the population distribution and the ingestion model used in the design and, as a result, sensor monitoring networks should be designed using the most realistic descriptions available for population distribution and the timing of when people ingest tap water [10]. Sensor network performance (i.e., the ability to reduce public health consequences through the optimal placement of sensors to detect contaminants) can decrease substantially when conditions used for design differ from what actually occurs during a contamination event [10]. However, some sensor network designs perform better under changed conditions than others [10]. For example, sensor monitoring networks based on the mean statistic generally outperform worst-case designs when minimizing worst-case impacts when conditions differ from those assumed in the designs [10].

Table 5.3.5.1 below provides three example contamination scenarios.

Table 5.3.5.1. Example Contamination Scenarios

Contaminant & Behavior	Mass or Quantity	Mass or Quantity Release Rate	Time of Injection	Duration of Injection	Public Health Consequence Measure	Sensor Network Design Approach
Example Toxin Used in this Manual (assumed no decay or loss)	300 g	625 mg/min	12:00 AM local time	8 h	pk (LD ₅₀ = 6.0E-6 mg/Kg)	Objective = pk SP statistic = mean
Example Less Toxic Chemical (assume no decay or loss)	>47Kg	32,939 mg/min	6:00 AM local time	24 h	pk (LD ₅₀ = 0.001 mg/Kg)	Objective = pk SP statistic = pk
Very toxic chemical or toxin (assume no decay or loss)	=> 500 g	=> 8330 mg/min	6:00 AM local time	1 h	LD ₅₀ <= 0.001 mg/kg Public health consequences for dose Levels (DL) ranging from 0.0001 to 1 mg	Objective = pk or pd (use with DL) Statistic = mean
Very toxic biological (assume no decay or loss)	=> 10 ¹⁴ organisms	4.2 x 10 ¹² organisms/min	6:00 AM local time	24 h	ID ₅₀ <= 1,000 organisms Public health consequences for dose Levels (DL) ranging from 1 to 10 ⁶ organisms	Objective = pk or pd (use with DL) SP statistic = mean

DL: Dose level (see definitions).

LD₅₀: Refers to mean lethal dose resulting in 50% mortality.

pd: Population dosed, number of people who receive a dose greater than a given dose level.

pk: Population Killed, sensor placement optimization objective in TEVA-SPOT.

SP statistic: Sensor placement optimization statistic (see definitions).

5.4 Quality Assurance Features within TEVA-SPOT-GUI

Here we describe three quality assurance (QA) features that a user can utilize to decrease errors and to improve the accuracy of the results: (1) use of description boxes, (2) running “Perform Mass Balance Analysis”, and (3) removing potentially problematic contamination scenarios using “Injection Location Exclusions”.

5.4.1 Use of Description Boxes

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 what was done in case the documentation is needed months or years after execution.

5.4.2 Running “Perform Mass Balance Analysis”

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 may also want to click the box “Perform Mass Balance Analysis” within the “Ensemble Options” dialogue box and run the mass balance analyses. Figure 5.4.2.1 is a screen shot from TEVA-SPOT-GUI displaying the “Perform Mass Balance Analysis” check box (circled in red). Checking this box will enable the mass balance analyses to be run when the “EPANET Simulations” module is run.

Re-open the ensemble “Network_4_Utility Facilities” and check the box associated with “Perform Mass Balance Analysis”. Re-run the “EPANET Simulations” module.

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

C:\TEVA-SPOT-Database\C-Values\Network_4_Utility_Facilities\BaseEnsemble.

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

- (1) massData.[ENSEMBLE_NAME],
- (2) massDataRatio.[ENSEMBLE_NAME].

Open the file “massDataRatio[ENSEMBLE_NAME] with Microsoft Excel. This table “massDataRatio.[ENSEMBLE_NAME]” provides the results of a mass balance analysis for each contamination scenario executed within the “EPANET Simulations” module. The file contains six columns of data. Column 1 specifies the contamination scenario or node ID. The second column reports the ratio of mass removed to mass injected $((\text{Mass Removed} + \text{Mass in Pipes} + \text{Mass in Tanks})/\text{Mass Injected})$ for each contamination scenario. Columns 3 through 6 details 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.Network_4_Utility_Facilities”. Within this file are the complete mass balance results for each contamination scenario and for each time step of the simulation. Here is a complete, bulleted description of the “massData.[ENSEMBLE_NAME]” file:

- The first row is a header row describing the contents of each column. The headings starting at column 3 (or “column C” when opened in Excel) is the time step of the simulation and extends to the right of the table n columns, with n denoting the number of time steps of the simulation
- 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 . There are four categories of data 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.

5.4.3 Running “Perform Mass Balance Analysis”

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 [9]. For those contamination scenarios that have a ratio greater than 1.1 or less than 0.9, a text file (.txt) should be created from the file “massDataRatio.Network_4_Utility_Facilities”. The resulting text file must contain a single column of node IDs corresponding to those nodes that have a ratio of mass injected to mass removed greater than 1.1 or less than 0.9. The resulting file must be saved to a suitable location and then uploaded through the “Select” box associated with “Injection Location Exclusions” box within the “Ensemble Options” dialogue box. A screen shot of the “Injection Locations Exclusions” upload dialogue box is shown in Figure 5.4.3.1. The text file generated of excluded contamination injection locations could be used for other ensembles using the same network model.

Once the file of excluded scenarios is uploaded, the “EPANET Simulations”, any consequence modules and sensor placement module will need to be re-run.

Figure 5.4.2.1. Screen shot of “Perform Mass Balance Analysis” check box.

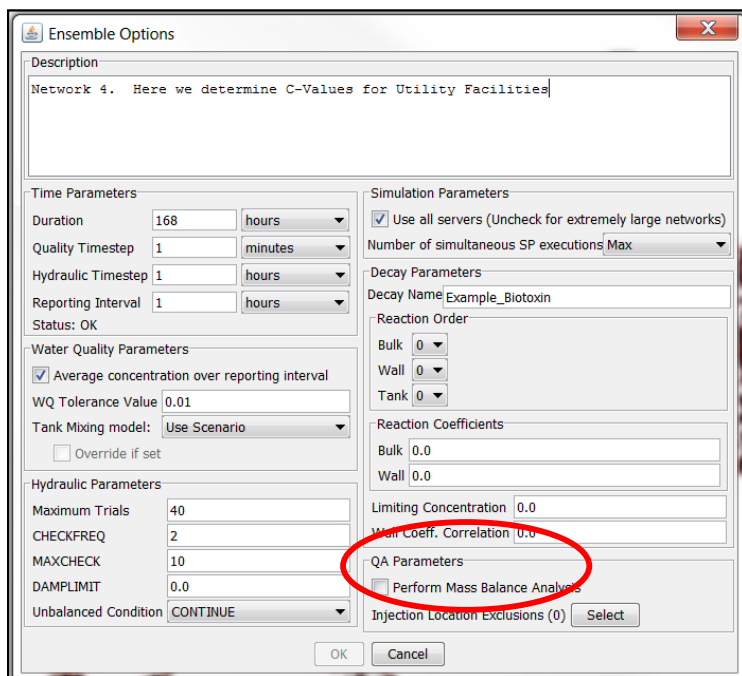
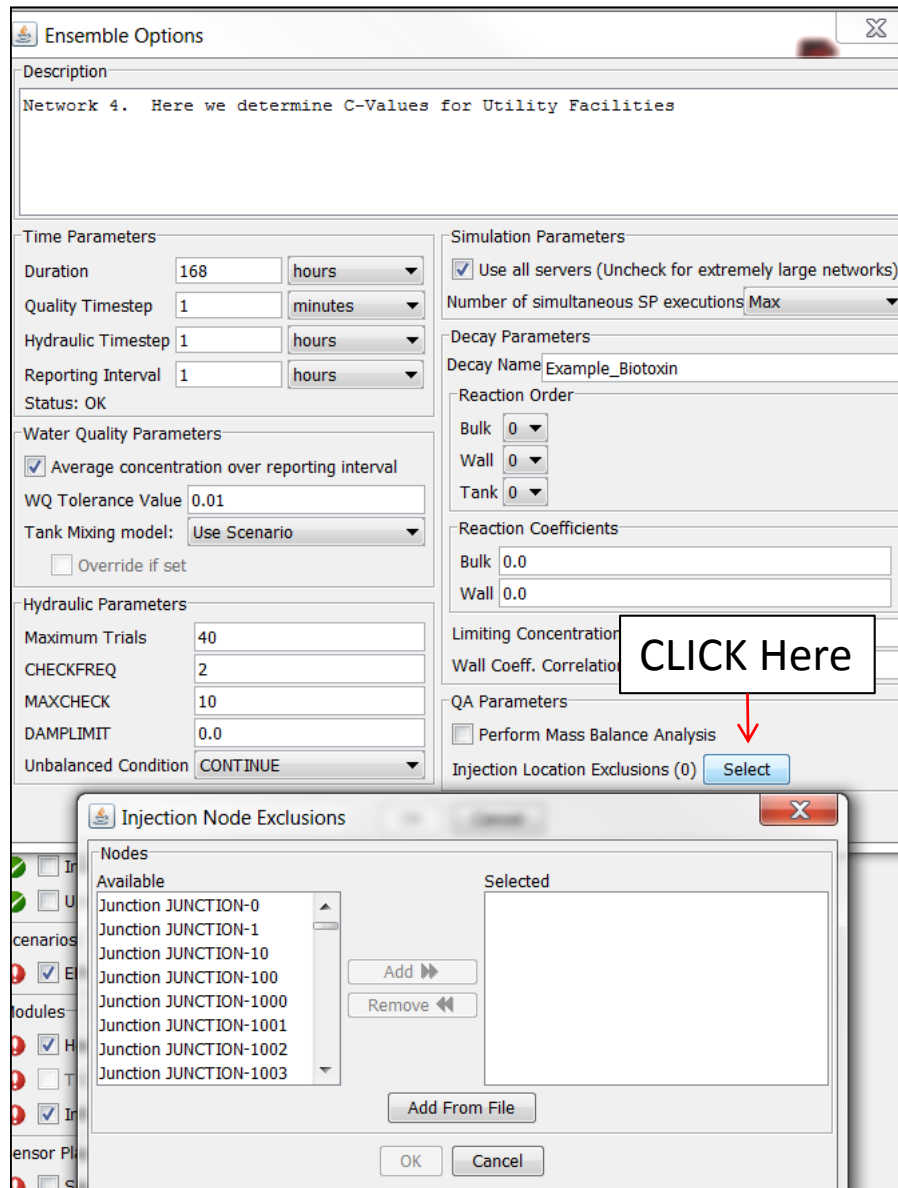


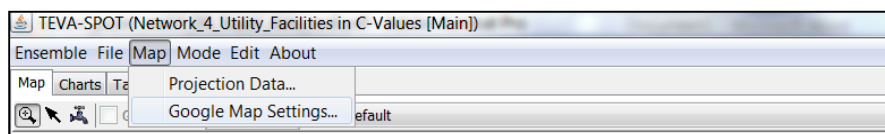
Figure 5.4.3.1. Screen shot of “Injection Location Exclusions” dialogue box.



5.5 Using Google Maps™ within TEVA-SPOT-GUI

This section describes how to view a network distribution system 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 5.5.1) and the selection of “Projection Data...” and “Google Map Settings...”, Figures 5.5.2 and 5.5.3, respectively.

Figure 5.5.1. Accessing Google Maps within TEVA-SPOT-GUI.



In order to properly display the distribution system network, network model projection information is needed. In order 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.

There are two common types of coordinate systems, geographic coordinate system and projected coordinate system. A geographic coordinate system may 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. Table 5.5.1 provide projection information for a particular water system. Notice the bolded information in Table 5.5.1. This information can be entered into TEVA-SPOT-GUI to project the water system model onto a user-selected Google Map backdrop.

Table 5.5.1. Example projection Information for a water system model.

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.

To demonstrate here, the user selects “State Plane”, “GRS 1980”, “Feet”, and “zone: 0901: Florida-East” within the panel of options shown in Figure 5.5.2 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 5.5.3 demonstrates the display of a small portion of a water distribution system model within Google Maps (road backdrop) using the projection data described in Table 5.5.1.

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 5.5.3) 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 most likely is a result of errors in the projection information or the coordinates associated with the pipes/nodes in the model has errors. See Figure 5.5.4 (satellite backdrop), which displays a small portion of another distribution system model. 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.

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. 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 5.5.2. Projection panel to access google maps (default data shown).

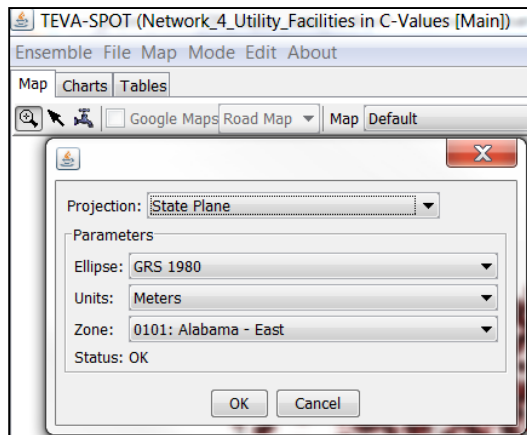
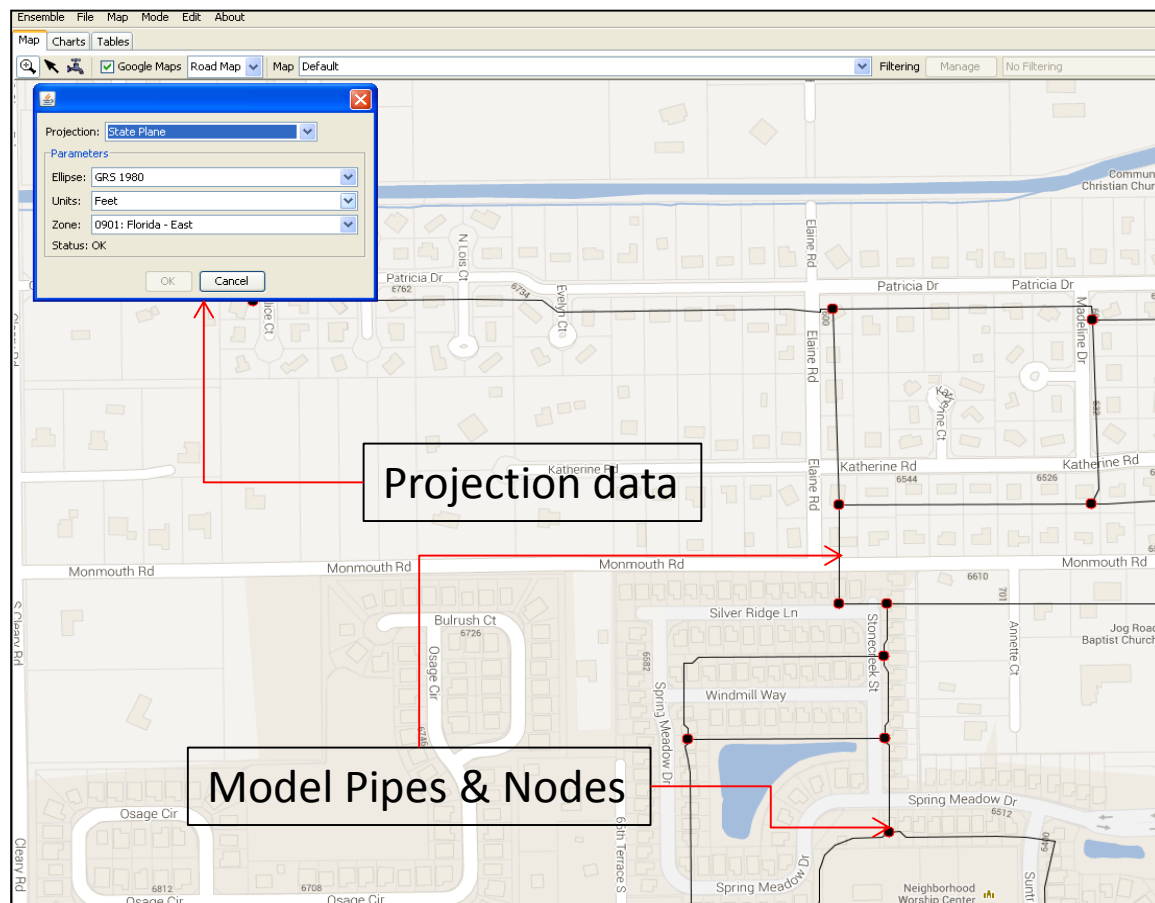


Figure 5.5.3. Example distribution system model (small portion of model) projection.



Google Maps™ mapping service is a registered trademarks of Google Inc.

Figure 5.5.4. Example of a properly projected distribution system model.

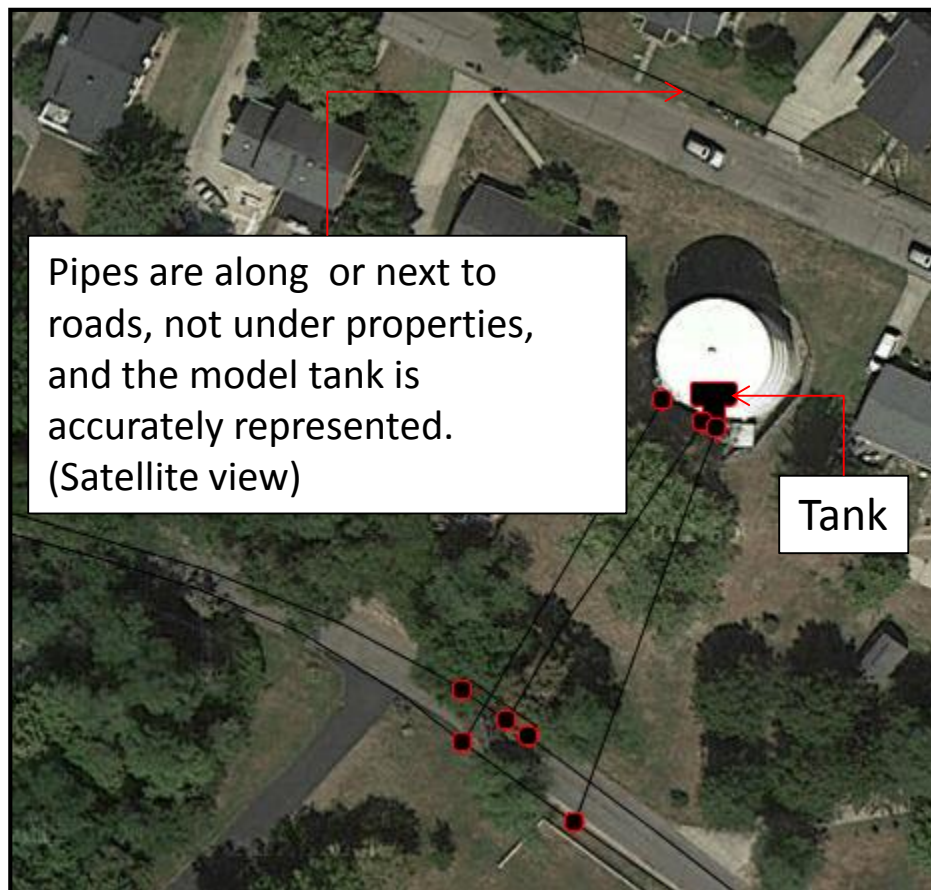
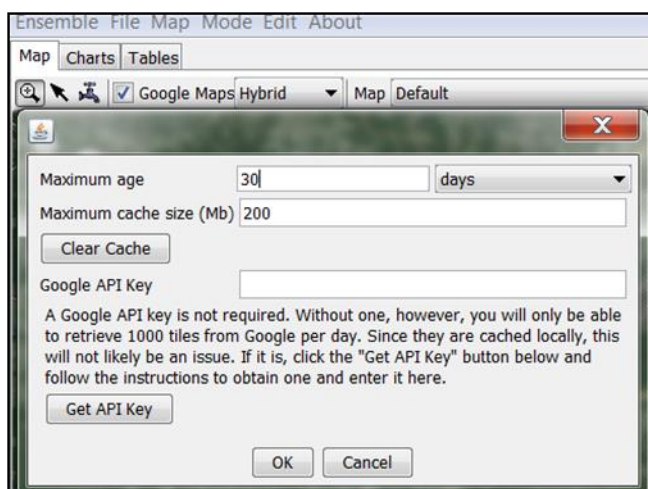


Figure 5.5.5. Google Map settings.



The maximum age specifies how long a piece of map data will be kept in the local cache. They shouldn't be kept forever because Google does update the map data periodically and that would ensure that the

user would have relatively fresh data. The “Clear Cache” can be used to clear the cache. The maximum cache size controls how big the cache can grow. After it reaches that size, the least recently used tiles are removed.

5.6 Trouble-Shooting TEVA-SPOT-GUI Problems

Here we provide some trouble shooting tips in using TEVA-SPOT-GUI. In Section 5.6.1 we describe some trouble shooting tips for ensuring that TEVA-SPOT-GUI is running properly. In Section 5.6.2 we provide some information about the numerous log files that are created by TEVA-SPOT-GUI that can be used to identify potential problems.

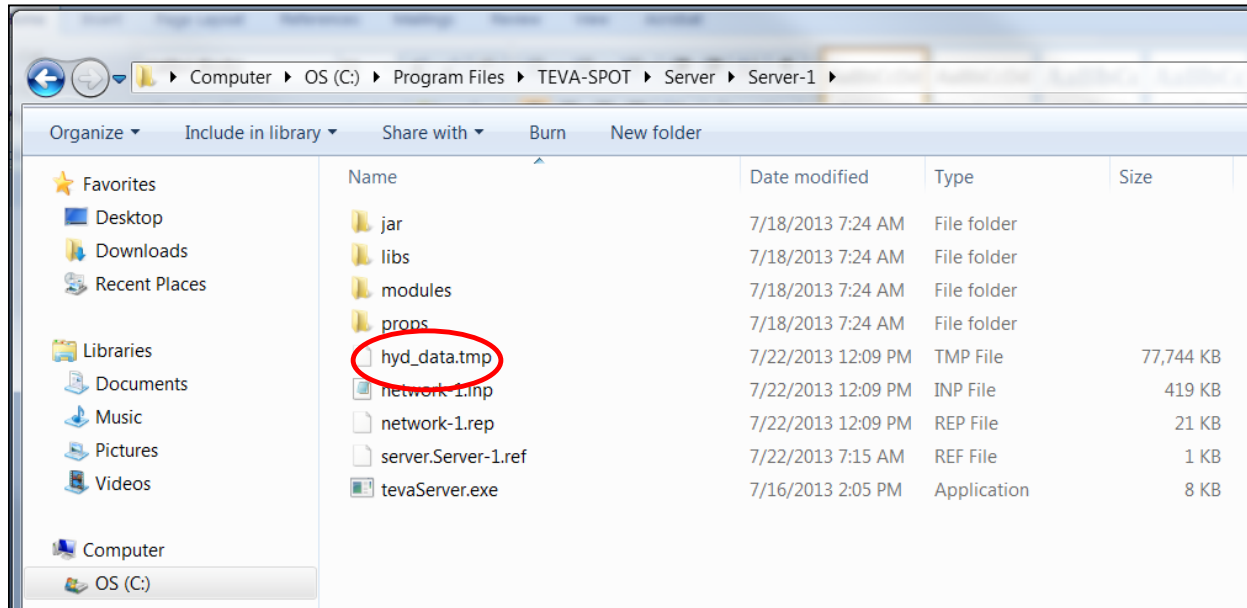
5.6.1 Execution

The uncertainty as to whether TEVA-SPOT-GUI is operating properly after clicking “Execute” can sometimes be vexing to the user. It is important that the network model (.inp file) 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. Figure 5.6.1 is a screen shot showing the temporary hydraulic file. Be sure there is sufficient hard drive space to accommodate the temporary hydraulic file. For very large networks, the temporary hydraulic file may be several gigabits or more in size. Since multiple computer cores are likely processing the simulations, the total space required to accommodate all the hydraulic files could be quite large.
- 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 may take some time before “Randomsample.exe” execution(s) begin. On multi-core computers with sufficient memory, there may be multiple “Randomsample.exe” services running.

Figure 5.6.1. Screen shot of temporary hydraulic file.



A key trouble-shooting tool within TEVA-SPOT-GUI is the “Restart TEVA-SPOT Services” program available from the START Menu under TEVA-SPOT. 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 re-start TEVA-SPOT services, or (3) rebooting computer. Choosing “Terminate” may take a while 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” may 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 performed.

5.6.2 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 is not compatible with easy viewing of the log files output by TEVA-SPOT-GUI, i.e., everything looks jumbled. An open source program called emacs can be downloaded from the link below.

<http://www.xemacros.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 here, 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.

- **ExecutionController**
 - **ExecutionController_[Date].log** – Provides communication and status information about the “ExecutionController”. Look here for the key words “Severe Exceptions”.
 - ExecutionController_[Date].memory.log – Memory utilization information.
 - **ExecutionController_[Date].execstats.log** - This will provide 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** – This file will provide 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** - This file will provide 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. The DBServer 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. 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 “.txt”. Coordination through email can be used for any other problems, including installing or using the TEVA-SPOT-GUI software.

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