GIRAFFE USER'S MANUAL

Version 4.2

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INTRODUCTION

1.1 BACKGROUND

Water supplies constitute a key component of critical civil infrastructure that supports fire protection and provides water for potable household consumption as well as industrial and commercial uses. Water is conveyed mostly in underground pipelines. Thus, ground movements triggered by earthquakes have a direct effect on the integrity and reliability of water distribution networks. Water supplies are vulnerable to earthquakes. This vulnerability has been demonstrated by extensive damage sustained during previous earthquakes, such as the 1906 San Francisco (e.g., Schussler, 1906; Manson, 1908; Lawson, 1908), 1971 San Fernando (e.g., Steinbrugge, et al., 1971; Eguchi, 1982), and 1994 Northridge (e.g., Lund and Cooper, 1995; Hall, 1995; Eguchi and Chung, 1995; O'Rourke, et al., 2001) earthquakes. Earthquake damage to water supply systems may disrupt residential, commercial, and industrial activities; impair fire-fighting capacities; and prolong local community recovery in the aftermath of earthquakes. It is very important, therefore, to model the earthquake performance of water supply systems in a robust and reliable way for emergency planning, community restoration, and assessment of regional economic impacts.

Earthquake performance of a water supply system depends on the available flows and pressures in the damaged system. The flows and pressures can be predicted using hydraulic network analysis, which involves solving a set of linear and/or nonlinear algebraic equations, normally by means of computer programs. Commercial hydraulic network analysis software packages are designed for undamaged systems, and may predict unrealistically high negative pressures when used for damaged systems. Hydraulic network analysis results with negative pressures are inaccurate. Real water supply systems are not air tight, and thus their ability to support negative pressures is limited. To simulate the seismic performance of water supply systems, earthquake damage to pipelines needs to be added to the network and then hydraulic simulation performed using the damaged network. There are no pipe break or leak simulation algorithms in commercial software packages. It is therefore important to develop an algorithm to model pipe breaks and leaks, and integrate this algorithm into an analysis program for simulation purposes.

A computer program, GIRAFFE, has been developed for the hydraulic network simulations of heavily damaged water supply systems. GIRAFFE stands for Graphical Iterative Response Analysis for Flow Following Earthquakes. It involves over 10,000 lines of C++ code and works iteratively with the EPANET hydraulic network analysis engine. GIRAFFE embodies an iterative procedure for negative pressure elimination, methods for simulating pipeline breaks and leaks, and the simulation of earthquake demands associated with distribution networks. GIRAFFE can perform both deterministic and probabilistic simulations, and provides results which can be directly linked to GIS to conduct spatial analysis and map presentations.

This manual is written to provide users with a tool for understanding the main features, modeling methodology, and input and output parameters and data files for GIRAFFE simulations. Selected examples are presented to help users to understand the GIRAFFE simulation procedures.

1.2 SCOPE

This manual is divided into 7 chapters. The first chapter provides the background of GIRAFFE. Chapter 2 presents an overview of GIRAFFE simulations.

Chapters 3 to 5 present the methodologies applied in GIRAFFE simulations. Chapter 3 provides an introduction of hydraulic network analyses and negative pressure treatment. Chapter 4 describes the pipe damage modeling methodology applied in GIRAFFE. Chapter 5 presents the methodology used for earthquake demand simulations associated with distribution networks.

Chapter 6 provides a detailed description of the GIRAFFE input and output parameters and data files. Chapter 7 provides three examples associated with the three GIRAFFE simulation options, which are deterministic, Monte Carlo with fixed simulation runs, and Monte Carlo with flexible simulation runs.

CHAPTER 2

OVERVIEW OF GIRAFFE SIMULATIONS

2.1 INTRODUCTION

The first version of GIRAFFE was designed to work in an MS-DOS environment. GIRAFFE versions 2 and 3 are equipped with a graphical user interface (GUI) to provide a better user experience. Version 3 is installed by opening the file, *Giraffe_Install.exe*, on the installation disc. The installation procedure will also allow you to install EPANET2.0 and the necessary Microsoft .NET Framework 1.1 Package. It is recommended that users install the EPANET2.0 software as it provides a GUI to help users visualize the hydraulic network and GIRAFFE simulation results. EPANET can be downloaded from the installation disk or from the EPANET website: http://www.epa.gov/ORD/NRMRL/wswrd/epanet.html#Downloads.

GIRAFFE can perform both deterministic and Monte Carlo simulations. For a deterministic simulation, GIRAFFE adds damage to the network deterministically and then performs a hydraulic analysis on the damaged network. For Monte Carlo simulation, users can either specify the number of Monte Carlo simulation runs or let the code decide the simulation runs automatically using the built-in self-termination algorithm. For each Monte Carlo simulation, GIRAFFE damages the system probabilistically and then analyzes the damaged network.

A complete GIRAFFE simulation includes five major modules, which are system definition, seismic damage, earthquake demand simulation, hydraulic network analysis, and compilation of results. A flow chat of a GIRAFFE simulation is shown in Figure 2.1. The major functions of each module are introduced in the following sections.

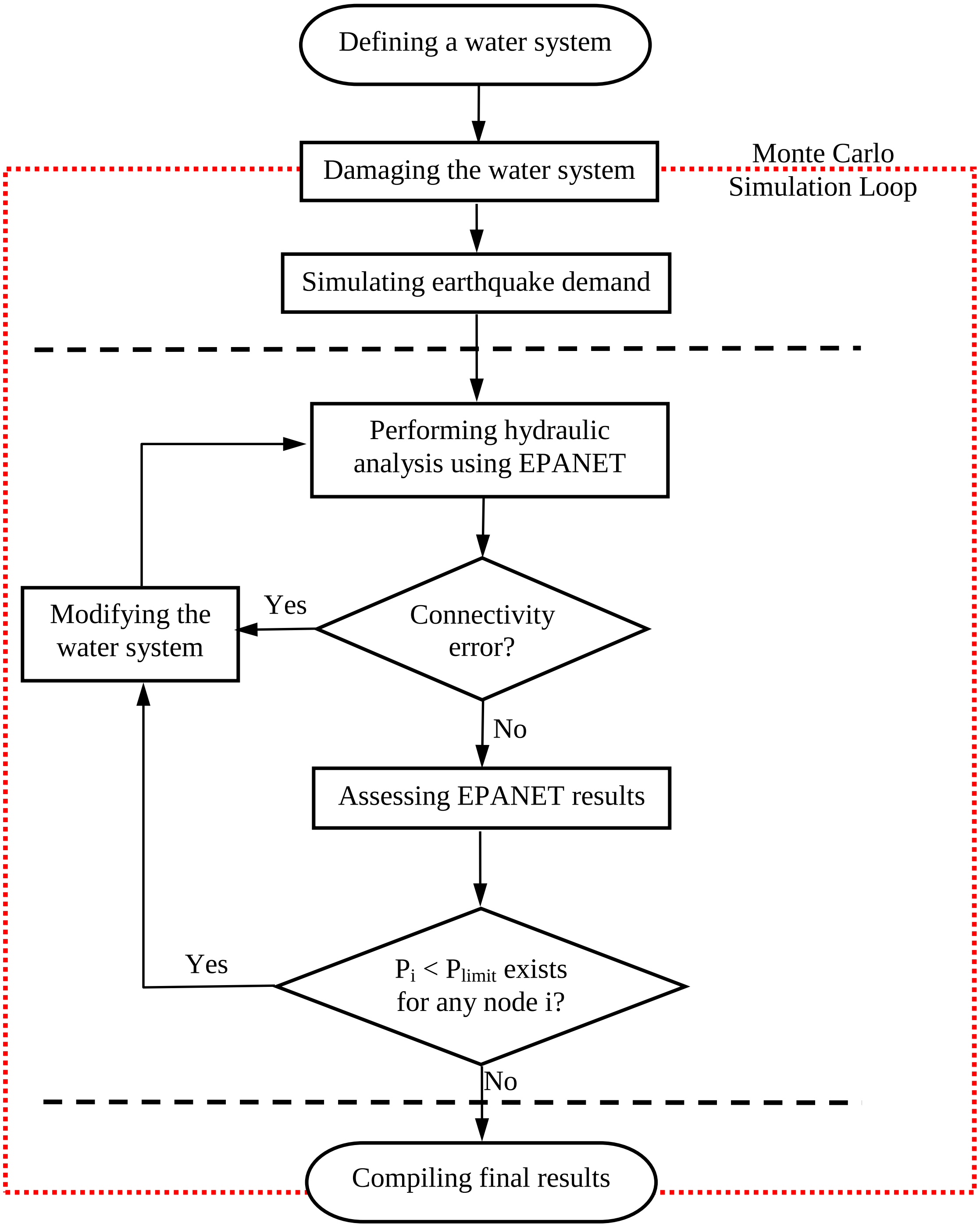


Figure 2.1 GIRAFFE Simulation Flow Chart

2.2 SYSTEM DEFINITION

The system definition module defines the hydraulic network being analyzed. It provides information on the physical and operational properties, topology, and demands of a system. Users can use the GUI of EPANET for system definition and then export the system definition file. The hydraulic network model of the water supply system operated by the Los Angeles Department of Water and Power (LADWP) is developed based on the software, H2ONET (LADWP, 2002), which uses EPANET as the analysis engine and an AutoCAD platform for network visualization and the presentation of results. The LADWP hydraulic network model can be exported from H2ONET into EPANET format, which can then be analyzed by GIRAFFE. Therefore, when GIRAFFE is used to analyze the LADWP hydraulic network, users do not need to define the system and only need to export the H2ONET hydraulic model into the EPANET format. Chapter 7 provides an example on how to export a hydraulic network model developed using H2ONET into the EPANET format.

2.3 SYSTEM DAMAGE

The damage module adds damage to pipelines. The detailed modeling methodology for pipe damage is described in Chapter 4. In general, pipe breaks and leaks can be modeled. A pipe leak can be classified as five different types: annular disengagement, round crack, longitudinal crack, local loss of pipe wall or local tear of pipe wall. One pipe can have multiple breaks and leaks. Two simulation options, deterministic and probabilistic, are provided for pipe damage.

GIRAFFE also incorporates the earthquake performance of tanks by accounting for water losses with time from damaged pipelines. When considering the tank performance, hydraulic simulation is divided into different time steps, which are set by users. Within each time step, GIRAFFE performs a steady state hydraulic simulation for a fixed set of tank levels. From one time step to the next, the tank levels are updated based on the current tank water levels, tank outflows, and tank cross-sectional areas.

2.4 EARTHQUAKE DEMAND SIMULATION

The earthquake demand simulation module implicitly considers the effects of damage to small diameter distribution pipelines, which are not included in the hydraulic network model, by increasing nodal demands. The increase of nodal demands is determined by fragility curves, which relate demand to pipe repair rate. The fragility curves are developed on the basis of Monte Carlo simulations of the LADWP distribution networks. The detailed methodology for earthquake demand simulation is provided in Chapter 5. Because the earthquake demand is simulated probabilistically by fragility curves, this module only works for probabilistic simulations.

2.5 HYDRAULIC NETWORK ANALYSIS

This module uses the EPANET hydraulic network engine iteratively to solve the damaged hydraulic network and eliminate negative pressures. As shown in Figure 2.1, the damaged system is sent to the EPANET engine for hydraulic network analysis. It is possible that the damaged system cannot be solved because some elements may not have connectivity with the main system due to earthquake damage. In this case, the EPANET engine gives error messages, which tell the user the ID of each element disconnected from the main system. GIRAFFE reads the error messages and fixes the errors by eliminating the disconnected elements from the database. GIRAFFE then checks the nodal pressures, and identifies the lowest nodal pressure in the system. If the lowest pressure is higher than the preset pressure limit, which is zero for negative pressure elimination, the hydraulic analysis stops. If the lowest pressure is lower than the pressure limit, the program eliminates the node, the links connected to this node, and the operational parameters associated with the node and links. After each step of elimination, GIRAFFE performs a hydraulic network analysis again, and this process continues until there is no pressure lower than the pressure limit in the system. GIRAFFE requires the user to set the pressure limit to increase the flexibility of the program. For example, areas with inadequate pressures for fire fighting can be identified by setting a pressure limit required for fire fighting purposes.

2.6 COMPILATION OF RESULTS

This module compiles the hydraulic analysis results into a format compatible with GIS. It also provides a performance index to measure the system serviceability.

2.6.1 Hydraulic Network Analysis Results

The H2ONET LADWP hydraulic network model database can be exported as GIS data, in which junctions, pipes, pumps, valves, and tanks are exported into separate shapefiles. The hydraulic analysis results are thus compiled for these five types of elements. Please note, reservoirs are treated as a special type of tank which have a fixed grade. A user may classify a reservoir as a tank to allow water levels to vary dynamically (See Appendix D for special notes regarding this case). The major outputs for pipes, valves, and pumps are their respective flow rates. The major outputs for junctions and tanks are their respective pressures and grades. For the components that are eliminated from the main system due to either negative pressure or connectivity problems, their results are set to zero to represent the isolation of these components. For a deterministic simulation, the outputs for the five types of components are reported. For a probabilistic simulation, the outputs for the five types of components are reported for each run of the Monte Carlo simulation. The flow rates in pipes and pressures at junctions, which are the key outputs, are reported for each Monte Carlo simulation run. The mean, standard deviation, and coefficient of variation (COV) of the flow rate in each pipe and pressure at each node for all Monte Carlo simulation runs are also calculated and reported. If users perform time-history simulation to consider the tank performance, the outputs are reported for each time step.

2.6.2 Performance Index

This module provides an index for measuring the seismic serviceability of a damaged water supply system. The serviceability is defined as the ratio of the available demand to required demand corresponding to a seismic damage scenario,

$$S_s = \frac{Q_T}{Q_T^*} \tag{2.1}$$

where S_s is the serviceability, Q_T is the available demand, and Q_T^* is the required demand. The serviceability can be calculated for each demand node and for the entire system. For a deterministic simulation, the serviceability for each demand node is either 0, if this demand node is isolated due to the negative pressure or connectivity problems, or 1, if this demand can be satisfied. The serviceability for the entire system is the sum of the demands that can be satisfied over the sum of the total required demands. For a probabilistic simulation, the system serviceability is reported in a matrix format. For each Monte Carlo simulation run, the serviceability is reported for each demand node and for the entire system. The mean of the nodal and system serviceability for all Monte Carlo simulation runs is also calculated and reported. If users perform time-history simulation to consider the tank performance, the outputs are reported for each time step.

GIRAFFE provides a simulation option, in which the program will determine how many Monte Carlo simulation runs are needed to have statistically significant results using the system serviceability as an index. In this simulation option, GIRAFFE calculates the mean and COV of the system serviceability, starting from ten simulation runs. Then after every five simulation runs, GIRAFFE calculates the mean and COV of the system serviceability of all the simulations and compares the current mean and COV of the system serviceability with the previous ones. If the difference of both mean and COV of the system serviceability from the two sets of results is smaller than a user defined percentage (the default is set to 2%), the simulation is terminated, otherwise, the simulation continues.

CHAPTER 3

HYDRAULIC NETWORK ANALYSIS

3.1 INTRODUCTION

The basic function of a water supply system is to deliver water from sources to customers. Moving water from source to customer requires a network of pipes, pumps, valves, and other appurtenances. Storing water to accommodate fluctuations in demand due to varying rates of usage or fire protection requires storage facilities, such as tanks and reservoirs. Pipes, pumps, valves, storage, and the supporting infrastructure together comprise a water supply system. A hydraulic network model is a mathematical model of a water supply system in which the physical components of the system are represented as nodes and links. Hydraulic network analysis utilizes the physical and operational properties, topology, and demands of a water supply system as basic input data, and calculates pressures at nodes and flows in links. Hydraulic network analysis can be used to predict pressure and flow conditions in a water supply system under different operational scenarios to ensure that sound, cost-effective engineering solutions can be implemented in the design, planning, and functioning of the water supply system.

This section provides a brief introduction of hydraulic network analysis. The basic methodology for hydraulic network analysis is introduced. The EPANET hydraulic simulation models are described. The negative pressure treatment for simulating heavily damaged water supply systems is discussed.

3.2 COMPONENTS IN HYDRAULIC NETWORKS

In general, a hydraulic network model consists of two basic classes of elements: nodes and links. The nodes represent facilities at specific locations in a water supply system, and the links define relationships between nodes. Typical nodal elements include junctions and storage nodes, and typical link elements are pipes. Other components, such as valves and pumps, can be modeled as either links or nodes, depending on different modeling techniques. The primary modeling purpose of each physical element is briefly described below.

1. *Junctions*: represent locations where links intersect and where water enters or leaves the network.
2. *Storage nodes*: represent locations of storage reservoirs and tanks. The pressures at storage nodes are known and treated as boundary conditions to solve flow equations. In contrast to tanks, which have limited storage capacity and for which the volume of stored water varies with simulation time, reservoirs represent external water sources with unlimited storage capacity, such as sources from lakes, rivers, or ground aquifers.
3. *Pipes*: represent links conveying water from one node to another.
4. *Pumps*: represent elements adding energy to flowing water in the form of an increased hydraulic grade. A pump can be modeled as either a node or link.
5. *Valves*: represent elements controlling water flow or pressure from one node to another. A valve can be modeled as either a node or link. There are different types of valves with different functions, such as check, pressure reducing, flow control, throttle control, air release, and vacuum breaking valves.

These physical components are interconnected to form a network and operate together under some operational rules. Typical operational rules include the change of the status of pipes, pumps, and valves under certain conditions. For example, the status of a pump is typically controlled by the water level of the tank it serves. When water in the tank is lower than a certain level, the pump is opened to boost water to the tank. When water in the tank is higher than a certain level, the pump is closed and the tank supplies water to customers. The operational rules give a water supply system the ability to work efficiently under different operation scenarios.

3.3 GOVERNING LAWS

Hydraulic network analysis assumes that a pipeline network is always full and pressurized with water, and steady state flow condition is reached for every pipeline.

Incompressible flow in a pipeline network is then governed by two principle laws: the laws of mass and energy conservation.

3.3.1 Equation of Continuity

In hydraulic network analyses, conservation of mass is typically expressed as equation of continuity, which simply states that the algebraic sum of flows into and out of any node should be zero (Jeppson, 1976). Consider a node *i*, for which the continuity equation can be expressed as

$$\sum_{k=1}^{n_{pi}} Q_{ik} = \tilde{Q}_i \tag{3.1}$$

in which $\tilde{Q}_i$ is the external flow at node *i*, (normally called demand), n_{pi} is the number of pipes connected to node *i*, *k* is an index for pipes, and Q_{ik} is the flow rate in pipe *k* to node *i*. Typically, Q_{ik} is positive for flows coming into the node and negative going out. In contrast, $\tilde{Q}_i$ is positive for flows going out of the node and negative coming into.

3.3.2 Bernoulli Equation

The conservation of energy between two cross-sections, *i* and *j*, within a flow is expressed by the Bernoulli equation (Jeppson, 1976) in the form of hydraulic head as

$$z_i + \frac{p_i}{\gamma_w} + \frac{\mathrm{v}_i^2}{2g} + h_p = z_j + \frac{p_j}{\gamma_w} + \frac{\mathrm{v}_j^2}{2g} + h_f \tag{3.2}$$

where z is the elevation head, p is the internal pressure measured from atmospheric levels, γ_w is the unit weight of water, p/γ_w is the pressure head, v is the flow velocity, g is the gravitational acceleration, $\mathrm{v}^2/2g$ is the velocity head, h_p is the head gain from external mechanical energy, such as pumps, and h_f is the head losses including frictional and minor losses.

A fundamental aspect of the Bernoulli equation is that there is only one hydraulic head at each node in a hydraulic network. The algebraic sum of the head losses and gains around any closed loop should be zero, which is expressed as

$$\sum_{k=1}^{n_L} h_k = 0 \qquad (3.3)$$

where n_L is the number of pipes in the loop and h_k is the head gain or loss in pipe k.

3.4 ENERGY LOSSES

Whenever water flow passes a fixed wall or boundary, friction exists due to the viscosity of water. The friction transforms part of the useful energy into heat or other forms of non-recoverable energy, which results in frictional head losses. A number of appurtenances, such as inlets, bends, elbows, contractions, expansions, valves, meters, and pipe fittings are commonly included in water supply systems. These devices alter the flow pattern in pipes by creating additional turbulence, which leads to head losses in excess of frictional head losses. These additional head losses are called minor or local losses.

3.4.1 Frictional Loss

Frictional loss results from the shear stress developed between water and the pipe wall. Its magnitude depends on the density, viscosity, and velocity of water, as well as the internal roughness, length, and size of the pipe (Jeppson, 1976). There are various formulations to evaluate frictional head losses, and all formulations can be generalized into the following form (Walski, et al., 2001):

$$h_{fk} = K_{fk} Q_k^{n_k} \tag{3.4}$$

in which h_{fk} is the frictional head loss along pipe k, Q_k is the flow rate through the pipe, K_{fk} is a resistance coefficient, and n_k is a constant flow exponent.

The most widely used formulations to calculate frictional head losses in hydraulic network analysis are the Darcy-Weisbach, Hazen-Williams, and Chezy-Manning equations. The resistance coefficient, K_{fk}, and flow exponent, n_k, associated with each formulation are listed in Table 3.1. The Darcy-Weisbach equation is physically-based, as it is derived from the basic equations of Newton's Second Law. The main disadvantage associated with the Darcy-Weisbach equation is that the frictional factor, f, and thus the resistance coefficient, K_{fk}, is a function of flow rate, Q_k. When Equation 3.4 is used to solve flow rate, Q_k, with known head loss, h_{fk}, the equation is an implicit expression of the flow rate. Trial-and-error or numerical methods must be applied to solve it. The Hazen-Williams and Manning formulas are empirically-based expressions developed from experimental data. The Hazen-Williams formula is the most frequently used formulation for hydraulic network analysis in the U.S. Jeppson (1976) provides a detailed discussion of the three formulas.

3.4.2 Minor Loss

Minor losses (also called local losses) are induced by local turbulence. The importance of such losses depends on the geometric dimension of the hydraulic network and the required simulation accuracy. If pipelines are relatively long, these minor losses may be truly minor compared with frictional losses and can be neglected. In contrast, if pipelines are short, the minor losses may be large and should be considered. If devices, such as a partly closed valve, cause large losses, the minor losses can have an important influence on the flow rate. In practice, some engineering judgment is required to decide if the minor losses need to be considered.

Table 3.1 Frictional Head Loss Evaluation Formulas

Equation	Resistance Coefficient K_{fk}	Flow Exponent n^k
Darcy-Weisbach	$\frac{8fl_k}{gd_k^5\pi^2}$	2
Hazen-Williams	$\frac{Bl_k}{C^{1.852}d_k^{4.87}}$	1.852
Chezy-Manning	$\frac{Al_k\mu^2}{d_k^{5.333}}$	2

Notes:

g: Acceleration of gravity

f: Friction factor in Darcy-Weisbach formulation, a function of the flow rate and physical properties of the pipeline. The friction factor, f, can be determined using the Colebrook-White equation (Jeppson, 1976), Moody diagram (Moody, 1944), or Swamee-Jian formula (Swamee and Jian, 1976).

l_k: Length of pipe

d_k: Diameter of pipe

B: Dimensional constant in Hazen-Williams formulation, equal to 4.73 and 10.70 in British and SI units, respectively.

C: Hazen-Williams roughness coefficient, a function of the pipe physical properties. The values of C for different types of pipeline are available in the literature (e.g., Jeppson, 1976; Armando, 1987; Walski, et al., 2001).

A: Dimensional constant in Chezy-Manning formulation, equal to 4.64 and 10.29 in British and SI units, respectively.

μ: Manning roughness coefficient, a function of the pipe physical properties. The values of μ for different types of pipeline are available in the literature (e.g., Jeppson, 1976; Armando, 1987; Walski, et al., 2001).

The minor losses are generally expressed as

$$h_{mk} = \frac{K_{mk}}{2gA_k^2} Q_k^2 = K'_{mk} Q_k^2 \tag{3.5}$$

in which $K'_{mk} = K_{mk} \big/ (2gA_k^2)$, g is the acceleration of gravity, Q_k is the flow rate, K_{mk} is the minor loss coefficient, and A_k is the pipe cross-sectional area. The values of K_{mk} for different types of minor losses have been determined from experiments, and are available in the literature (e.g., Crane Company, 1972; Miller, 1978; Armando, 1987; Idelchik, 1999; Waskli, et al., 2001). Sometimes, it is more convenient to equate the minor losses to frictional losses caused by a fictitious length of pipe, known as an equivalent pipe length. This length can be derived from Equations 3.4 and 3.5, with the substitution of the selected resistance coefficient K_{fk} and flow exponent n_k.

3.5 ENERGY GAINS

There are many occasions when energy needs to be added into a hydraulic system to overcome elevation difference, as well as frictional and minor losses. A pump is a device to which mechanical energy is applied and transferred to water as hydraulic head. The head added to water is called pump head, and is a function of discharge through the pump. The relationship between pump head and discharge rate is called a pump head characteristic curve, as shown in Figure 3.1. The pump characteristic curve is nonlinear, and as expected, the more water that passes through the pump, the less head it can add.

The head that is plotted in the head characteristic curve is the head difference across the pump, called the total dynamic head. This curve needs to be described as a mathematical equation to be used in hydraulic simulation. Some models fit a polynomial curve to selected data points, but a more common approach is to describe the curve using a power function in the form of

$$h_P = h_o - cQ_P^m \tag{3.6}$$

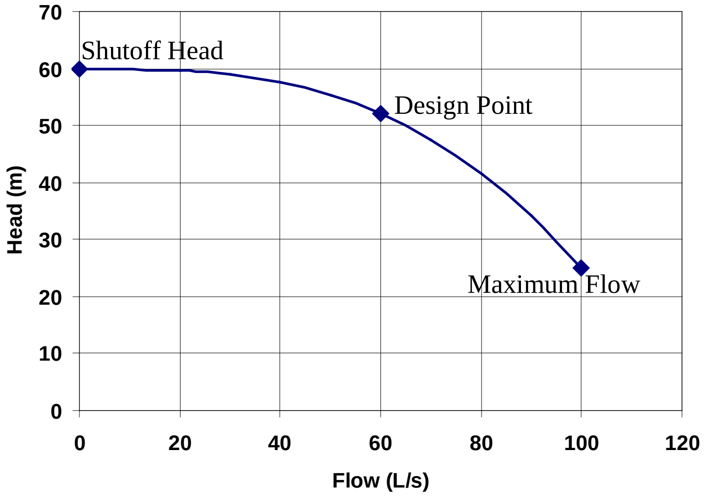


Figure 3.1 General Shape of Pump Characteristic Curve

where h_P is the pump head, h_o is the cutoff (shutoff) head (pump head at zero flow), Q_P is the pump discharge, and c and m are the coefficients describing the curve shape.

The purpose of a pump is to overcome elevation differences and head losses due to pipe friction and obstructed flow at fittings. The amount of head which a pump must add to overcome elevation differences is referred to as static head or static lift and is dependent on system topology but independent of the pump discharge. Frictional and minor losses, however, are highly dependent on the pump discharge rate. When these losses are added to the static head for a series of discharge rates, the resulting plot is called a system head curve. The pump characteristic curve is a function of the pump and independent of the system, while the system head curve is dependent on the system and independent of the pump. When a pump characteristic curve and a system head curve are plotted on the same axes, there is only one point that lies on both of them. This intersection, as shown in Figure 3.2, defines the pump operation point, which represents the discharge that passes through the pump and the head that the pump adds in hydraulic network simulations.

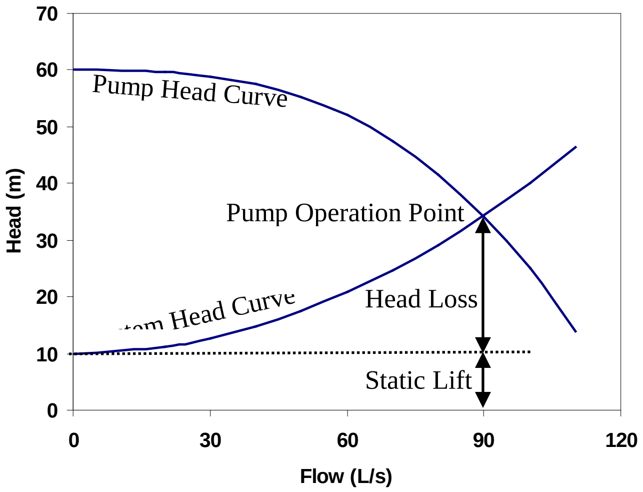


Figure 3.2 Pump Operation Point

3.6 FLOW EQUATIONS

Hydraulic network analysis is governed by the laws of mass (continuity equation) and energy (Bernoulli equation) conservation. The major unknowns that need to be determined are flows in links and hydraulic head at nodes. The flows and hydraulic heads are linked with each other by the head loss equations, Equations 3.4 and 3.5. Based on different primary unknowns used in the equations, four types of flow equations can be developed, which are Q-, H-, ΔQ- and hybrid equations (Jeppson, 1976), to express the laws of mass and energy conservation. The four types of equations set flow rates in links, hydraulic heads at nodes, corrective flows in network loops, and mixture of flow rates in links and hydraulic heads at nodes as primary unknowns, respectively. Shi (2006) provides a detailed description of the four types of flow equations. The solution to these equations requires solving a set of linear and/or nonlinear equations. For networks with a large number of components, numerical methods must be used. Four widely used numerical methods are Hardy-Cross, Newton-Rapshon, linear theory, and the gradient method. References on the detailed procedures of applying the four numerical methods to flow equations are included in Shi (2006).

3.7 EPANET

Many commercial software packages are available in the market for hydraulic network analysis. Among them, EPANET, developed and distributed by the US Environmental Protection Agency (EPA) (Rossman, 2000), is one of the earliest and most widely used. Because EPANET contains a state-of-the-art hydraulic analysis engine and its source code is freely available to the public, a family of software packages including WaterCAD (WaterCAD, 2005), MIKENET (MIKENET, 2005), H2ONET (MWH Soft Inc., 1999), and others, use the EPANET analysis engine and develop their own products around it.

EPANET was designed to be a research tool for improving the understanding of the movement and fate of drinking water constituents in water distribution systems (Rossman, 2000). It has two major capabilities: hydraulic and quality modeling for water in a pressurized pipeline network. The water quality modeling is beyond the scope of this study, and therefore, only the hydraulic modeling capabilities of EPANET are discussed. The following discussion is based on, but not limited to, the information provided in the EPANET user manual by Rossman (2000).

EPA released a DOS and Windows version of EPANET. The DOS version is an analysis engine that is coded in the C language. The Windows version includes the analysis engine with a GUI written with the Daphi language. To run EPANET in the DOS environment, all network input data are stored in an input text file and analysis results are written into an output text file. To run EPANET in the Windows environment, users can use the GUI to construct a hydraulic network model and input network attributes graphically. The GUI compiles the input information into a text file, and calls on the engine to do the analysis. After finishing the analysis, the GUI retrieves data from the text output file generated by the engine and displays the results graphically for visualization. The source codes and executable files of both the analysis engine and GUI are available from the Internet free of charge. Thus, users can use EPANET to perform hydraulic network analyses, and can also modify the source codes for their own product development.

3.7.1 EPANET Hydraulic Network Components

An EPANET hydraulic network model consists of various physical components, which are the mathematical representations of physical objects in a real water supply system. Mathematical representations are also used for operational components that control the behavior and operational properties of the physical components.

3.7.1.1 Physical Components

EPANET models a water supply system as a collection of links connected to nodes. The nodes represent junctions and storage nodes, including tanks and reservoirs. The links represent pipes, pumps, and control valves. Figure 3.3 illustrates how these objects can be connected to one another to form a network. Each reservoir, tank, pump, and valve, because of its different physical properties and/or functions, can have different modeling options. Table 3.2 lists all the physical components that EPANET can model. In total, there are 17 different components, including 1 junction, 4 storage nodes, 1 pipe, 4 pumps, and 7 valves. Table 3.2 provides a brief description of the functions and basic input and output parameters associated with hydraulic simulations of each physical component.

3.7.1.2 Operational Components

In addition to the physical components, EPANET employs three types of operational components: curves, patterns, and controls that describe the operational aspects of the physical components.

Curves

Curves are objects that contain data pairs representing a relationship between two quantities. An EPANET model can utilize four types of curves, which are pump characteristic, efficiency, volume, and head loss curves. A pump characteristic curve represents the relationship between the head and flow rate that a pump can deliver. EPANET can model three

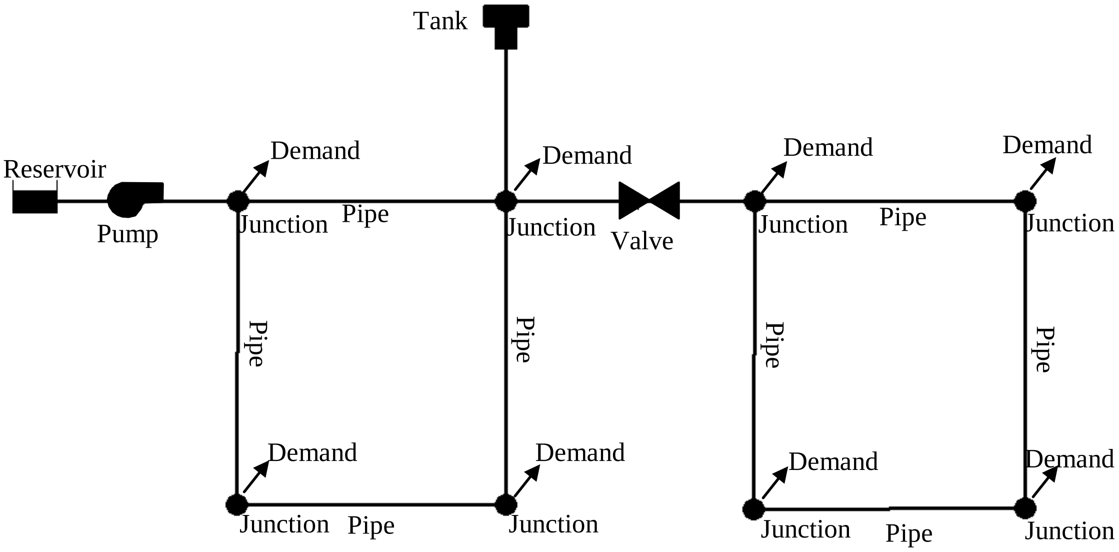


Figure 3.3 Physical Components in an EPANET Hydraulic Network

different shapes of pump curves: single-, three-, and multi-point curves, dependent on the number of points used to calibrate the pump characteristics. An efficiency curve describes pump efficiency as a function of pump flow rate and is used for determining energy consumption and calculating costs associated with pump operations. These calculations are not considered in this study. A volume curve describes how storage tank volume varies as a function of water level. It is used when it is necessary to accurately represent tanks, for which the cross-sectional area varies with water height. A head loss curve is used to describe the head loss through a general purpose valve as a function of flow rate. It provides the capability to model devices and situations with unique head loss-flow relationships, such as reduced flow-backflow prevention valves, turbines, and well draw-down behavior.

Time Patterns

A time pattern is a collection of multipliers that can be applied to a quantity to allow it to vary over simulation time. Nodal demands, reservoir heads, and pump schedules can all have time patterns associated with them. When applying time pattern to a quantity, the hydraulic simulation time is divided into different time intervals, which are set by users. Within each time

Table 3.2 Summary Table for Physical Components in an EPANET Hydraulic Network Model

Components			**Descriptions**	**Inputs**	**Outputs**
Junction			Points where links join together and where water enters or leaves the network	Coordinates; elevation; demand	Hydraulic head; pressure
Storage Node	**Reservoir**	**Constant Level**	Unlimited capacity water sources with constant water level during simulation time	Coordinates; hydraulic head (a constant value)	Hydraulic head
		Variable Level	Unlimited capacity water sources with water level varying with simulation time	Coordinates; hydraulic head curve (hydraulic head vs. time)	
	Tank	**Cylindrical**	Limited capacity water sources with cylindrical shape	Coordinates; bottom elevation; diameter; initial, minimum, and maximum water level	Hydraulic head
		Variable Area	Limited capacity water sources with variable cross-sectional area	Coordinates; volume vs. hydraulic grade curve	Hydraulic head
Pipe			Links conveying water from one node in the network to another	Start and end node; diameter; length; roughness and minor loss coefficients; status (open, closed, or containing check valve)	Flow rate; head loss
Pump	**Constant Power**		Pumps which a supply constant amount of energy to water	Start and end node; diameter; energy; status (open or closed)	Flow rate; head gain
	One-Point		Pumps with characteristic curves defined by one point	Start and end node; diameter; operation flow and head gain; status (open or closed)	
	Three-Point		Pumps with characteristic curves defined by three points	Start and end node; diameter; pump curve; status (open or closed)	
	Multiple-Point		Pumps with characteristic curves defined by multiple points	Start and end node; diameter; pump curve; status (open or closed)	

Table 3.2 (Continued)

Component		Description	Input	Output
Valve	**Check (CVs)**	Allow water through one direction (built in pipe)	None (presence is indicated by a "CV" at the end of a pipe definition line)	
	Pressure Reducing Valves (PRVs)	PRVs limit the pressure on their downstream end to not exceed a pre-set value when the upstream pressure is above the setting. If the upstream pressure is below the setting, then flow through the valve is unrestricted. If the downstream pressure exceeds the upstream pressure, the valve closes to prevent reverse flow.	Start and end node; diameter; minor loss coefficient; downstream pressure setting; status (open or closed)	Flow rate; head loss
	Pressure Sustaining Valves (PSVs)	PSVs attempt to maintain a minimum pressure on their upstream end when the downstream pressure is below the setting. If the downstream pressure is above the setting, then flow through the valve is unrestricted. If the downstream pressure exceeds the upstream pressure, the valve closes to prevent reverse flow.	Start and end node; diameter; minor loss coefficient; downstream pressure setting; status (open or closed)	
	Pressure Breaker Valves (PBVs)	PBVs force a specified pressure loss to occur across the valve. Flow through the valve can be in either direction.	Start and end node; diameter; minor loss coefficient; pressure setting; status (open or closed)	
	Flow Control Valves (FCVs)	FCVs limit the flow to a specified amount.	Start and end node; diameter; minor loss coefficient; flow setting; status (open or closed)	
	Throttle Control Valves (TCVs)	TCVs simulate a partially closed valve by adjusting the minor head loss coefficient of the valve.	Start and end node; diameter; minor loss coefficient; status (open or closed)	
	General Purpose Valves (GPVs)	GPVs are used to represent a link where the user supplies a special flow-head loss relationship instead of following one of the standard hydraulic formulas.	Start and end node; diameter; head loss vs. flow rate curve; status (open or closed)	

interval the quantity remains at a constant level, equal to the product of its nominal value and the pattern multiplier for that time period.

Controls

Controls are statements that determine how the network is operated over time. They specify the status of selected links as a function of time, tank water levels, and pressures at select junctions within the network. There are two types of controls in EPANET hydraulic network simulations: simple and rule-based. Simple controls change the status or setting of a link based on one control condition, such as water level in a tank, pressure at a junction, time into the simulation, or the time of day. Rule-based controls change the link status or settings based on a combination of conditions that might exist in the network.

3.7.2 EPANET Input File

EPANET stores all input data in a text file with the file extension, *.inp*. The *inp* file is organized into sections with each section beginning with a key word enclosed in brackets. The various sections are listed in Table 3.3. Detailed examples of the input file can be found in Chapter 7. In general these sections can be classified into five categories; Network Components, System Operation, Water Quality, Options and Reporting, and Network Map/Tags.

The Network Components category stores information about the hydraulic properties of network physical components including junctions, reservoirs, tanks, pipes, pumps, and valves. The System Operation category stores information of system operational properties such as curves, patterns, initial status, controls, rules, and demand. The Water Quality category stores information for water quality simulation. The Options and Reporting category stores information of simulation and report options, and times for extended period simulation. The Network Map/Tags category stores information on the coordinates of each node and coordinates of each vertex of links.

Table 3.3 Sections in an EPANET Input File

Network Components	System Operation	Water Quality	Options and Reporting	Network Map/Tags
[TITLE]	[DEMANDS]	[SOURCES]	[ENERGY]	[COORDINATES]
[JUNCTIONS]	[CURVES]	[QUALITY]	[OPTIONS]	[VERTICES]
[RESERVOIRS]	[PATTERNS]	[REACTIONS]	[TIMES]	[END]
[TANKS]	[ENERGY]		[REPORT]	
[PIPES]	[STATUS]			
[PUMPS]	[CONTROLS]			
[VALVES]				

Users can use the GUI provided by EPANET to construct a hydraulic model and export the *inp* file. Because EPANET is one of the most widely used hydraulic software programs, most of the commercial hydraulic network analysis software packages can export EPANET input files for data exchange. For example, a network model constructed by H2ONET can be directly exported with the EPANET input file format and analyzed by the EPANET engine. Furthermore, because the EPANET input file is well organized with different sections, portions can be easily modified via a text editor.

3.7.3 EPANET Hydraulic Simulation Methodology

The EPANET hydraulic engine can perform either steady state or extended period simulation. During a steady state simulation, EPANET computes junction heads and link flows for a fixed set of reservoir levels, tank levels, and water demands at a fixed point of time. For extended period simulation, EPANET computes junction heads and link flows for a fixed set of reservoir levels, tank levels, and water demands over a succession of points in time. From one time step to the next, reservoir levels and junction demands are updated according to their prescribed time patterns while tank levels are updated using the current flow solution. The solution for head and flow at a particular time involves simultaneously solving a set of hybrid equations using the gradient method (Todini and Pilati, 1987).

3.7.4 EPANET Output File

The outputs from the EPANET engine are generated in a text file with the extension of file name, *.rpt*. An output file can contain four sections: Status, Energy, Nodes, and Links. Users can apply the control parameters in the input file to specify the interested sections and the quantities associated with each section to be reported.

The Status section lists the initial status of all reservoirs, tanks, pumps, valves, and pipes, as well as any changes in the status of these components as they occur over time in an extended period simulation. The Energy section lists the energy consumption and cost for the operation of each pump in the network. The Nodes section lists simulation results for nodes with the quantities specified by the user. The default quantities reported for each node include demand, hydraulic head, and pressure. Results are listed for each reporting time step of an extended period simulation. The Links section lists simulation results for links with quantities specified by the user. The default quantities reported for each link include flow, velocity, and head loss. Diameter, length, water quality, status, setting, reaction rate, and friction factor can also be reported if required by the user.

3.8 NEGATIVE PRESSURE TREATMENT

Hydraulic network analysis solves for incompressible water flow in a pressurized pipeline network based on two principle laws: the laws of mass and energy conservation. The law of mass conservation can be expressed as the equation of continuity, which assumes that all demands in a system must be satisfied. The law of energy conservation indicates that water can only flow from nodes with high energy to nodes with low energy. The energy of water is expressed as hydraulic head, which is the summation of elevation and pressure heads. Hydraulic head neglects velocity, which is typically small and does not contribute significantly to the energy balance. The conventional hydraulic network analysis algorithm does not differentiate positive and negative pressures, and only uses the total head difference to drive water flow to satisfy demands. The forced satisfaction of all demands, with no differentiation of positive and negative pressures, may lead to the prediction of unrealistically high negative pressures at some nodes. This outcome is especially true in an earthquake-damaged system, in which demands due to water losses from pipeline breaks and leaks may be much higher than the supply from reservoir and transmission pipeline sources.

To account more accurately for flows and pressures, hydraulic network analysis in a damaged system should be based on the assumption that a water distribution network is not air tight when internal pressures fall below atmospheric levels (Markov, et al., 1994). Consider node i, shown in Figure 3.4, of a water supply system with pressure $p_i < 0$, where zero stands for the atmospheric pressure. The hydraulic head at node i is $H_i = H_{iE} + p_i/\gamma_w$, in which H_{iE} is the elevation head and γ_w is the unit weight of water. Since the physical system is not air tight, air enters it through node i, causing the pressure at node i to become equal to the atmospheric pressure so that $p_i = 0$ and $H_i = H_{iE}$. Let Q_k be the flow in pipe k connected with nodes i and j. Q_k will be zero if the hydraulic head at node i is higher than that at node j $(H_{iE} = H_i > H_j)$. If this is the case for all pipes connected with node i, the node is considered as a no-flow node through which no water can pass. If there are pipes where this condition is not satisfied, the node is considered as a partial flow node, through which water can pass with reduced flow rates compared with those predicted by conventional hydraulic network analysis with negative pressures. By admitting air into the system, flow conditions around the partial flow node become complicated. They may involve pressurized flow, transition from pressurized flow to open-channel flow, and open-channel flow (Shi, 2006). Open-channel flow is characterized by the existence of a free water surface in the flow profile and is more difficult to solve than pressurized flow. Currently, commercial software packages are not configured to solve the flow conditions around partial flow nodes.

In GIRAFFE, an isolation approach is applied to treat the negative pressures. This isolation approach works with EPANET hydraulic network engine iteratively. After hydraulic network analysis of the damaged system using the EPANET engine, nodes with negative pressures are identified and isolated step by step, starting with the node of highest negative pressure. The isolation is simulated by eliminating the node, all connected links, and control parameters associated with the node and links from the **.inp* system definition file. After each elimination, network connectivity is checked. If part of the system is isolated from the main system without

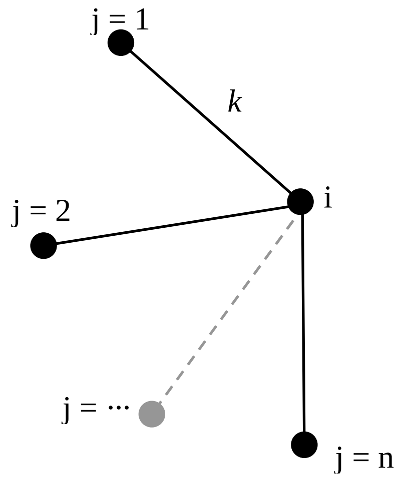


Figure 3.4 Negative Pressure Node Demonstration (after Markov, et al., 1994)

water sources, it is taken out of the system. The flow analysis and the elimination process continue until no negative pressure nodes exist in the system.

By discounting water conveyance through partial-flow nodes, the approach adopted in GIRAFFE removes flow under atmospheric conditions as well as transitional pressures approaching atmospheric. Such flow will generally occur at relatively low rates and is not reliable for fire protection after an earthquake. Hence, the model eliminates piping with uncertain and/or unreliable flows, thus concentrating on those parts of the system that can be effective during emergency response.

The modeling approach adopted in GIRAFFE, in effect, expresses a damage state as an operational state by converting the damaged network into one that meets the requirements of positive pressure and flow in all pipes. By eliminating pipelines with unreliable flow, it has the practical advantage of showing the system operator what parts of the network are no longer functional, and thus provides information about the most vulnerable distribution sectors and potential strategies for mitigation. The model does not account explicitly for water delivery and pressure losses associated with unsteady flow because accurate network analyses for this condition are not available. Instead, the model removes the unreliable portions of the system to display the remaining part of the network that meets threshold serviceability requirements for positive pressure.

CHAPTER 4

PIPE DAMAGE MODELING

4.1 INTRODUCTION

To predict the flow and pressure conditions in a damaged water supply system using hydraulic network analysis, pipeline damage, including leaks and breaks, needs to be added into the network, followed by the hydraulic simulation of the damaged system. GIRAFFE provides comprehensive methods for pipe damage modeling. This chapter presents the methodology for pipe damage simulation used in GIRAFFE. It begins with the definition of pipe leaks and breaks. The hydraulic models of leaks and breaks are discussed with special attention given to leak simulation. A classification for leak types is proposed and mathematical formulations are developed to determine the opening area of each leak type. Finally, the implementation of the pipeline break and leak models in association with Monte Carlo simulation is described.

4.2 DEFINITIONS

Following the seismic guidelines for water pipelines by the American Lifelines Alliance (2005), “a break is defined as the complete separation of a pipeline, such that no flow will pass between the two adjacent sections of the broken pipe; and a leak is defined as a small leak in a pipeline, such that water will continue to flow through the pipeline, albeit at some loss of pressure and flow rate being delivered, with some flow being lost through the leak”. Leaks can include pin holes in pipe barrels, very minor joint separations on segmented pipelines, and very small splits in large diameter steel transmission pipelines. A pipe with a break loses its water transportation function totally, and a pipe with a leak loses its function partially.

4.3 PIPE LEAK SIMULATION

This section provides the methodology of leak simulation used in GIRAFFE. The hydraulic model of a leak is discussed. Leaks are classified into five different types and the leak area is simulated as a function of pipe diameter.

4.3.1 Hydraulic Model

A pipe leak is essentially an orifice in the pipe wall or at a pipe joint, which allows water to be discharged into the surrounding soil. In GIRAFFE, a pipe leak is simulated as a fictitious pipe with one end connected to the leaking pipe and the other end open to the atmosphere, simulated as an empty reservoir. A check valve is built into the fictitious pipe, only allowing water to flow from the leaking pipe to the reservoir but not in the reverse direction. The roughness and minor loss coefficients of the fictitious pipe are taken as infinite and 1, respectively, such that all energy loss from the leak is related to the minor loss. The minor loss results from flow turbulence created by the sudden expansion of water passing through the flow area of the orifice to an infinite area external to the pipe (Jeppson, 1976). The diameter of the fictitious pipe is determined by the leak area.

Based on this hydraulic model, water loss from a leak can be calculated as

$$Q = [2g/(K\gamma_w)]^{0.5}Ap^{0.5} = (2g/\gamma_w)^{0.5}Ap^{0.5} = C_D\, p^{0.5} \tag{4.1}$$

in which Q is the flow rate, g is the gravitational acceleration, γ_w is the unit weight of water, K is the minor loss coefficient equal to 1, A is the orifice area, p is the pipe internal pressure, and C_D is the discharge coefficient equal to $(2g/\gamma_w)^{0.5}A$. The pipe leak can be considered as analogous to a sprinkler used in fire protection, from which water flow is governed by the same flow equation as Equation 4.1 (Puchovsky, 1999). To validate the model, a set of sprinkler data with discharge coefficient, C_D, and orifice area, A, are used to test the theoretical relationship between C_D and A

from Equation 4.1. The comparison in Figure 4.1 shows that the theoretical predictions and real data follow closely spaced, parallel trends. The C_D of the real sprinklers is roughly 10% lower than the theoretical C_D. The small difference results from the frictional loss of real sprinklers that have a short length; while the model ignores all frictional loss and leads to more water loss.

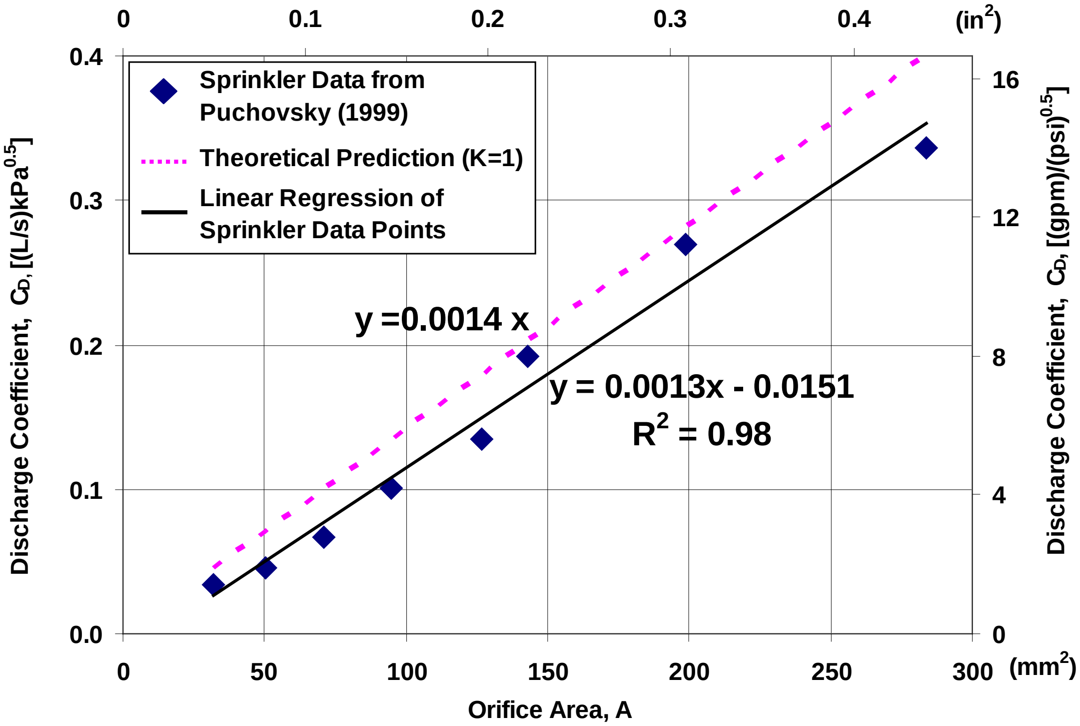


Figure 4.1 Comparison Between Model Predictions and Sprinkler Data

Figure 4.2 shows the implementation of the pipe leak model in GIRAFFE. It is assumed that a leak occurs in the pipe *ab*, which is connected to the upstream node *A* and downstream node *B*. The length of pipe *ab* is *L* and the leak occurs at a distance λL, measured from the upstream node *A* along the longitudinal direction of pipe *ab*, in which λ is a constant, called the length ratio in this study. GIRAFFE simulates the leak by: 1) eliminating pipe *ab* from the network; 2) adding a new junction, *A1Jab*, at the leak location, of which the elevation is determined by the linear interpolation of the elevations of nodes *A* and *B*; 3) adding two pipes, *A1Oab* and *A2Oab*, which have the same diameter and roughness as pipe *ab*, to replace the original pipe *ab*. Pipe *A1Oab* is connected to node *A* and junction *A1Jab*, and pipe *A2Oab* is connected to junction *A1Jab* and node *B*; 3) adding an empty reservoir *A1Rab*, which has the same elevation as the newly added junction *A1Jab;* and 4) adding a pipe, *A1Lab*, to connect the newly added junction, *A1Jab*, and reservoir, *A1Rab*. The length of pipe *A1Lab* is set to 0.5 feet, roughness is 1,000,000, and minor loss coefficient is 1, such that all energy loss from pipe *A1Lab* is accounted for as minor loss. A check valve is built in pipe *A1Lab* such that water can only flow from the leaking pipe to the empty reservoir.

Pipe leaking

Hydraulic model

Figure 4.2 Hydraulic Model for Leak Simulation

In general, to simulate a pipe leak, GIRAFFE deletes one pipe and adds three new pipes, one junction, and one empty reservoir. To ensure that each new element has a unique ID, all new elements are assigned to an ID starting with a letter A and ending with the ID of original pipe. The third character in the ID of the new elements is either an O indicating this pipe is used to replace the original pipe, R indicating the element is a newly added reservoir, J indicating the element is a newly added junction, or L indicating the element is a newly added pipe to model leak. The second character is a number to indicate the order of this type of elements. For example, the number 1 in *A1Oab* indicates that this pipe is the first section from the upstream node of the original pipe and number 2 in *A2Oab* indicates that this pipe is the second section of the original pipe.

4.3.2 Leak Classification

Using the leak simulation model, a key input parameter is the orifice area, which depends on pipe material and joint properties, as well as seismic loading characteristics. To develop a rational basis for estimating the orifice area, a detailed study has been performed by Shi (2006) on the material properties, joint characteristics, and damage mechanisms of five of the most commonly used types of pipelines in North America, including cast iron, ductile iron, concrete, steel with riveted joints, and steel with welded slip joints. Based on this study, leaks are classified into five different types A described in the following sections.

4.3.2.1 Annular Disengagement

Annular disengagement refers to joint looseness of segmented pipelines resulting from joint axial pullout movement during seismic loading. A schematic drawing of annular disengagement is shown in Figure 4.3. This leak type may occur in cast iron, ductile iron, jointed concrete cylinder, and riveted steel pipelines. The opening from annular disengagement occurs in the circumferential direction, and its area is determined by the joint configuration, relative pullout movement, and condition of the gasket seal or caulking material.

To estimate the opening area of an annular disengagement, the opening area, called equivalent orifice area (EOA) in this study, is correlated to an area index and the maximum possible annular area, and calculated as

$$A = k \times A_{\max} \tag{4.2}$$

where A is the EOA, $A_{\max}$ is the maximum annular area, and k is a constant. The $A_{\max}$ is determined by the configuration of the joint and can be estimated as

$$A_{\max} \approx tD\pi \tag{4.3}$$

where D is the pipeline diameter and t is the thickness of maximum possible annular space.

Substituting Equation 4.3 into 4.2 results in

$$A = k \times A_{\max} = tkD\pi \tag{4.4}$$

Since a leak is modeled as a fictitious pipeline in hydraulic network analyses, the orifice needs to be converted into a pipe with a cross-sectional area equal to the EOA. The diameter of the fictitious pipe, called equivalent orifice diameter (EOD) in this study, can be calculated as

$$d = \sqrt{4A/\pi} = 2\sqrt{tkD} \tag{4.5}$$

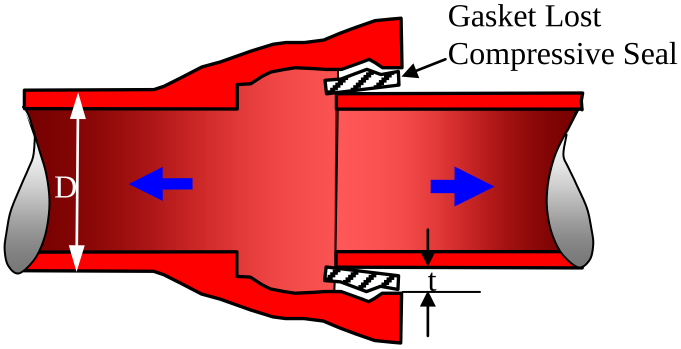


Figure 4.3 Schematic Drawing of Annular Disengagement

In GIRAFFE, the maximum possible annular space, *t*, is taken as 10 mm (0.4 in.) based on the studies conducted by Shi (2006) on the configurations of joints for the four types of pipelines in which annular disengagement may occur. As for the ratio, *k*, of the actual leak area to the maximum possible leak area, a default value of 0.3 is proposed on the basis of field observations (O'Rourke, 2005) from previous earthquakes. Users may change the default values for *t* and *k* through the O*ptions* menu within GIRAFFE (Click on Options | Configuration | Pipe Leakage Model).

4.3.2.2 Round Crack

The second leak type is a round crack, which refers to the circumferential cracking of the pipe barrel or joint under the effects of bending or the combination of bending and tensile forces. A schematic drawing of a round crack is shown in Figure 4.4. Round cracks occur in pipes composed of brittle material and joints, such as cast iron pipes with lead caulked joints. The EOA is determined by the opening angle of the crack and pipe diameter, and can be calculated as

$$A = 0.5\pi D \times (\theta D) = 0.5\pi\theta D^2 \tag{4.6}$$

where θ is the open angle of the crack and D is the pipe diameter.

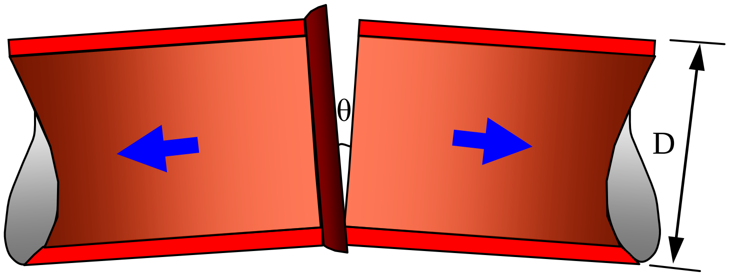


Figure 4.4 Schematic Drawing of Round Crack

The EOD of a round crack can be calculated as

$$d = \sqrt{4A/\pi} = \sqrt{4(0.5\pi\theta D^2)/\pi} = \sqrt{2\theta}D \tag{4.7}$$

Based on field observations (O'Rourke, 2005), a default value of 0.5$^{\text{o}}$ is proposed for the opening angle in GIRAFFE. Users may change the default value for the opening angle, θ, through the *Options* menu within GIRAFFE (Click on Options | Configuration | Pipe Leakage Model).

4.3.2.3 Longitudinal Crack

The third leak type is a longitudinal crack, which refers to the cracking of the pipe barrel or seam along the length of the pipe (longitudinal direction) caused by the external loading and/or high internal pressures during earthquakes. A schematic drawing of a longitudinal crack is shown in Figure 4.5. The longitudinal cracking may occur in metal pipes, which include cast iron, ductile iron, and riveted steel pipes.

The EOA of a longitudinal crack can be calculated as

$$A = L \times W \tag{4.8}$$

where *L* and *W* are the length and width of the crack, respectively. The length, *L*, is in the pipe longitudinal direction and can be taken as the length of a pipe section. The width, *W*, is in the pipe circumferential direction and can be estimated as a function of the opening angle, θ, of the crack and pipe diameter, *D*. The width, *W*, can be calculated as

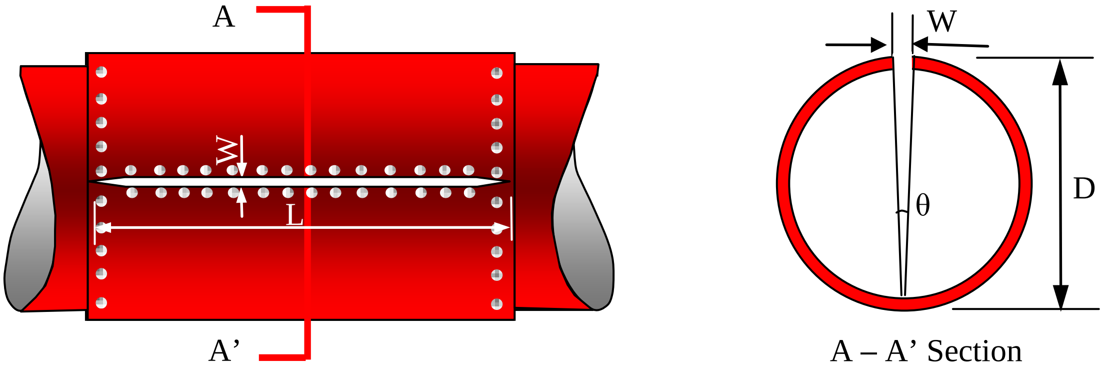


Figure 4.5 Schematic Drawing of Longitudinal Crack

$$W = D\theta \tag{4.9}$$

Substituting Equation 4.9 into Equation 4.8 results in

$$A = W \times L = LD\theta \tag{4.10}$$

The EOD of a longitudinal crack can be calculated as

$$d = \sqrt{4A/\pi} = 2\sqrt{LD\theta/\pi} \tag{4.11}$$

The default value for length of the longitudinal crack is taken as thirteen meters (40 ft), which provides a reasonable, but conservative estimate of the length of metal pipe sections. The opening angle of the longitudinal crack is estimated as 0.1° from field observations (O'Rourke, 2005). Users may change the default values for the opening angle, θ, and longitudinal crack length, *L*, through the *Options* menu within GIRAFFE (Click on Options | Configuration | Pipe Leakage Model).

4.3.2.4 Local Loss of Pipe Wall

The fourth leak type is the local loss of pipe wall. This leak type is caused by the loss of a small portion of pipe wall, which is deteriorated by corrosion, under the earthquake loading effects. A schematic drawing of a local loss of pipe wall is shown in Figure 4.6. The EOA of a local loss of pipe wall can be calculated as

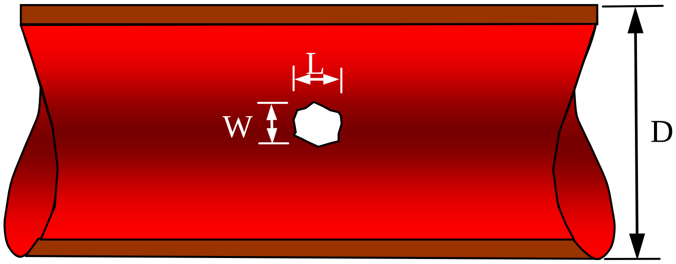


Figure 4.6 Schematic Drawing of Local Loss of Pipe Wall

$$A = L \times W \tag{4.12}$$

where *L* and *W* are the length and width of the orifice. The length, *L*, is along the pipe longitudinal direction and can be estimated as a ratio, k_1, of pipe diameter as

$$L = k_1 \times D \tag{4.13}$$

The width, *W*, is along the pipe circumferential direction and can be estimated as a ratio, k_2, of the pipe circumferential length to yield

$$W = k_2 \pi D \tag{4.14}$$

Substituting Equations 4.14 and 4.13 into 4.12 results in

$$A = \pi k_1 k_2 D^2 \tag{4.15}$$

The EOD of a local loss of pipe wall can be calculated as

$$d = \sqrt{4A/\pi} = \sqrt{4(\pi k_1 k_2 D^2)/\pi} = 2\sqrt{k_1 k_2} D \tag{4.16}$$

The loss of pipe wall due to corrosion is usually small. Five percent is proposed as a rough estimate of the parameters, k_1 and k_2, in GIRAFFE. Users may change the default value for k_1 and k_2 through the *Options* menu within GIRAFFE (Click on Options | Configuration | Pipe Leakage Model). However, it is always assumed that $k_1 = k_2$.

4.3.2.5 Local Tear of Pipe Wall

The fifth leak type is local tear of a pipe wall, which typically occurs as a rupture in the bell casing of a wrinkled welded slip joint and is induced by compressive forces. A schematic drawing of a local tear of a steel pipeline with welded slip joint is shown in Figure 4.7.

The EOA of a local tear of pipe wall can be calculated as

$$A = L \times W \tag{4.17}$$

in which, L and W are the length and width of the split, respectively. The length, L, is along the pipe circumferential direction and can be estimated with a ratio, k, of the pipe circumferential length,

$$L = k \pi D \tag{4.18}$$

Substituting Equation 4.18 into Equation 4.17 results in

$$A = W \times L = k\pi DW \tag{4.19}$$

The EOD of a local tear of pipe wall can be calculated as

$$d = \sqrt{4A/\pi} = \sqrt{4(k\pi D * W)/\pi} \quad = 2\sqrt{kWD} \tag{4.20}$$

In GIRAFFE, the default value for length of a local tear is taken as 30% of the pipe circumferential length, and the width is assumed to be 12 mm (0.5 in.) based on the data from Northridge earthquake (Shi, 2006). Users may change the default values for *k* and *W* through the *Options* menu within GIRAFFE (Options | Configuration | Pipe Leakage Model).

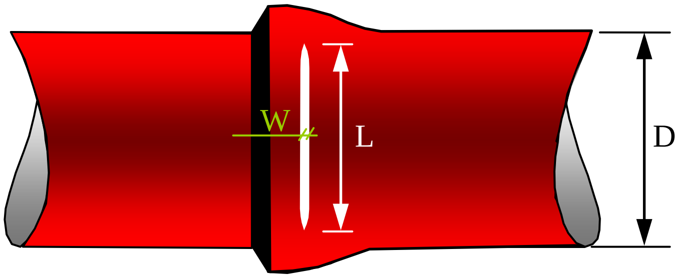


Figure 4.7 Schematic Drawing of Local Tear of Pipe Wall

4.3.3 Probability of Leak Types

Since each type of pipeline can have multiple types of leaks, the relative likelihood of each leak type has to be estimated for each type of pipeline to model pipe leaks using Monte Carlo simulation. Based on pipeline material and joint properties, as well as limited field data, a probability table shown in Table 4.1 is proposed for the five leak types associated with various types of pipelines. It should be noted that the default probabilities associated with the leak types under Options | Configuration | Pipe Leak Model do not match the values listed in Table 4.1 due to the way Monte Carlo simulation calculations are performed in the GIRAFFE code. Users interested in understanding this process should refer to Chapter 6, Section 2.3 in Wang (2006).

It should be noted that the only leak type for welded steel pipelines is the local tear of pipe wall resulting from compressive buckling. The majority of locations of local buckling, although they need to be repaired after earthquakes, are not severe enough to tear the pipe wall and cause leakage. A conservative estimate adopted in this work is that 80% of repairs from local buckling would not cause leakage, and 20% of repairs would cause leakage. Therefore, in GIRAFFE, the repair rate is discounted to 20% when using the repair rate to estimate the number of leaks for steel pipeline performance simulation after earthquakes.

Table 4.1 Probability of Leak Types for Different Pipelines

Pipe Material	Type 1 Annular Disengagement	Type 2 Round Crack	Type 3 Longitudinal Crack	Type 4 Local Loss of Pipe Wall	Type 5 Local Tear of Pipe Wall
Cast Iron	0.3	0.5	0.1	0.1	N/A[1]
Ductile Iron	0.8	N/A[1]	0.1	0.1	N/A[1]
Riveted Steel	0.6	N/A[1]	0.3	0.1	N/A[1]
Welded Steel	N/A[1]	N/A[1]	N/A[1]	N/A[1]	1.0
Jointed Concrete	1.0	N/A[1]	N/A[1]	N/A[1]	N/A[1]

1: Not Applicable

4.4 PIPE BREAK SIMULATION

Following the definition of pipe breaks used in this study, a break is a complete disconnection of the original pipeline. Water can flow from the two broken ends into the surrounding soil. Figure 4.8 shows the hydraulic model of a pipe break in GIRAFFE. It is assumed that a break occurs in the pipe *ab*, which is connected to the upstream node *A* and downstream node *B*. The length of pipe *ab* is *L* and the break occurs at a distance *λL* measured from the upstream node *A* along the pipe *ab*. GIRAFFE simulates the break by: 1) eliminating pipe *ab* from the network; 2) adding two new empty reservoirs, *A1Rab* and *A2Rab,* of which the elevation is determined by the linear interpolation of the elevations of nodes *A* and *B*; and 3) adding two pipes, *A1Oab* and *A2Oab*, which have the same diameter and roughness as pipe *ab*. Pipe *A1Oab* is connected to node *A* and junction *A1Rab*, and pipe *A2Oab* is connected to node *B* and junction *A1Rab*. A minor loss coefficient of 1 and a check valve are added to each of pipes *A1Oab* and *A2Oab* to represent the energy loss and to prevent water from flowing back into the broken pipeline. In general, to simulate a pipe break, GIRAFFE deletes one pipe and adds two new pipes and two empty reservoirs. The rules to assign IDs to the new elements are the same as those used in leak simulations.

4.5 IMPLEMENTATION OF PIPE DAMAGE MODELS

To simulate the earthquake performance of a water supply system, pipe damage including breaks and leaks needs to be added into the network. Hydraulic simulation is then performed on the damaged network to predict the flow and pressure distributions. The pipeline break and leak models can be implemented into a hydraulic network model both deterministically and probabilistically.

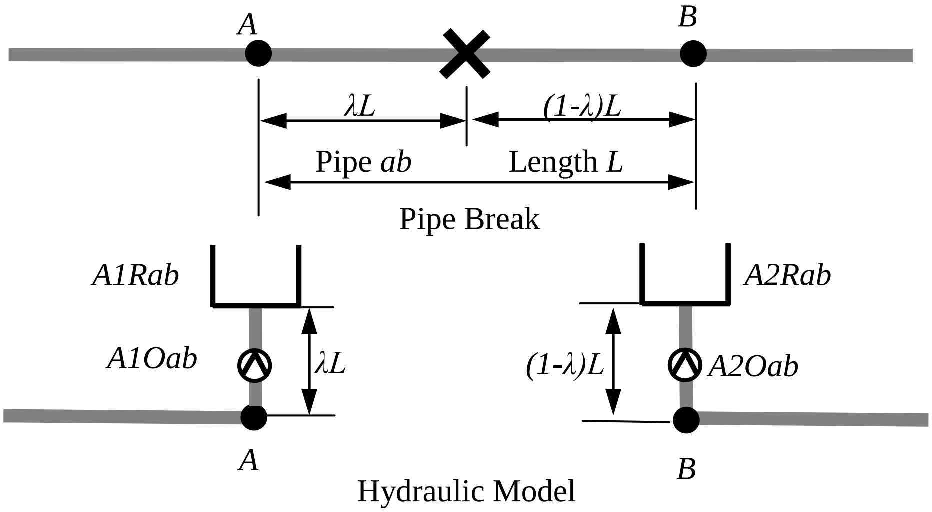


Figure 4.8 Hydraulic Model for Pipe Break

4.5.1 Deterministic Implementation

The deterministic implementation specifies the number and location of leaks and breaks, and the orifice area of each leak, occurring in a pipeline network. Pipe leaks and breaks are then added in the network using the models shown in Figures 4.2 and 4.8, respectively. The deterministic implementation can be used to simulate the performance of a water supply system under a specific damage scenario.

4.5.2 Probabilistic Implementation

The probabilistic implementation generates randomly distributed pipeline breaks and leaks in the system according to pipeline repair rate, RR, length, L, and the conditional probability of pipe break, P_{bk}, given that damage occurs. In addition, the probabilistic implementation determines the type of each leak probabilistically. The probabilistic implementation includes three steps: generating pipe damage, deciding on damage states (leak or break), and determining leak type.

4.5.2.1 Generating Pipe Damage

To generate the locations of pipe damage probabilistically, it is assumed that pipe damage follows a Poisson process with a mean arrival rate equal to repair rate, RR. The repair rate is correlated with the seismic hazard parameters, such as peak ground velocity (PGV) and permanent ground deformation (PGD). The determination of repair rate for each pipeline involves spatial manipulation which is performed by GIS.

For a Poisson process with a mean arrival rate *RR*, let L_1 be the first location of damage, which is measured from the upstream node of the pipeline along its longitudinal direction. Let L_k be the distance between the $(k\text{-}1)^{th}$ and k^{th} locations of damage. The $\{L_1, L_2, \cdots, L_k, \cdots\}$ is called the sequence of interarrival distances in Poisson processes (Sheldon, 2000). The actual distance of the k^{th} location of damage measured from the pipe upstream node is the cumulative distance from L_1 to L_k. For instance, if $L_1 = 0.1L$ and $L_2 = 0.5L$, where L is the length of the original pipeline, then the first location of damage occurs at 0.1 of pipe length measured from the pipe upstream node, and the second location of damage occurs at 0.1 + 0.5 = 0.6 of pipe length.

The L_1, L_2, $\cdots$, L_k can be simulated as independent exponential random variables with a mean equal to $1/RR$ (Sheldon, 2000) and generated using the Monte Carlo simulation algorithm

$$L_k = -\frac{1}{RR}\ln(1-u_1) \tag{4.21}$$

where u_1 is a random variable which is uniformly distributed between 0 and 1. By generating the interarrival distance L_k repeatedly until the cumulative length exceeds the pipe length, L, it is able to determine the locations of damage in the pipeline. Figure 4.9 provides an illustration of the pipe damage generation. In this example, a total of three locations of damage are generated at points *A*, *B* and *C*, in the pipeline, because the cumulative length of the fourth location of damage exceeds the pipe length.

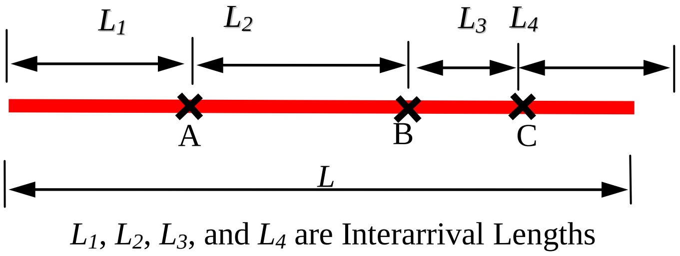


Figure 4.9 Poisson Process for Pipe Damage Generation

4.5.2.2 Deciding on Damage State

After generating pipe damage for each location of damage, a uniformly distributed random number μ_2 over (0, 1) is generated and compared with the conditional probability of pipe break, P_{bk}, given that damage occurs. The damage is treated as a break if μ_2 exceeds P_{bk}, and a leak otherwise.

The current version of GIRAFFE focuses on PGV-related pipe damage and assigns a default value of 0.2 for the conditional probability of pipe break, P_{bk}, for cast iron, ductile iron, steel with riveted joints, concrete, and other material of pipelines. For steel pipelines with welded joints, previous data show that they are unlikely to break. Thus a default value of 0 is assigned to P_{bk} for steel pipelines with welded joints. If better information is available, users can change these default values under the *Options* menu in GIRAFFE by clicking on Options | Configuration | Pipe Damage Probability.

4.5.2.3 Determining Leak Type

The third step determines the type of each leak probabilistically and calculates the orifice area of each leak using the equations developed in Section 4.3.2. The default probabilities of each type of leak, corresponding to various types of pipeline, are listed in Table 4.1. To determine the type of each leak, a uniformly distributed random number, μ_3, over (0, 1) is generated and compared with the cumulative probability of the leak types associated with the pipeline. For example, assume the probability that a leak in a cast iron pipeline is an annular disengagement is 0.3, round crack is 0.5, longitudinal crack is 0.1, and local loss of pipe wall is 0.1. The leak is classified as an annular disengagement if the uniformly distributed random number is within the range between 0 and 0.3; round crack if within the range between 0.3 and 0.8, longitudinal crack if within the range between 0.8 and 0.9, and local loss of pipe wall if within the range between 0.9 and 1.0. After deciding on the leak type, the EOA and EOD can be calculated for each leak.

CHAPTER 5
EARTHQUAKE DEMAND SIMULATION

5.1 INTRODUCTION

Water supply systems are characterized by broad coverage and a high level of detail. The broad coverage is associated with a large service area. The high level of detail is related to the large amount of different pipelines and facilities in the system. A hydraulic network model, which models both broad coverage and component details, will be difficult to manage and troubleshoot. One technique for simulating a complex system is to decouple various parts of the system, apply models with appropriate levels of complexity to each part, and integrate the decoupled analyses to show system performance.

A water supply system typically consists of trunk and distribution systems. The trunk system consists of large diameter trunk lines, which serve as the backbone of the system by transporting water from sources to local areas. The distribution system consists of small diameter distribution lines which receive water from trunk lines and distribute it to customers. One technique to simulate a complex water supply system is therefore to decouple the trunk and distribution systems. The response of the system can be simulated with a system-wide trunk line model which covers the entire service area but includes only large diameter trunk lines. In the trunk line model, the small diameter distribution lines are replaced with demand nodes. The local response of the system can be simulated using distribution network models, which cover a small local area but include small diameter distribution lines. Using multi-scale modeling, a complex water supply system can be decoupled into several systems which have manageable complexity.

The H2ONET LADWP hydraulic network model is a trunk line model that includes 2200 km of pipelines from the LADWP trunk line system ranging in diameter from 300 to 3850 mm and replaces the remaining 9800 km of distribution pipelines as demand nodes. The trunk line model can give an accurate prediction of flows and pressures in the trunk system if the nodal demands can be simulated accurately. These demands represent the aggregated demands from the downstream distribution networks. In normal operations, the demands from the distribution networks are known values that are relatively easy to simulate. The demands are much more difficult to simulate after the system has sustained earthquake-induced damage.

GIRAFFE provides a method to simulate the earthquake demand associated with distribution networks. The earthquake demands are simulated by means of fragility curves relating demand to repair rate in local distribution networks. The repair rate is correlated with seismic hazard parameters including peak ground velocity and permanent ground deformation. The fragility curves were developed using distribution network simulations of the LADWP water supply system.

5.2 METHODOLOGY

A detailed description of the development of the fragility curves for earthquake demand simulation is provided by Shi (2006). To develop the fragility curves, five distribution networks were selected to be representative of the roughly 30 LADWP distribution network models used for local flow and pressure analyses. Each distribution network model covers one large pressure zone or several small pressure zones. Figure 5.1 shows the locations of the five chosen distribution networks. Figure 5.2 provides an expanded view of the distribution network in pressure zone 1000, superimposed on the trunk system model. The distribution network includes both large diameter trunk lines and small diameter distribution lines. The smallest pipelines in the distribution networks have a diameter of 100 (4 in.) or 150 mm (6 in.), and the majority of pipelines have diameters smaller than 300 mm (12 in.).

In distribution network simulations, pipe damage is evaluated only in the distribution lines since trunk line damage is accounted for explicitly in the trunk system model. The pipe damage is assumed to follow a Poisson process with a mean arrival rate equal to repair rate, RR, and is generated using Monte Carlo simulation. Flow analysis is performed for the damaged system and negative pressures are eliminated using the iterative approach described in Chapter 3. Flows in trunk lines before and after damage to distribution lines are monitored, and the flows after damage are normalized to the flows before damage. The normalized flows provide a proxy for the normalized demands since water from the trunk lines is distributed by means of nodal demands. Monte Carlo simulations were performed for RR ranging from 0.02 to 100 repairs/km and statistical analysis is performed for RR ranging from 0.02 to 1 repairs/km, which is a typical range for PGV-related pipeline damage.

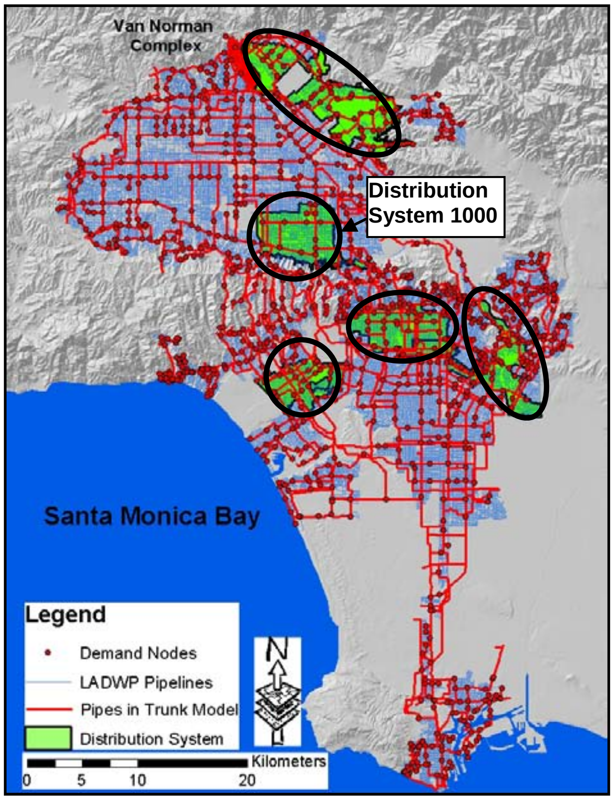


Figure 5.1 LADWP Water Supply System.

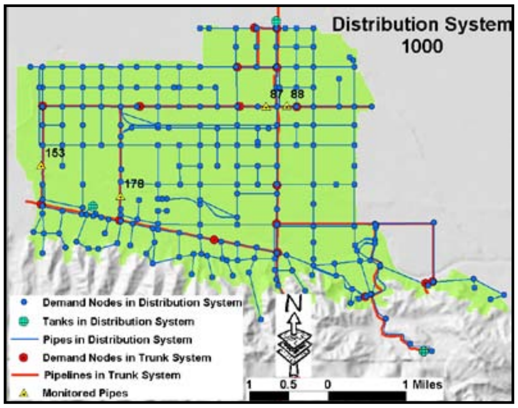


Figure 5.2 Overlay of Distribution and Trunk system.

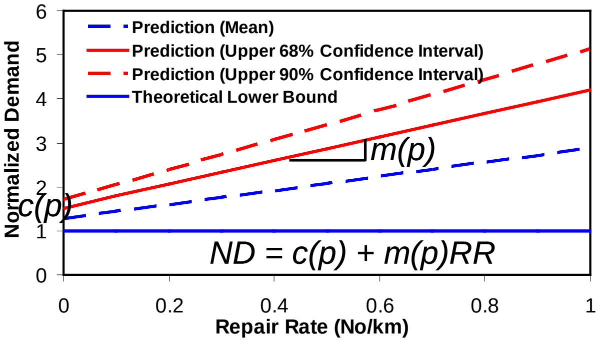


Figure 5.3 Prediction of Normalized Demand

The normalized demands, representing the increase of demands from damage to distribution lines, are expressed as fragility curves in the format

$$ND = I + S \times RR \tag{5.1}$$

in which *ND* is the normalized demand, *I* and *S* are the intercept and slope of the linear regression, respectively, and RR is the repair rate. The intercept, *I*, and slope, *S*, are further correlated with the mean pressure, *MP*, of the distribution network and statistically estimated from the simulation data in the five distribution networks (Shi, 2006). Estimates with different confidence levels can be obtained for the intercept, *I*, and slope, *S*.

Two simulation options are provided in GIRAFFE, mean prediction with noise terms and 90% confidence level prediction. The equation for the mean prediction with noise terms is in a format of

$$\begin{aligned} ND &= I + S \times RR \\ &= \left[II + IS \times MP + N(0,\sigma_I)\right] + \left[SI + SS \times MP + N(0,\sigma_S)\right] \times RR \\ &= \{0.9012 + 0.0036MP + N[0, (-0.0198 + 0.0015MP)]\} \\ &+ \{-0.877 + 0.0248MP + N[0, (-0.351 + 0.0094MP)]\}RR \end{aligned} \tag{5.2}$$

in which, *II* and *IS* are the intercept and slope of the intercept term, *I*, $N(0,\sigma_I)$ is a Gaussian random variable with zero mean and standard deviation of σ_I, *SI* and *SS* are the intercept and slope of the slope term, *S*, and $N(0,\sigma_S)$ is a Gaussian random variable with zero mean and standard deviation σ_S. The default values of *II, IS, SI* and *SS* used in GIRAFFE are determined from the mean regressions on the basis of the simulation data from the five representative distribution networks (Shi, 2006). Users have the option of changing these parameters under the *Options* menu in GIRAFFE (Options | Configuration | Nodal Demand Calibration). The σ_I and σ_S are used to simulate the variation of the mean values of the intercept, *I*, and slope, *S*, with respect to their mean values. The σ_I and σ_S are also correlated with mean pressure, MP, and their values are evaluated using regressions of the simulation data from the five representative distribution networks (Shi, 2006). Users may change the default values for σ_I and σ_S under the *Options* menu in GIRAFFE (Options | Configuration | Nodal Demand Calibration).

The equation for the 90% confidence level prediction is in a format of

$$\begin{aligned} ND &= I + S \times RR \\ &= \left[II + IS \times MP\right] + \left[SI + SS \times MP\right] \times RR \\ &= (1.1412 + 0.0055MP) + (-0.0514 + 0.0347MP)RR \end{aligned} \tag{5.3}$$

in which, *II* and *IS* are the intercept and slope of the intercept term, *I*, and *SI* and *SS* are the intercept and slope of the slope term, *S*. The default values of *II*, *IS*, *SI* and *SS* in GIRAFFE are determined from the 90% confidence level regressions of the simulation data from the five representative distribution networks (Shi, 2006). Users may change the default values for *II*, *IS*, *SI* and *SS* under the *Options* menu in GIRAFFE (Options | Configuration | Nodal Demand Calibration).

Figure 5.3 shows the prediction of normalized demands in a pressure zone with a mean pressure of 0.69 MPa (100 psi). From this figure, the mean estimate of demand including post-earthquake demand from leaks and breaks for a RR equal to 1 repair/km is approximately 2.5 times the design demand, while the upper 90% confidence level estimate is roughly 5 times the design demand.

The earthquake demand simulation is pressure zone based. The basic input parameters are MP and RR associated with each demand node. For a demand node, MP is the average nodal pressure in the pressure zone in which the demand node is located before system damage. The MP can be obtained by performing a hydraulic network analysis on the undamaged system and then conducting a statistical analysis on the nodal pressures with respect to pressure zones. The RR represents the repair rate of the distribution lines around the demand node. For PGV-related pipe damage, the RR is calculated using regression relationships between PGV and RR developed from previous investigations (e.g., Jeon, 2002; Jeon and O'Rourke, 2005). The determination of RR for a given earthquake scenario involves spatial manipulation and is performed using GIS, which gives the RR related to each demand node as input to GIRAFFE. The GIS procedures for determining the RR is explained in Shi (2006). Users may change the value for RR under the *Options* menu in GIRAFFE (Options | Configuration | Nodal Demand Calibration). After the determination of ND for each demand node, GIRAFFE then calculates the demands after the earthquake by multiplying the ND by the original demands, and modifies the system definition file by replacing the original demands with the post-earthquake demands.

CHAPTER 6

GIRAFFE INPUTS AND OUTPUTS

6.1 INTRODUCTION

The input for GIRAFFE simulations includes control parameters and data files. The control parameters specify the lowest pressure to be eliminated, the time length and time step to update tank water levels, and simulation options. The input data includes files for system definition, pipe damage generation, and earthquake demand simulation. The major outputs from GIRAFFE simulations are hydraulic analysis results of network physical components, including junctions, tanks, pipes, pumps, and valves, and the serviceability of the damaged system. The input parameters and data files and the output files are introduced in this chapter.

6.2 INPUT

GIRAFFE can perform both deterministic and probabilistic simulations. For probabilistic simulations, users can either specify the number of Monte Carlo simulation runs or let the program determine the number of simulation runs using the self-termination algorithm built into the code. For both deterministic and probabilistic simulations, users need to input some common control parameters to specify the system definition file, lowest pressure to be eliminated, total length of time to update tank water levels, and time step to update tank water levels.

6.2.1 Control Parameters

Upon starting the GIRAFFE program, a window appears prompting the user to select a simulation option: Deterministic, Monte Carlo Fixed or Monte Carlo Flexible. Users may also select the simulation type by clicking on the *Simulations* drop down menu in the toolbar. Table 6.1 lists the input control parameters that are required for each of the 3 simulation options.

Table 6.1 GIRAFFE Control Parameters

Name	Description
System Definition File	Name of the EPANET system definition file with the extension of *.inp*. File name may have a maximum length of 80 characters.
Minimum Pressure to Eliminate	Pressure limit, in psi, below which GIRAFFE eliminates the node and connected links from the system. The typical input is 0 psi for negative pressure elimination.
Simulation Time	Total length of simulation time in hours to update tank water levels. 0 for steady state simulation.
Simulation Time Step	The time step in hours to update tank water levels. 1 for steady state simulation.

6.2.2 Deterministic Simulations

If the user selects a deterministic simulation, the GIRAFFE GUI window that appears asks the user to input the name of the file in which the pipe damage information is stored. An example of the GUI window is shown in Figure 7.3. Table 6.2 shows the name and descriptions of the parameter for specifying the pipe damage file. Table 6.3 shows an example of the pipe damage file.

The pipe damage file is a tab-delimited text file. Users can use Microsoft Word, Excel, or Notepad to construct the file and save it with the typical extension of text files, such as *.inp*. Users may also create a pipe damage file via the GIRAFFE GUI for a deterministic simulation as shown in Appendix A. The input file consists of two blocks with one storing pipe break information and the other storing pipe leak information. The block storing pipe break information starts with the line [Pipe_Break_Information]. Users need to copy this exact line into their input file, and not leave any space before [Pipe_Break_Information], otherwise the program will not run correctly.

Table 6.2 Input Parameter for Pipe Damage Generation File for Deterministic Simulations

Name	Type	Description
PipeBreak	char	Name of input file for pipe damage generation. File name may have a maximum length of 80 characters.

Table 6.3 Input File for Pipe Damage Generation for Deterministic Simulations

```
[Pipe_Break_Information]
PipeID     PreRatio     BreakRatio      RepairNo       BreakNo       LeakNo        PreIndex

22             0            0.3             3              1             0              0
22             0.6          0.9             3              2             1              0
12             0            0.5             1              1             0              0


[Pipe_Leak_Information]
PipeID     LeakD       PreRatio     LeakRatio      RepairNo     BreakNo     LeakNo      PreIndex

22            2           0.3           0.6            3           1           1           1
```

The second line of the pipe damage file is a headline describing the type of values in each column in the pipe break records that follow. It is recommended that users copy the headline into their input file. The headline terms in the pipe break records are explained in Table 6.4.

The block storing pipe leak information starts with a line with [Pipe_Leak_Information]. Users need to copy this exact line into their input file and not leave any space before [Pipe_Leak_Information], otherwise the program will not run correctly. The next line is a headline describing the type of values in each column in the pipe leak records that follow. It is recommended that users copy the headline into their input file. The headline terms in the pipe leak records are explained in Table 6.5.

Table 6.4 Description of Columns in Pipe Break Section

Name	Type	Explanation
PipeID	char	The ID of the pipe which users want to break. Maximum length of 30 characters.
PreRatio	float	The length ratio of the previous location of pipe damage, either break or leak, in the same pipeline. If the current break is the first location of damage in the pipeline, then the PreRatio is set to 0.
BreakRatio	float	The length ratio of the location of the current pipe break.
RepairNo	int	The total number of locations of pipe damage, including breaks and leaks, in the pipeline.
BreakNo	int	The number of locations of breaks in the upstream of the current location of pipe break. The current location of pipe break is counted.
LeakNo	int	The number of locations of leaks in the upstream of the current location of pipe break.
PreIndex	int	The type of the previous location of pipe damage immediately upstream of the current break: 0 for leak and 1 for break. If the current break is the first location of pipe damage in the pipeline. The PreIndex is set to 0.

Table 6.5 Description of Columns in Pipe Leak Section

Name	Type	Explanation
PipeID	char	The ID of the pipe which users want to add the leak. Maximum length of 30 characters.
LeakD	float	Equivalent orifice diameter of the leak with the units of inches.
PreRatio	float	The length ratio of the previous location of pipe damage, either break or leak, in the same pipeline. If the current leak is the first location of damage in the pipeline, then the PreRatio is set to 0.
LeakRatio	float	The length ratio of the location of the current leak.
RepairNo	int	The total number of locations of pipe damage, including breaks and leaks, in the pipeline.
BreakNo	int	The number of locations of breaks in the upstream of the current location of pipe leak.
LeakNo	int	The number of locations of leaks in the upstream of the current location of pipe leak. The current location of pipe leak is counted.
PreIndex	int	The type of the previous location of pipe damage immediately upstream of the current leak: 0 for leak and 1 for break. If the current leak is the first location of pipe damage in the pipeline. The Preindex is set to 0.

6.2.3 Monte Carlo with Fixed Simulation Runs

If the user selects a "Monte Carlo Fixed Number" simulation, GIRAFFE will perform a Monte Carlo simulation with a number of simulation runs specified by the user. GIRAFFE will ask the user to input the name of the file storing information for probabilistic pipe damage generation. A user has the option to choose to perform the earthquake demand simulation or not. If users choose to perform the earthquake demand simulation, they need to choose between the simulation options of mean prediction with noise terms or 90% confidence level prediction. An example of the GUI window with inputs is shown in Figure 7.8. The parameters users need to input (in addition to the control parameters) are listed in Table 6.6 in sequence.

Table 6.6 Input Parameters for Monte Carlo Simulations with Fixed Simulation Times

Name	Description
Pipe Repair Rate File	Name of the input file for probabilistic pipe damage generation. File name may have a maximum length of 80 characters.
Number of Simulations	Monte Carlo simulation time ranging from 1 to 100
Random Seed	Seed for random number generation.
Nodal Demand Calibration	Option to choose to simulate the earthquake demand or not: “Yes” for simulated and “No” for not simulated.
Regression Equation	(If “Yes” was selected for “Nodal Demand Calibration”, this value is required.) Options for earthquake demand simulation: “Mean Prediction Plus Noise Terms” or “90% Confidence Level Prediction”.
Mean Pressure File	(If “Yes” was selected for “Nodal Demand Calibration”, this value is required.) Name of the input file for earthquake demand assessment. File name may have a maximum length of 80 characters.

One example of an input file for probabilistic pipe damage generation is given in Table 6.7. This file is a tab-delimited text file and users can use Microsoft Word, Excel, or Notepad to construct the input file and save it with the extension *.inp*. The probabilistic pipe damage input file starts with a headline, followed by the record of each pipeline. It is recommended that users copy the headline to their own files. The headline terms in the pipe damage generation input file are explained in Table 6.8.

An example of an input file for earthquake demand simulation is shown in Table 6.9. This is also a tab-delimited text file which users can create using Microsoft Word, Excel, or Notepad, and save as a text file with the extension *.inp*. The input file starts with a headline, followed by the record of each demand node. The headline terms in the earthquake demand simulation input file are explained in Table 6.10.

Table 6.7 Input File for Probabilistic Pipe Damage Generation

PipeID	Length_km	RR	Material
10	1	1	CI
12	1	1	CI
16	1	1	DI
18	1	1	DI
20	1	1	CON
22	1	1	CON
4	1	1	RV
6	1	1	RV
8	1	1	STL

Table 6.8 Description of Columns in Probabilistic Pipe Damage Input File

Name	Type	Description
PipeID	char	The ID of the pipe which users want to damage. Users have to make sure this pipe is in the system definition file otherwise the program cannot run correctly. Maximum length 30 characters
Length	float	The length of the pipe in km. The length of each pipe can be obtained from the system definition file.
RR	float	Pipe repair rate in repairs per kilometer of pipe length, which is correlated with seismic hazard parameters, such as peak ground velocity and permanent ground deformation. The determination of repair rate for each pipeline involves spatial manipulation, which is conducted using GIS.
Material	char	The material of the pipeline. CI: cast iron pipeline; DI: ductile iron pipeline, RS: riveted steel pipeline; CON: concrete pipeline; STL: welded steel pipeline, and N/A: other types of pipelines beside the abovementioned five types of pipeline.

Table 6.9 Input File for Earthquake Demand Simulation

ID	G_RR	Ave_PRESSURE
CC1007	0.15160	77.1906
CC1043	0.13645	59.7064
CC1053	0.11148	77.1906

Table 6.10 Description of Columns in Earthquake Demand Simulation Input File

Name	Type	Description
ID	char	The ID of the demand node. Users have to make sure this demand node is in the system definition file otherwise the program cannot run correctly. Maximum length of 30 characters.
G_RR	float	Pipe repair rate in repairs per kilometer of pipe length, which is correlated with seismic hazard parameters, such as peak ground velocity and permanent ground deformation. The determination of repair rate for each pipeline involves spatial manipulation, which is conducted using GIS.
Ave_PRESSURE	float	The average nodal pressure of the pressure zone, in which the demand node is located.

6.2.4 Monte Carlo with Flexible Simulation Runs

If the user selects a “Monte Carlo Flexible Number” simulation, GIRAFFE will perform a Monte Carlo simulation in which the program will automatically determine how many simulation runs are needed as per default or user-specified convergence criteria. An example of a GUI window with “Monte Carlo Flexible” inputs is shown in Figure 7.9. The input parameters are similar to those for the “Monte Carlo Fixed” simulation and are shown in Table 6.11. The pipe damage generation and demand simulation input files have the same formats as those used for a “Monte Carlo Fixed Number” simulation. Users can refer to Tables 6.7 to 6.10 for the format of these input files.

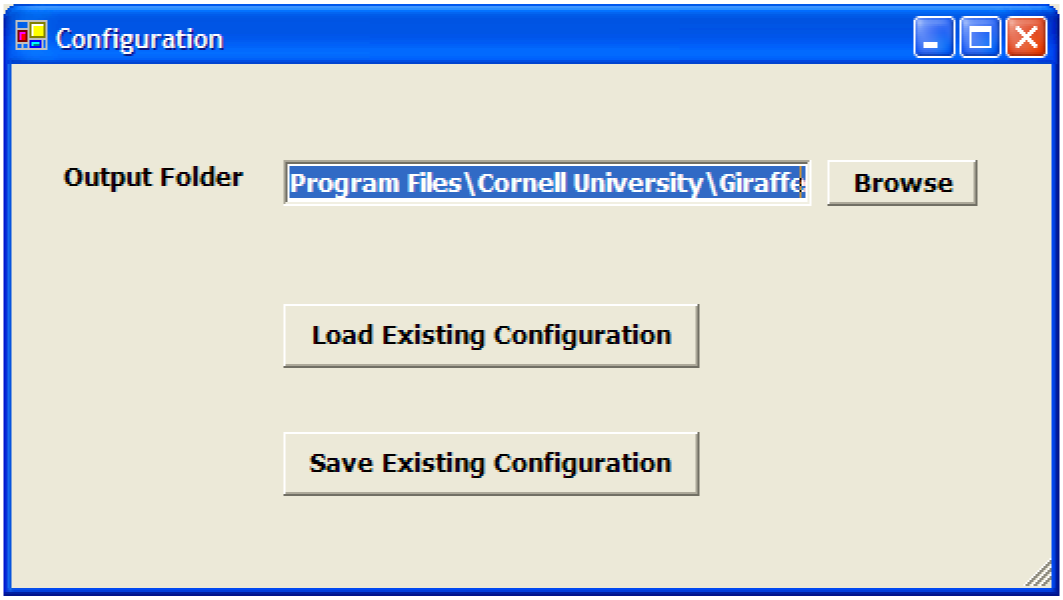
Table 6.11 Input Parameters for Monte Carlo Simulations with Flexible Simulation Runs

Variable Name	Explanation
Pipe Repair Rate File	Name of input file for pipe damage generation. File name may have a maximum length of 80 characters.
Random Seed	Seed of random number generation.
Calibrate Nodal Demand	Options to choose to simulate the earthquake demand or not: “Yes” for simulated and “No” for not simulated.
Regression Equation	(If “Yes” was selected for “Nodal Demand Calibration” this value is required.) Options for earthquake demand simulation: “Mean Prediction Plus Noise Terms” or “90% Confidence Level Prediction”.
Mean Pressure File	(If “Yes” was selected for “Nodal Demand Calibration” this value is required.) Name of the input file for earthquake demand assessment. File name may have a maximum length of 80 characters.

6.3 Definition Parameters

Besides the parameters and data files described above, the GIRAFFE code includes a parameter definition file named as *parameter_definition.h*, which defines the simulation capacity, parameters for leak simulations, and parameters for earthquake demand simulations. GIRAFFE is configured to work with the LADWP water supply system, which represents one of the largest water supply systems in the world. As such, GIRAFFE should have enough capacity to simulate other water supply systems but doing so may require a change to the definition parameters. The default parameters for leak and earthquake demand simulations are based on the best data currently available. The parameter definition file is shown in Table 6.12 with comments on each defined parameter. Users generally do not need to change the values of the parameters in *parameter_definition.h*. As such, these parameters are defined in the code to avoid too many input parameters from users. Users have the ability to change many of the default parameters by clicking on Options | Configuration in the GIRAFFE toolbar menu. Alternatively, a user can modify the file, *parameter_definition.h*, by changing the number after each variable definition and rebuilding the code to generate a new executable file.

Users may change any of these default parameters located in the toolbar menu under Options | Configuration and then save the new system configuration. The default parameter configuration is saved as *Default.txt* in the "Configuration" folder that exists in the same directory where the GIRAFFE application is installed. To save a new configuration, click on Options | Configuration | System Options in the GIRAFFE toolbar and a window as shown in Figure 6.1 appears. From this window, the user can change the output folder, load an existing configuration or save an existing configuration. Clicking on "Load Existing Configuration" will take the user to the "Configurations" folder where they can select any saved configuration files to load. Clicking on "Save Existing Configuration" will allow the user to save the current set of parameters that can be defined under the Options | Configuration menu. This option allows the user to switch between different parameter configurations quickly and easily and thus avoid having to change parameter values between simulation runs.



Output Folder Program Files\Cornell University\Giraffe

Figure 6.1 Configuration Window for System Options

Table 6.12 Parameter Definition File

```
//********************************Defining Constants************************************//
#define NJunction  10000  //Maximum number of junctions in a network//
#define NPipe  10000  //Maximum number of pipes in a network//
#define NLink  20000  //Maximum number of links in a network//
#define NNode  20000  //Maximum number of nodes in a network//
#define NDemandNode  1200  //Maximum number of demand nodes in a network//
#define LID  20  //Maximum number of characters for network component IDs//
#define MaxNSimu  100  //Maximum number of Monte Carlo simulations//
#define LFileName  80  //Maximum number of characters for file name and directory//
#define LLine  255  //Maximum number of characters in a line in input text files//
#define MLinktoNode 15  //Maximum number of links connected to the same node//
#define MaxNDamage  100  //Maximum number of locations of damage in a pipeline//
#define MaxLMat  3  //Maximum number of characters used to define pipe material//
#define MaxTime 10 //Maximum times to update the tank water level in a simulation//
#define MaxBreak  200 // Maximum number of breaks occurring in a network//
#define MaxLeak  1000 // Maximum number of leaks occurring in a network//

//**************************Defining Parameters for Modeling Leakage************************//
#define DLLeak  0.5  //Default length of an added pipe for simulating leaks//
#define DCLeak  1000000  //Default roughness coefficient of an added pipe for simulating leaks//
#define DMLeak  1  //Default minor loss coefficient of an added pipe for simulating leak//

#define BreakProCI  0.2  //Probability of pipe break, given pipe damage occurs, for cast iron pipes//
#define BreakProDI  0.2  //Probability of pipe break, given pipe damage occurs, for ductile iron pipes//
#define BreakProRS  0.2  //Probability of pipe break, given pipe damage occurs, for riveted steel pipes//
#define BreakProCON  0.2  //Probability of pipe break, given pipe damage occurs, for concrete pipes//
#define BreakProSTL  0  //Probability of pipe break, given pipe damage occurs, for welded steel pipes//
#define STLLeakRatio  0.2  //Probability of pipe leak, given pipe damage occurs, for welded steel pipes//

#define Type1tD  0.4  //Thickness of annular space for leak type 1, annular disengagement, in the units //
                      // of inches; t in Eqn. 4.5//
#define Type1kD  0.3  //Ratio of actual leak area to the maximum possible leak area for leak type 1, annular//
                      //disengagement; k in Eqn. 4.5//
#define Type2aD  0.5  //Opening angle of leak type 2, round crack, in the units of degrees; θ in Eqn. 4.7//
#define Type3kD  480  //Length of leak type 3, longitudinal crack, in the units of inches; L in Eqn. 4.11//
```

Table 6.12 Continued

```
#define Type3aD  0.1  //Opening angle of leak type 3, longitudinal crack, in the units of degrees; θ in //
                      //Eqn. 4.11//
#define Type4kD  0.05  //Ratio of the length and width of leak type 4, local loss of pipe wall, to the pipe //
                      //diameter and circumferential length, respectively; k1 and k2 in Eqn. 4.15//
#define Type5kD  0.3  //Ratio of the length of leak type 5, local tear of pipe wall, to the pipe circumferential//
                      //length; k in Eqn. 4.19//
#define Type5wD  0.5  //Width of the leak type 5, local tear of pipe wall, in the units of inches; w in Eqn. 4.19//

#define CIType1D  0.3  //Probability of leak type 1 for cast iron pipelines//
#define CIType2D  0.8  //Cumulative probability of leak types 1 to 2 for cast iron pipelines//
#define CIType3D  0.9  //Cumulative probability of leak types 1 to 3 for cast iron pipelines//
#define CIType4D  1.0  //Cumulative probability of leak types 1 to 4 for cast iron pipelines//
#define CIType5D  1.0  //Cumulative probability of leak types 1 to 5 for cast iron pipelines//

#define RSType1D  0.6  //Probability of leak type 1 for riveted steel pipelines//
#define RSType2D  0.6  //Cumulative probability of leak types 1 to 2 for riveted steel pipelines//
#define RSType3D  0.9  //Cumulative probability of leak types 1 to 3 for riveted steel pipelines//
#define RSType4D  1.0  //Cumulative probability of leak types 1 to 4 for riveted steel pipelines//
#define RSType5D  1.0  //Cumulative probability of leak types 1 to 5 for riveted steel pipelines//

#define CONType1D  1.0  //Probability of leak type 1 for concrete pipelines//
#define CONType2D  1.0  //Cumulative probability of leak types 1 to 2 for concrete pipelines//
#define CONType3D  1.0  //Cumulative probability of leak types 1 to 3 for concrete pipelines//
#define CONType4D  1.0  //Cumulative probability of leak types 1 to 4 for concrete pipelines//
#define CONType5D  1.0  //Cumulative probability of leak types 1 to 5 concrete pipelines//

#define DIType1D  0.8  //Probability of leak type 1 for ductile iron pipelines//
#define DIType2D  0.8  //Cumulative probability of leak types 1 to 2 for ductile iron pipelines//
#define DIType3D  0.9  //Cumulative probability of leak types 1 to 3 for ductile iron pipelines//
#define DIType4D  1.0  //Cumulative probability of leak types 1 to 4 for ductile iron pipelines//
#define DIType5D  1.0  //Cumulative probability of leak types 1 to 5 for ductile iron pipelines//

#define STLType1D  0.0  //Probability of leak type 1 for welded steel pipelines//
#define STLType2D  0.0  //Cumulative probability of leak types 1 to 2 for welded steel pipelines//
#define STLType3D  0.0  //Cumulative probability of leak types 1 to 3 for welded steel pipelines//
#define STLType4D  0.0  //Cumulative probability of leak types 1 to 4 for welded steel pipelines//
#define STLType5D  1  //Cumulative probability of leak types 1 to 5 for welded steel pipelines//
```

Table 6.12 (Continued)

```
#define OtherType1D  0.2  //Probability of leak type 1 for welded pipelines with other materials//
#define OtherType2D  0.4  //Cumulative probability of leak types 1 to 2 for pipelines with other materials//
#define OtherType3D  0.6  //Cumulative probability of leak types 1 to 3 for pipelines with other materials//
#define OtherType4D  0.8  //Cumulative probability of leak types 1 to 4 for pipelines with other materials//
#define OtherType5D  1.0  //Cumulative probability of leak types 1 to 5 for pipelines with other materials//

//******************Defining Parameters for Earthquake Demand Simulation*********************//
#define MiiMP  0.9012  //Intercept of the intercept term of the linear regression between normalized //
                        //demand and repair rate for mean regression; II in Eqn. 5.2//
#define MisMP  0.0036  //Slope of the intercept term of the linear regression between normalized //
                        //demand and repair rate for mean regression; IS in Eqn. 5.2//
#define MsiMP  0.877  //Intercept of the slope term of the linear regression between normalized //
                      //demand and repair rate for mean regression; SI in Eqn. 5.2//
#define MssMP  0.0248  //Slope of the slope term of the linear regression between normalized //
                        //demand and repair rate for mean regression; SS in Eqn. 5.2//
#define MiiSD -0.0198  //Intercept of the linear regression between the standard deviation of mean intercept//
                       //and mean pressure; see Eqn. 5.2//
#define MisSD  0.0015  //Slope of the linear regression between the standard deviation of mean intercept//
                       //and mean pressure; see Eqn. 5.2//
#define MsiSD  -0.351  //Intercept of the linear regression between the standard deviation of mean slope//
                       //and mean pressure; see Eqn. 5.2//
#define MssSD  0.0094  //slope of the linear regression between the standard deviation of mean slope//
                       //and mean pressure; see Eqn. 5.2//
#define UiiMP  1.1412  //Intercept of the intercept term of the linear regression between normalized //
                       //demand and repair rate for 90% confidence level regression; II in Eqn. 5.3//
#define UisMP  0.0055  //Slope of the intercept term of the linear regression between normalized //
                       //demand and repair rate for 90% confidence level regression; IS in Eqn. 5.3//
#define UsiMP  -0.0514  //Intercept of the intercept term of the linear regression between normalized//
                       //demand and repair rate for 90% confidence level regression; SI in Eqn. 5.3//
#define UssMP  0.0347  //Slope of the intercept term of the linear regression between normalized //
                       //demand and repair rate for 90% confidence level regression; SS in Eqn. 5.3//

#define pi  3.1415926  //Constant pi//
#define mRRCap  0.02  //Lower bound of repair rate for Monte Carlo simulation, below which it is assumed //
                       //that no pipe damage occurs. The lower bound is to avoid the numerical stability //
                       //problems when using the Eqn. 4.20 to generation locations of pipe damage.//
```

6.4 Outputs

The major outputs for GIRAFFE simulations are the hydraulic analysis results for each type of network physical component, including junctions, tanks, pipes, pumps, and valves. GIRAFFE also reports the serviceability of the damaged system.

6.4.1 Deterministic Simulations

The main outputs of deterministic simulations are hydraulic analysis results for junctions, tanks, pipes, pumps, and valves, which are reported in the text files, *JunctionResults_Time*.out*, *TankResults_Time*.out*, *PipeResults_Time*.out*, *PumpResults_Time*.out*, and *ValveResults_Time*.out*, respectively. GIRAFFE also reports the serviceability of each demand node and the entire system in the text file, *Serviceability*.out*. GIRAFFE saves the damaged system in *Damage_System_Time*.inp*, and modified system in *Modified_System_Time*.inp*, for users to visualize the damaged and modified systems. In these files, the character * represents the simulation time in the units of hours. For example, a simulation including tank level change over 24 hours where the tank level update is set at 24 hours would have two sets of results generated, one at time 0 and one at time 24. The *Damage_System_Time0.inp* represents the system immediately after pipeline damage is added in the network. No hydraulic simulation and negative pressure elimination are performed to the *Damage_System_Time0.inp*. The *Modified_System_Time0.inp* represents the system after hydraulic simulation and negative pressure elimination of the *Damage_System_Time0.inp*. The *Damage_System_Time24.inp* is the *Modified_System_Time0.inp* with tank water levels updated according to the simulation results at time 0 and the time step, 24 hours. The *Modified_System_Time24.inp* represents the system after hydraulic simulation and negative pressure elimination to the *Damage_System_Time24.inp*. The detailed formats of these files can be found in the examples presented in Chapter 7.

6.4.2 Monte Carlo Simulations

The main outputs of the Monte Carlo simulation are system serviceability. The system serviceability information is reported in the file, *Serviceability*.out*. The serviceability is reported in a matrix format. For each Monte Carlo simulation run, the serviceability is reported for each demand node and for the entire system. The mean of the nodal and system serviceability for all Monte Carlo simulation runs is also calculated and reported. GIRAFFE also reports the results of junctions, tanks, pipes, pumps, and valves, in *JunctionResults_Time*.out*, *TankResults_Time*.out*, *PipeResults_Time*.out*, *PumpResults_Time*.out*, and *ValveResults_Time*.out* for each run of simulation.

CHAPTER 7
GIRAFFE SIMULATION EXAMPLES

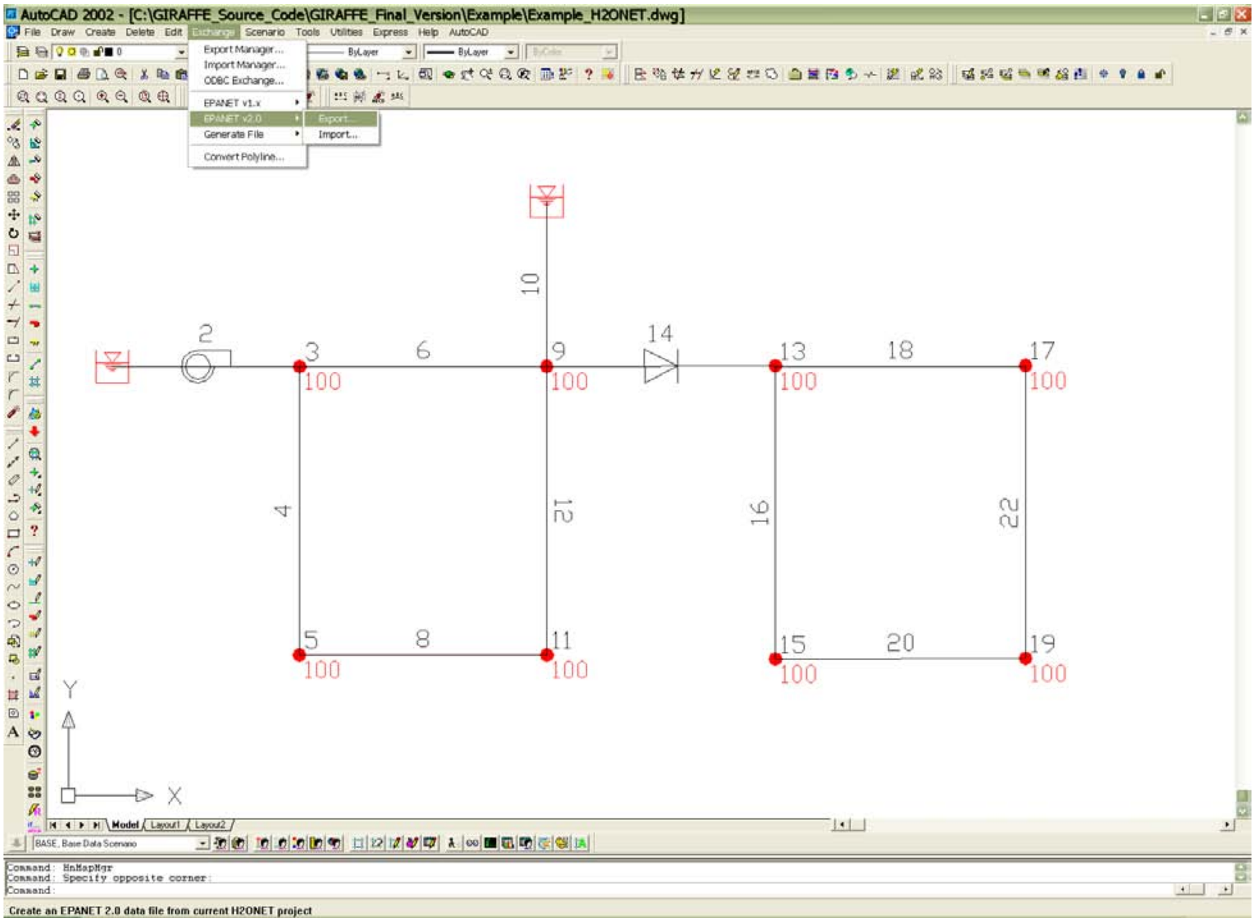
7.1 INTRODUCTION

This chapter provides an example associated with the three GIRAFFE simulation options, which are deterministic, Monte Carlo with fixed simulation runs, and Monte Carlo simulation with flexible runs. The water supply system used in the example is introduced in the first subheading. The inputs and outputs associated with each of the three simulation options are explained in the three subheadings that follow.

7.2 HYDRAULIC NETWORK MODEL

Since the LADWP hydraulic network model works with the H2ONET software, this example applies H2ONET to construct the hydraulic network model. Detailed procedures for constructing a hydraulic network model using H2ONET can be found in the H2ONET users manual (MWH Soft Inc., 1999). The H2ONET hydraulic network model is then exported directly from H2ONET to EPANET input file format. To export the H2ONET model, users need to go to the **Exchange** dropdown menu in the H2ONET GUI, find the **EPANET v2.0** menu, click the **Export** button, and specify the directory and name of the export file.

Figure 7.1 shows the hydraulic network model with the H2ONET GUI. The menu used to export the H2ONET hydraulic model to an EPANET input file is also shown in this figure. The network contains 1 reservoir with ID 1, 1 tank with ID 7, 1 pump with ID 2, 1 PRV with ID 14, and 9 pipes. Eight demand nodes are distributed around the network. Each demand node has a demand of 100 gpm. In general, water flows from the tank and reservoir in the northwest towards the southeast to satisfy the demands. The EPANET input file exported from H2ONET is shown in Table 7.1. Detailed descriptions of the EPANET input file can be found in the



```
Command: HnMapMgr
Command: Specify opposite corner:
Command:
```

Create an EPANET 2.0 data file from current H2ONET project

Figure 7.1 Hydraulic Network Model Constructed by H2ONET

EPANET Users Manual (Rossman, 2000). The hydraulic network exported from H2ONET can be analyzed by the EPANET engine and the analysis results can be visualized using the GUI of EPANET shown in Figure 7.2. In this figure, the node and link IDs are shown as black numbers. The link flows in units of *gpm* and nodal pressures in units of foot of water height are coded using the colors indicated in the legends.

Table 7.1 EPANET Format System Definition File

```
[TITLE]

[JUNCTIONS]
3         100.000000
5         100.000000
9         100.000000
11        100.000000
13        100.000000
15        200.000000
17        100.000000
19        200.000000

[RESERVOIRS]
1         450.000000

[TANKS]
7         450.000000       120.000000      0.000000        120.000000      30.000000       0.000000

[PIPES]
10            7            9           3048.00000      12.00000        100.000000      0.000000
12            9            11          3048.00000      12.00000        100.000000      0.000000
16           13            15          3048.00000      12.00000        100.000000      0.000000
18           13            17          3048.00000      12.00000        100.000000      0.000000
20           15            19          3048.00000      12.00000        100.000000      0.000000
22           17            19          3048.00000      12.00000        100.000000      0.000000
4            3             5           3048.00000      12.00000        100.000000      0.000000
6            3             9           3048.00000      12.00000        100.000000      0.000000
8            5             11          3048.00000      12.00000        100.000000      0.000000

[PUMPS]
2         1         3         POWER           10.000000

[VALVES]
14        9         13        4.000000        PRV       100.000000      0.000000

[DEMANDS]
3         100.000000
5         100.000000
9         100.000000
11        100.000000
13        100.000000
15        100.000000
17        100.000000
19        100.000000

[CURVES]

[PATTERNS]
PATN1  1.000000        1.000000        1.000000        1.000000        1.000000        1.000000
PATN1  1.000000        1.000000        1.000000        1.000000        1.000000
`
[STATUS]
```

Table 7.1 Continued

```
[CONTROLS]

[SOURCES]

[QUALITY]

[REACTIONS]
GLOBAL BULK 0.000000
GLOBAL WALL 0.000000

[ENERGY]

[OPTIONS]
UNITS GPM
HEADLOSS H-W
VISCOSITY 1.1e-005
DIFFUSIVITY 1.3e-008
SPECIFIC GRAVITY 1.000000
TRIALS 40
ACCURACY 0.001
DEMAND Multiplier 1.000000

[REPORT]
PAGESIZE 30
STATUS NO
NODE ALL
LINK ALL

[COORDINATES]
1       140.726688      174.581772
3       169.667221      174.431972
5       169.576993      130.595466
7       207.220708      199.588372
9       207.220708      174.450158
11      207.252760      130.579090
13      241.998111      174.517132
15      241.998111      129.944774
17      280.016223      174.565669
19      280.016223      130.044299

[VERTICES]

[End]
```

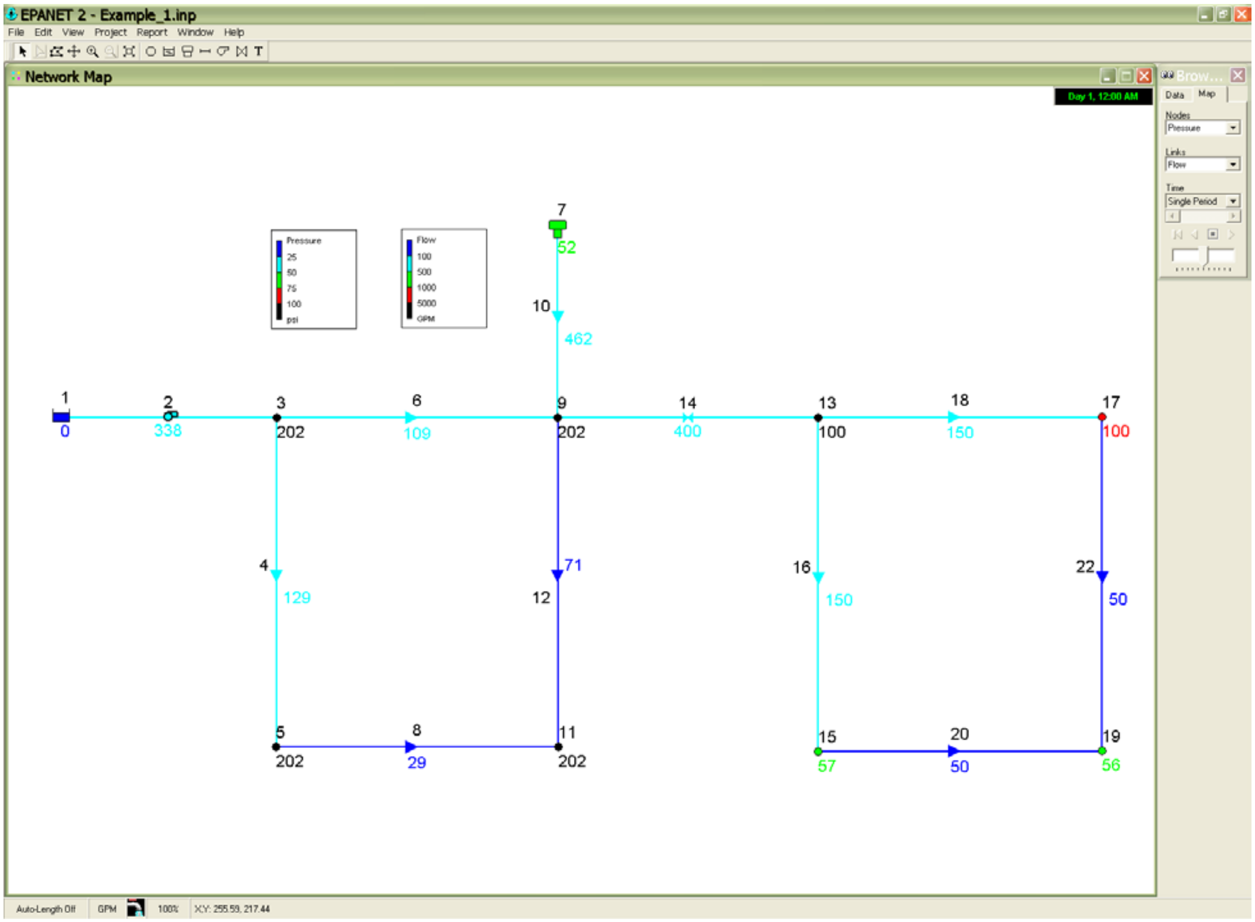


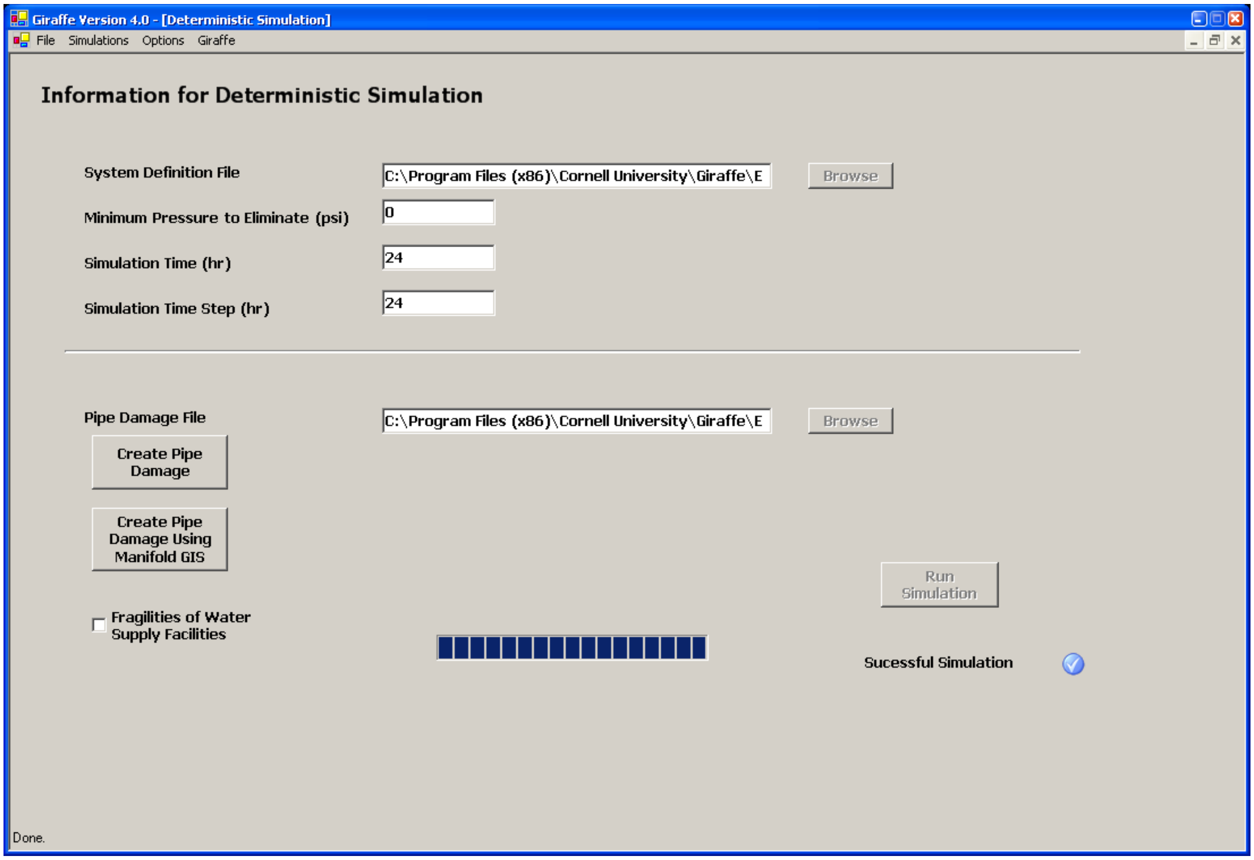
Figure 7.2 Hydraulic Simulation Results for Undamaged System from EPANET

7.3 DETERMINISTIC SIMULATIONS

The hydraulic network was first analyzed deterministically by GIRAFFE. The input parameters, data files, and output files for this deterministic simulation are described below.

7.3.1 Inputs

Figure 7.3 shows the GIRAFFE GUI window with inputs for a deterministic simulation. The hydraulic network model, which is defined in the EPANET system definition file, *Example_1.inp*, was analyzed by GIRAFFE. The simulation time is 24 hours and the time step to update the tank water levels is also 24 hours such that the tank water levels are updated once after 24 hours of running. Table 7.2 shows the input file for pipe damage generation, *Pipe_Damage.inp*. Three breaks occurred in this network with two breaks occurring in pipe 22 and one in pipe 12. The two breaks occurred in pipe 22 are differentiated by their different length ratios, 0.3 and 0.9, respectively. The one break in pipe 12 occurred at the middle point of pipe 12 with a length ratio of 0.5. One leak occurred in pipe 22 with a length ratio of 0.6 and leak diameter of 2 inches.



Information for Deterministic Simulation

System Definition File: C:\Program Files (x86)\Cornell University\Giraffe\E

Minimum Pressure to Eliminate (psi): 0

Simulation Time (hr): 24

Simulation Time Step (hr): 24

Pipe Damage File: C:\Program Files (x86)\Cornell University\Giraffe\E

☐ Fragilities of Water Supply Facilities

Sucessful Simulation ✓

Figure 7.3 Inputs for Deterministic Simulation

Table 7.2 Input File for Pipe Damage Information for Deterministic Simulation (*Pipe_Damage.inp*)

```
[Pipe_Break_Information]
PipeID      PreRatio    BreakRatio    RepairNo    BreakNo    LeakNo    PreIndex

22           0           0.3           3           1          0         0
22           0.6         0.9           3           2          1         0
12           0           0.5           1           1          0         0


[Pipe_Leak_Information]
PipeID      LeakD    PreRatio    LeakRatio    RepairNo    BreakNo    LeakNo    PreIndex

22           2        0.3         0.6          3           1          1         1
```

After GIRAFFE receives the inputs, it performs the deterministic simulation according to the following procedures.

1) Damage the network and output the damaged system, *Damage_System_Time01.inp*.
2) Apply the EPANET engine to perform hydraulic network analysis to the damaged system and the iterative approach to eliminate negative pressures or pressures below the set threshold pressure. The elimination process continues until no negative pressures exist in the network.
3) Output the system definition file, *Modified_System_Time01.inp*, and report the results of each type of physical component in the files, *JunctionResults_Time0.out*, *TankResults_Time0.out*, *PipeResults_Time0.out*, *PumpResults_Time0.out*, and *ValveResults_Time0.out*.
4) Calculate the system serviceability at time 0 and report the system serviceability in the file, *Serviceability0.out*.
5) Read the *TankResults_Time0.out*, determine the outflow of each tank, and update the tank water levels according to the initial tank water levels, tank cross-section areas, tank outflows, and the time step. In this example, GIRAFFE updates the water level of tank with ID 7 once after 24 hours of tank running.
6) Output the damaged system, *Damage_System_Time241.inp*.
7) Apply the EPANET engine to perform hydraulic network analysis to the system with tank water level updated, and the iterative approach to eliminate negative pressures. The elimination process continues until no negative pressures exist in the network.
8) Output the system definition file, *Modified_System_Time241.inp*, and report the hydraulic simulation results of each type of physical component in the files, *JunctionResults_Time24.out*, *TankResults_Time24.out*, *PipeResults_Time24.out*, *PumpResults_Time24.out*, and *ValveResults_Time24.out*.

9) Calculate the system serviceability at time 24 and report the system serviceability in the file, *Serviceability24.out*.

7.3.3 Outputs

GIRAFFE reports two sets of simulation results, with one at time 0 and the other at time 24.

7.3.3.1 Outputs at Time 0

The *Damage_System_Time01.inp*, shown in Table 7.3, stores the system definition information immediately after the system damage. Comparing Tables 7.1 and 7.3 show that 1) 1 junction with ID A1J22 is added in the [JUNCTION] section to model the pipe leak in pipe 22; 2) 7 reservoirs, with IDs A1R22, A2R22, A3R22, A4R22, A5R22, A1R12, and A2R12 are added in the [RESERVOIR] section to model the two breaks in pipe 22, 1 leak in pipe 22, and 1 break in pipe 12; 3) the original pipe 22 in the [PIPES] section is replaced with pipes A1O22, A2O22, A3O22, and A4O22 because of the three locations of damage, including two breaks and one leak, occurred in this pipe; 4) the original pipe 12 in the [PIPES] section is replaced with pipes A1O12 and A2O12 because one break occurred in the pipeline; and 5) One pipe A1L22 is added in the [PIPES] section to model the leak occurred in pipe 22. Users can use the EPANET GUI to visualize the damaged system as shown in Figure 7.4.

The *Modified_System_Time01.inp* stores system definition information after the GIRAFFE analysis of the *Damage_System_Time01.inp*. In this system, the negative pressure nodes and connected links have been eliminated in sequence. This system can be visualized using the EPANET GUI, as shown in Figure 7.5. This figure shows that node 19 and the connected pipes, 20 and A4O22, are eliminated because of the negative pressure. Node A1J22 and the connected pipes, A2O22, A3O22, and A1L22, are also eliminated.

Table 7.3 Damaged System at Time 0 (*Damage_System_Time01.inp*)

```
[TITLE]

[JUNCTIONS]
A1J22   160
3       100.000000
5       100.000000
9       100.000000
11      100.000000
13      100.000000
15      200.000000
17      100.000000
19      200.000000

[RESERVOIRS]
A1R22   130
A2R22   130
A4R22   190
A5R22   190
A1R12   100
A2R12   100
A3R22   160
1       450.000000

[TANKS]
7       450.000000     120.000000     0.000000      120.000000     30.000000     0.000000

[PIPES]
A1O22     17       A1R22    914.4           12            100            1            CV
A3O22     A1J22    A4R22    914.4           12            100            1
A4O22     19       A5R22    304.8           12            100            1            CV
A1O12      9       A1R12    1524            12            100            1            CV
A2O12     11       A2R12    1524            12            100            1            CV
A2O22     A1J22    A2R22    914.4           12            100            1            CV
A1L22     A1J22    A3R22    0.5             2             1e+006         1            CV
10         7       9        3048.00000      12.00000      100.000000     0.000000
16         13      15       3048.00000      12.00000      100.000000     0.000000
18         13      17       3048.00000      12.00000      100.000000     0.000000
20         15      19       3048.00000      12.00000      100.000000     0.000000
4          3       5        3048.00000      12.00000      100.000000     0.000000
6          3       9        3048.00000      12.00000      100.000000     0.000000
8          5       11       3048.00000      12.00000      100.000000     0.000000

[PUMPS]

2       1       3       POWER          10.000000

[VALVES]
14      9       13      4.000000       PRV     100.000000     0.000000

[DEMANDS]
3       100.000000
5       100.000000
9       100.000000
```

Table 7.3 Continued

```
11        100.000000
13        100.000000
15        100.000000
17        100.000000
19        100.000000

[CURVES]

[PATTERNS]
PATN1  1.000000        1.000000        1.000000        1.000000        1.000000        1.000000
PATN1  1.000000        1.000000        1.000000        1.000000        1.000000

[STATUS]
A3O22  Closed

[CONTROLS]

[SOURCES]

[QUALITY]

[REACTIONS]
GLOBAL BULK 0.000000
GLOBAL WALL 0.000000

[ENERGY]

[OPTIONS]
UNITS GPM
HEADLOSS H-W
VISCOSITY 1.1e-005
DIFFUSIVITY 1.3e-008
SPECIFIC GRAVITY 1.000000
TRIALS 40
ACCURACY 0.001
DEMAND Multiplier 1.00000011

[REPORT]
PAGESIZE 30
STATUS NO
NODE ALL
LINK ALL

[COORDINATES]
A1R22  284.468 163.435
A2R22  284.468 158.983
A4R22  284.468 136.723
A5R22  284.468 132.27
A1R12  211.622 154.711
A2R12  211.625 150.324
A1J22  280.016 147.853
A3R22  284.468 147.853
1         140.726688      174.581772
```

Table 7.3 Continued

```
3         169.667221        174.431972
5         169.576993        130.595466
7         207.220708        199.588372
9         207.220708        174.450158
11        207.252760        130.579090
13        241.998111        174.517132
15        241.998111        129.944774
17        280.016223        174.565669
19        280.016223        130.044299

[VERTICES]
A1O22   280.016 163.435
A3O22   280.016 136.723
A4O22   280.016 132.27
A1O12   207.235 154.708
A2O12   207.238 150.321
A2O22   280.016 158.983

[End]
```

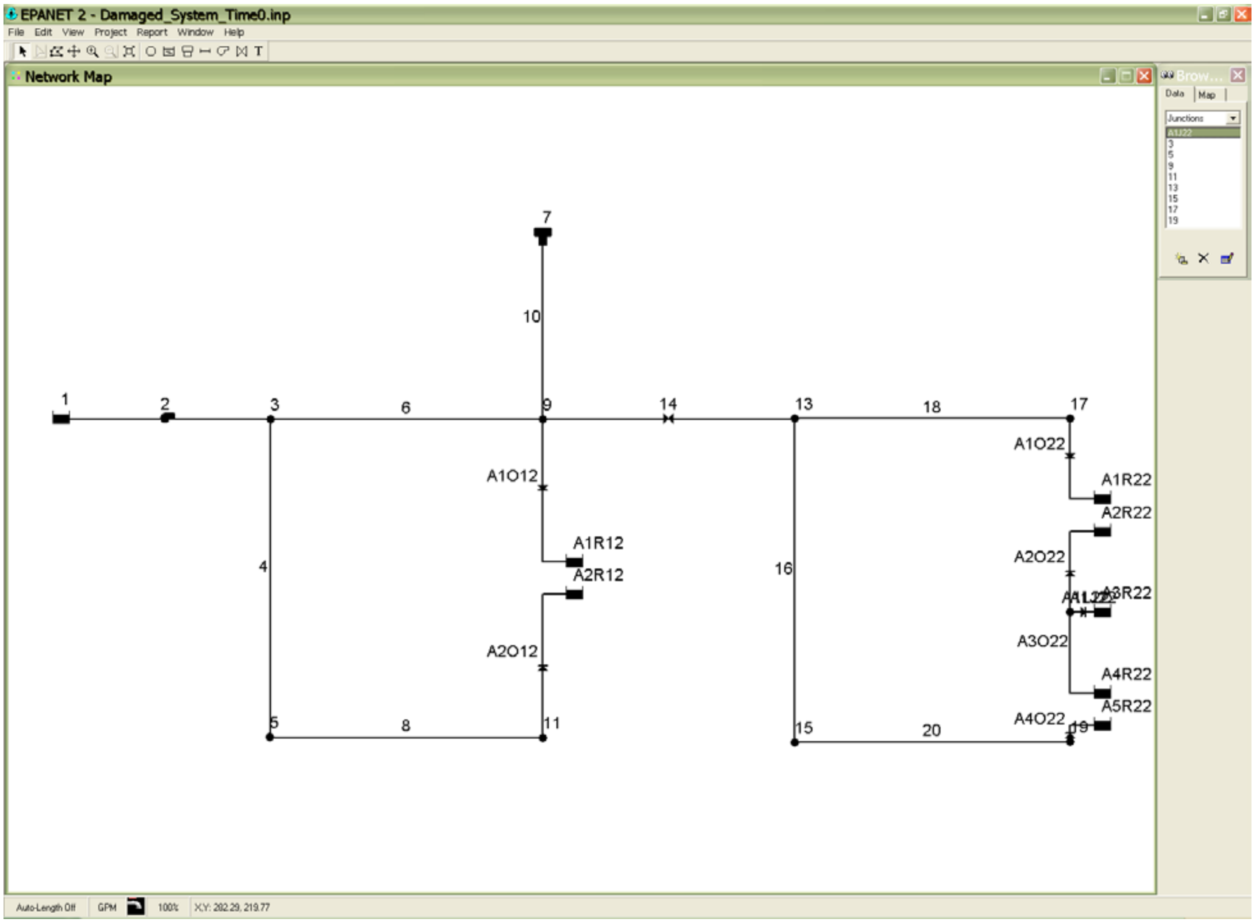


Figure 7.4 Damaged System at Time 0

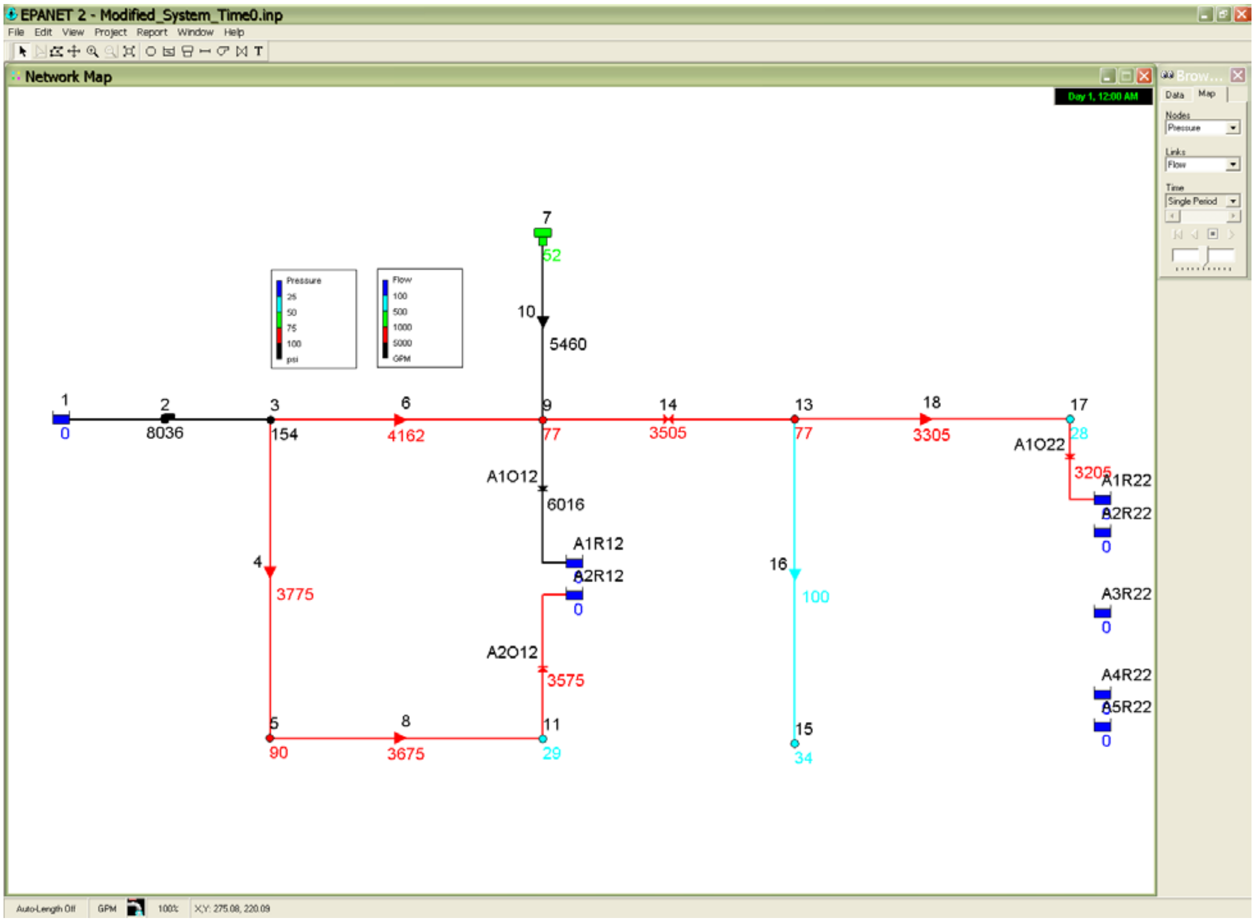


Figure 7.5 Simulation Results at Time 0

The detailed hydraulic simulation results associated with each type of component, including junctions, tanks, pipes, pumps, and valves, are shown in Tables 7.4 to 7.8. In these tables, only the results for the components in the original system are listed such that these data files can be linked into GIS for map presentations. The results of the eliminated components due to negative pressures or connectivity problems are set to 0. Figure 7.6 shows the simulation results in a GIS map. The GIS shapefiles of junctions, tanks, pipes, pumps, and valves are directly exported from the H2ONET software. By linking the simulation results for each type of the physical component with the corresponding GIS shapefile, it is possible to visualize the unsatisfied demands and the pipes unable to transport water.

Table 7.4 Junction Results at Time 0

Node_ID	Demand_gpm	Head_ft	Pressure_psi
3	100	454.92	153.79
5	100	307.92	90.09
9	100	278.8	77.47
11	100	168.05	29.49
13	100	278.8	77.47
15	100	278.62	34.07
17	100	163.86	27.67
19	0	0	0

Table 7.5 Tank Results at Time 0

Tank_ID	Demand_gpm	Head_ft	Pressure_psi
1	-8036.31	450	0
7	-5459.8	570	52

Table 7.6 Pipe Results at Time 0

Pipe_ID	Flow_gpm	Velocity_fps	Headloss_/1000ft
10	5459.8	15.49	95.54
12	0	0	0
16	100	0.28	0.06
18	3305.09	9.38	37.71
20	0	0	0
22	0	0	0
4	3774.68	10.71	48.23
6	4161.63	11.81	57.78
8	3674.68	10.42	45.89

Table 7.7 Pump Results at Time 0

Pump_ID	Flow_gpm	Velocity_fps	Headloss_/1000ft
2	8036.31	0	-4.92

Table 7.8 Valve Results at Time 0

Valve_ID	Flow_gpm	Velocity_fps	Headloss_/1000ft
14	3505.09	9.94	0

Table 7.9 Serviceability at Time 0

Node_ID	Demand	1	Node_Serviceability
3	100	100	1
5	100	100	1
9	100	100	1
11	100	100	1
13	100	100	1
15	100	100	1
17	100	100	1
19	100	0	0
Sum		0.875	0.875

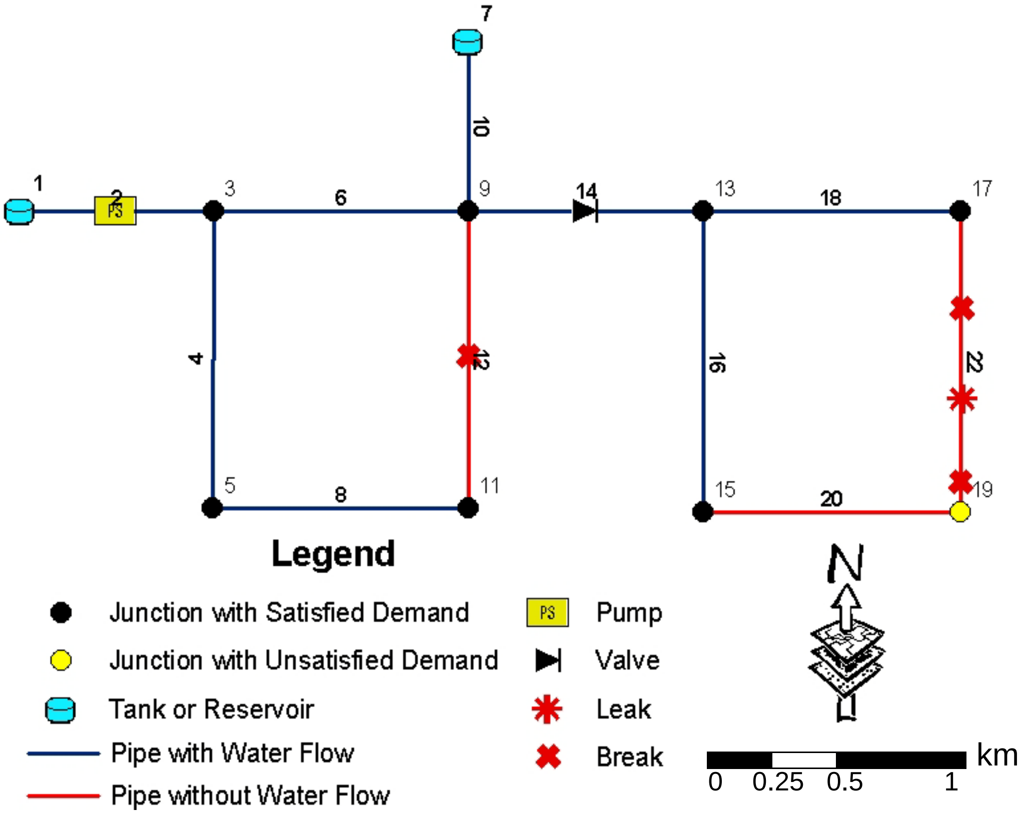


Figure 7.6 GIS Map for GIRAFFE Simulation Results at Time 0

7.3.3.2 Outputs at Time 24

The *Damage_System_Time241.inp* stores the system definition information at a time 24 hours after updating the tank water level. The *Modified_System_Time241.inp* stores the system definition information after GIRAFFE simulation of the *Damage_System_Time241.inp*. The final simulation results at time 24 can be visualized using the EPANET GUI as shown in Figure 7.7. This figure shows that tank 7 is depleted after 24 hours of running and therefore, there is no water flowing from this tank. All water flow in this network is supplied by reservoir 1. After the depletion of tank 7, negative pressure occurred at node15 and thus this node and the connected pipe 16 were eliminated. The system serviceability dropped from 0.875 to 0.75 due to the unsatisfied demand at node 16. The simulation results associated with each component, and the serviceability of each demand node and the entire system are shown in Tables 7.10 to 7.15. These simulation results can also be linked into a GIS.

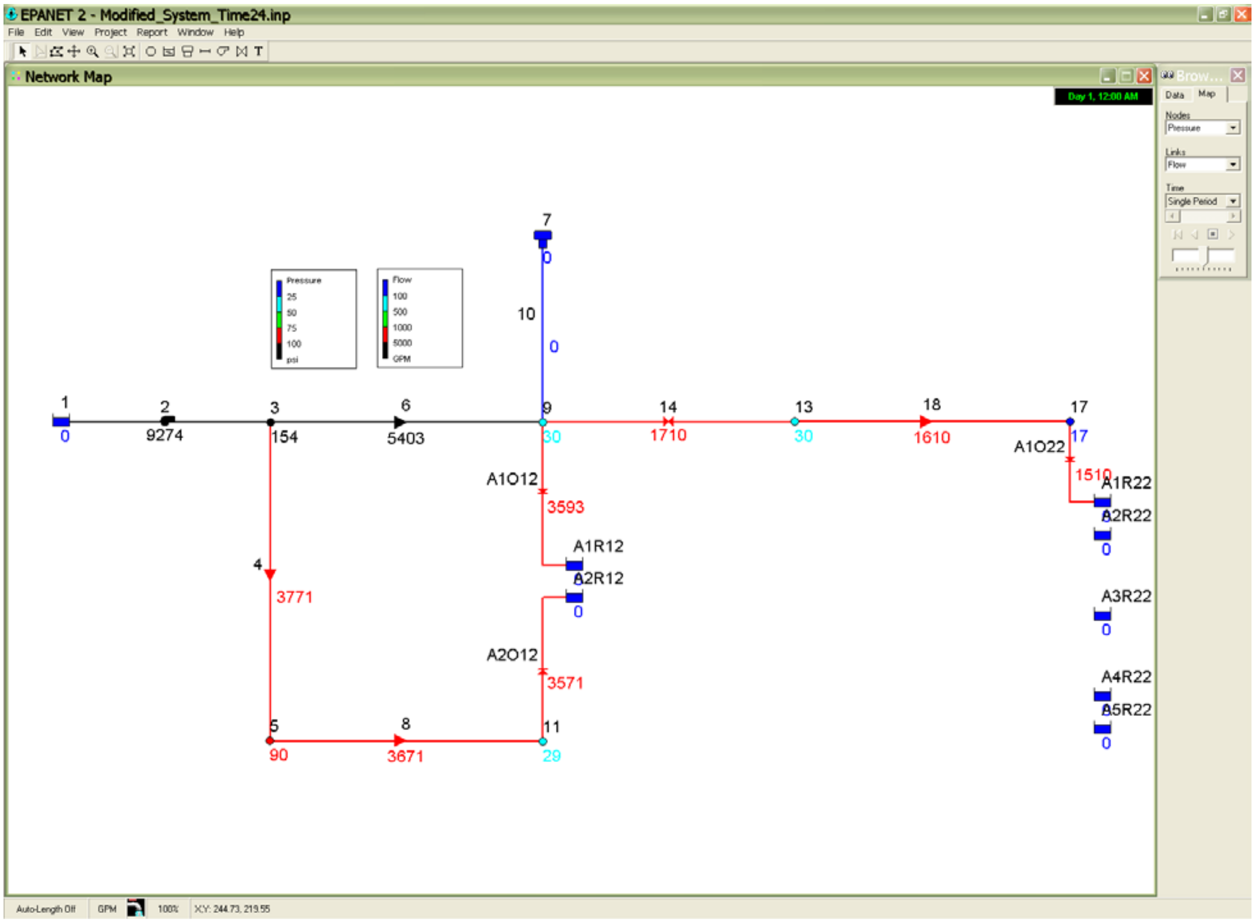


Figure 7.7 Simulation Results at Time 24

Table 7.10 Junction Results at Time 24

Node_ID	Demand_gpm	Head_ft	Pressure_psi
3	100	454.27	153.5
5	100	307.53	89.92
9	100	168.69	29.76
11	100	167.92	29.43
13	100	168.69	29.76
15	0	0	0
17	100	138.36	16.62
19	0	0	0

Table 7.11 Tank Results at Time 24

Tank_ID	Demand_gpm	Head_ft	Pressure_psi
1	-9273.55	450	0
7	0	450	0

Table 7.12 Pipe Results at Time 24

Pipe_ID	Flow_gpm	Velocity_fps	Headloss_/1000ft
10	0	0	0
12	0	0	0
16	0	0	0
18	1609.71	4.57	9.95
20	0	0	0
22	0	0	0
4	3770.99	10.7	48.14
6	5402.57	15.33	93.69
8	3670.99	10.41	45.8

Table 7.13 Pump Results at Time 24

Pump_ID	Flow_gpm	Velocity_fps	Headloss_/1000ft
2	9273.55	0	-4.27

Table 7.14 Valve Results at Time 24

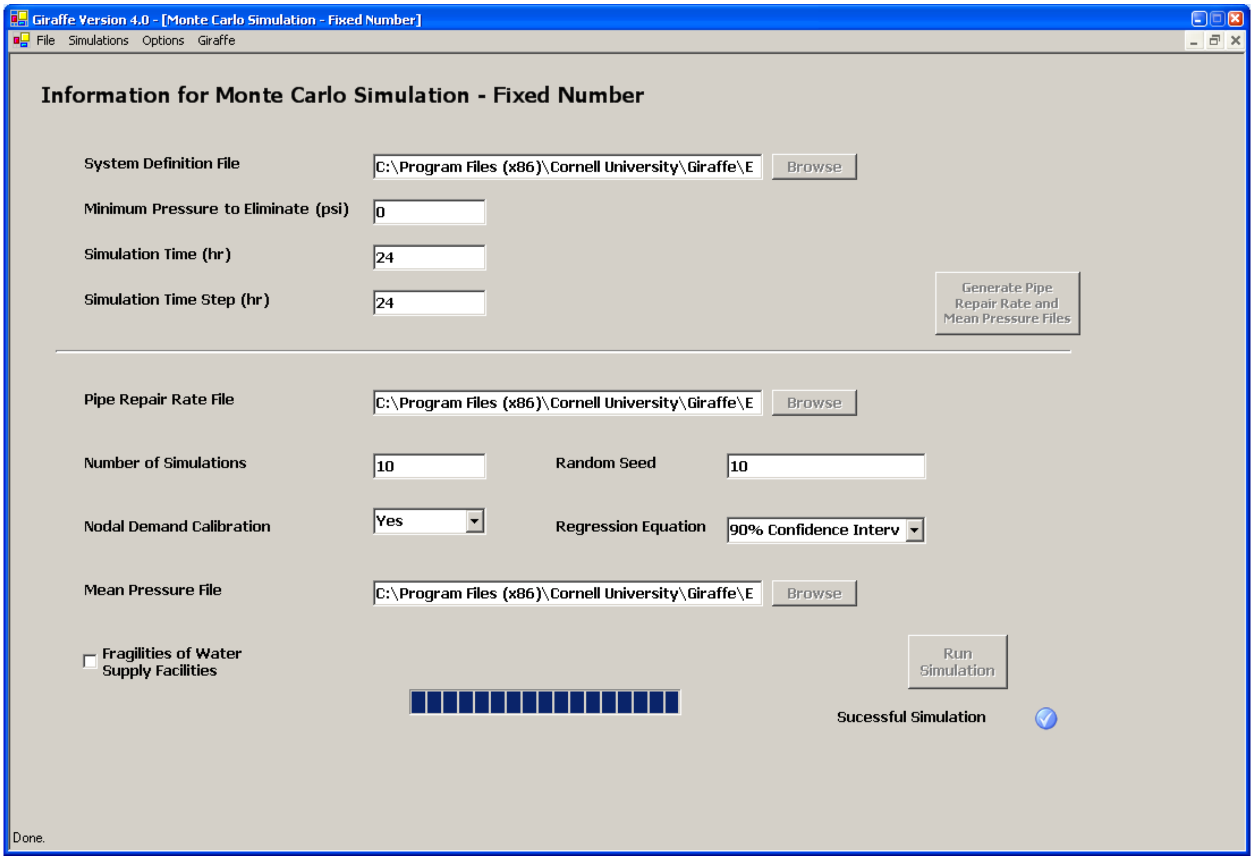
Valve_ID	Flow_gpm	Velocity_fps	Headloss_/1000ft
14	1709.71	4.85	0

Table 7.15 Serviceability at Time 24

Node_ID	Demand	1	Node_Serviceability
3	100	100	1
5	100	100	1
9	100	100	1
11	100	100	1
13	100	100	1
15	100	0	0
17	100	100	1
19	100	0	0
Sum		0.75	0.75

7.4 Monte Carlo with Fixed Simulation Runs

Figure 7.8 shows the GIRAFFE GUI window with inputs for the Monte Carlo simulation with fixed simulation times. The same hydraulic network as shown in last section was analyzed by GIRAFFE. Ten Monte Carlo simulations were performed. The earthquake demand associated with the distribution network damage is simulated using the 90% confidence level prediction. The input file for pipe damage generation, *rr.inp*, is shown in Table 7.16. It is assumed that each pipe has a RR = 1 repair/km in this example. The input file, *Node_Pressure.inp*, for earthquake demand simulation is shown in Table 7.17. It is assumed that the distribution network has a RR =1 repair/km around each demand node.



Information for Monte Carlo Simulation - Fixed Number

System Definition File: C:\Program Files (x86)\Cornell University\Giraffe\E

Minimum Pressure to Eliminate (psi): 0

Simulation Time (hr): 24

Simulation Time Step (hr): 24

Pipe Repair Rate File: C:\Program Files (x86)\Cornell University\Giraffe\E

Number of Simulations: 10

Random Seed: 10

Nodal Demand Calibration: Yes

Regression Equation: 90% Confidence Interv

Mean Pressure File: C:\Program Files (x86)\Cornell University\Giraffe\E

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Sucessful Simulation ✓

Done.

Figure 7.8 Inputs for Monte Carlo Simulation with Fixed Simulation Runs

It is further assumed that the network is divided into two pressure zones, one upstream of pressure reducing valve 14, including junctions 3, 5, 9, and 11, and the other downstream of pressure reducing valve 14, including junctions, 13, 15, 17, and 19. The mean pressure of each pressure zone is calculated by averaging the pressures at the junctions inside the pressure zone for the undamaged system and then the mean pressure is assigned to each demand node inside the pressure zone. The pressure at each junction for the undamaged system is shown in Figure 7.2.

GIRAFFE analyzes the network following to the same procedures described in Section 7.3.2 for ten simulation runs. GIRAFFE saves the damaged system definition file, *Damage_Info_Dert*.inp*, and the component results for each Monte Carlo simulation run. The files associated with each simulation run are bundled in separate folders and saved with a similar naming convention as that used in the deterministic simulation. The damaged system and modified system files are appended with a number indicating which simulation run they are associated with, e.g. *Damage_System_Time09.inp* is the damaged system file at time 0 for simulation run 9, and *Modified_System_Time245.inp* is the modified system file at time 24 for simulation run 5. Table 7.18 shows the damaged system for the last Monte Carlo simulation at time 0. Comparing Tables 7.3 and 7.18 shows that the demand in Table 7.18 is different. The demands at nodes 3, 5, 9, and 11, are changed from 100 gpm to 921 gpm and the demands at nodes 13, 15, 17, and 19, are changed from 100 gpm to 422 gpm. The increased demands are associated with water loss from damage to distribution networks around the demand nodes.

Table 7.16 Pipe Damage Input File for Monte Carlo Simulation with Fixed Simulation Runs (*rr.inp*)

PipeID	Length_km	RR	Material
10	1	1	CI
12	1	1	CI
16	1	1	DI
18	1	1	DI
20	1	1	CON
22	1	1	CON
4	1	1	RV
6	1	1	RV
8	1	1	STL

Table 7.17 Input File for Simulating Earthquake Demand for Monte Carlo Simulation with Fixed Simulation Runs (*Node_Pressure.inp*)

ID	G_RR	Ave_PRESSURE
3	1	202
5	1	202
9	1	202
11	1	202
13	1	78
15	1	78
17	1	78
19	1	78

The increased demands are calculated using Eqn. 5.3 and the appropriate values for RR and MP. Because the mean pressure of nodes 3, 5, 9, and 11 is much higher than that of nodes 13, 15, 17 and 19, the post-earthquake demands at nodes 3, 5, 9, and 11 are much higher than that at nodes, 13, 15, 17 and 19. GIRAFFE reports the system serviceability at two time points, times 0 and 24, in files *Serviceability0.out* and *Serviceability24.out*, respectively. These files are shown in Tables 7.19 and 7.20. These tables show that the system serviceability is reported in a matrix format. For each Monte Carlo simulation, the serviceability is reported for each demand node and for the entire system. The mean of the nodal and system serviceability for all Monte Carlo simulations is also calculated and reported.

Table 7.18 Damaged System for the Last Run of Monte Carlo Simulation at Time 0.

```
[TITLE]

[JUNCTIONS]
3       100.00000
5       100.00000
9       100.00000
11      100.00000
13      100.00000
15      200.00000
17      100.00000
19      200.00000
A1J6    100.00000
A1J10   445.01920
A1J12   100.00000
A2J12   100.00000

[RESERVOIRS]
1       450.00000
A1R6    100.00000
A1R10   445.01920
A1R12   100.00000
A1R18   100.00000
A2R12   100.00000
A2R18   100.00000

[TANKS]
7       450.000000     120.000000     0.000000       120.000000     30.000000      0.000000
```

Table 7.18 Continued

```
[PIPES]
4       3       5       3048.00000      12.00000        100.00000       0.00000
8       5       11      3048.00000      12.00000        100.00000       0.00000
16      13      15      3048.00000      12.00000        100.00000       0.00000
20      15      19      3048.00000      12.00000        100.00000       0.00000
22      17      19      3048.00000      12.00000        100.00000       0.00000
A106    3       A1J6    963.56244       12.00000        100.00000       0.00000
A1L6    A1J6    A1R6    0.50000 1.58533 1000000.00000   1.00000 CV
A206    A1J6    9       2084.43750      12.00000        100.00000       0.00000
A1010   7       A1J10   43.37563        12.00000        100.00000       0.00000
A1012   9       A1J12   2369.45337      12.00000        100.00000       0.00000
A1018   13      A1R18   2387.31592      12.00000        100.00000       1.00000 CV
A1L10   A1J10   A1R10   0.50000 1.58533 1000000.00000   1.00000 CV
A1L12   A1J12   A1R12   0.50000 1.20000 1000000.00000   1.00000 CV
A2010   A1J10   9       3004.62427      12.00000        100.00000       0.00000
A2012   A1J12   A2J12   646.33081       12.00000        100.00000       0.00000
A2018   17      A2R18   660.68408       12.00000        100.00000       1.00000 CV
A2L12   A2J12   A2R12   0.50000 1.58533 1000000.00000   1.00000 CV
A3012   A2J12   11      32.21569        12.00000        100.00000       0.00000

[PUMPS]

2       1       3       POWER 10.000000

[VALVES]
14      9       13      12.000000       PRV     100.000000      0.000000

[DEMANDS]
3       921.01996
5       921.01996
9       921.01996
11      921.01996
13      422.53998
15      422.53998
17      422.53998
19      422.53998

[CURVES]

[PATTERNS]
PATN1   1.000000        1.000000        1.000000        1.000000        1.000000        1.000000
PATN1   1.000000        1.000000        1.000000        1.000000        1.000000

[STATUS]

[CONTROLS]

[SOURCES]
```

Table 7.18 Continued

```
[QUALITY]

[REACTIONS]
GLOBAL BULK 0.000000
GLOBAL WALL 0.000000

[ENERGY]

[OPTIONS]
UNITS GPM
HEADLOSS H-W
VISCOSITY 1.1e-005
DIFFUSIVITY 1.3e-008
SPECIFIC GRAVITY 1.000000
TRIALS 40
ACCURACY 0.001
DEMAND Multiplier 1.000000
[REPORT]
PAGESIZE 30
STATUS NO
NODE ALL
LINK ALL

[COORDINATES]
1       140.7267        174.5818
3       169.6672        174.4320
5       169.5770        130.5955
7       207.2207        199.5884
9       207.2207        174.4502
11      207.2528        130.5791
13      241.9981        174.5171
15      241.9981        129.9448
17      280.0162        174.5657
19      280.0162        130.0443
A1J6    181.5390        174.4377
A1R6    181.5372        181.9484
A1J10   207.2207        199.2306
A1J12   207.2456        140.3457
A1R10   207.2207        204.2583
A1R12   211.6327        140.3521
A1R18   269.8697        178.3545
A2J12   207.2524        131.0428
A2R12   211.6395        131.0492
A2R18   273.6715        178.3594

[VERTICES]
A1018   269.8745        174.5527
A2018   273.6763        174.5576


[END]
```

Table 7.19 Serviceability of Monte Carlo Simulation with Fixed Simulation Times at Time 0 (*Serviceability0.out*)

```
Node_ID  Demand  1     2     3     4      5     6     7     8     9     10      Node_Serviceability

3        100     100   100   100   100    100   100   100   100   100   100          1
5        100     0     100   100   100    100   100   100   100   100   100          0.9
9        100     100   100   100   100    100   100   100   100   100   100          1
11       100     100   100   100   100    100   100   100   100   100   100          1
13       100     100   100   100   100    100   100   100   100   100   100          1
15       100     0     0     100   0      100   0     0     0     0     100          0.3
17       100     0     100   100   0      100   100   100   100   100   0            0.7
19       100     0     0     100   0      100   0     0     0     0     0            0.2

Sum              0.5   0.75  1     0.625  1     0.75  0.75  0.75  0.75  0.75         0.7625
```

Table 7.20 Serviceability of Monte Carlo Simulation with Fixed Simulation Times at Time 24 (*Serviceability24.out*)

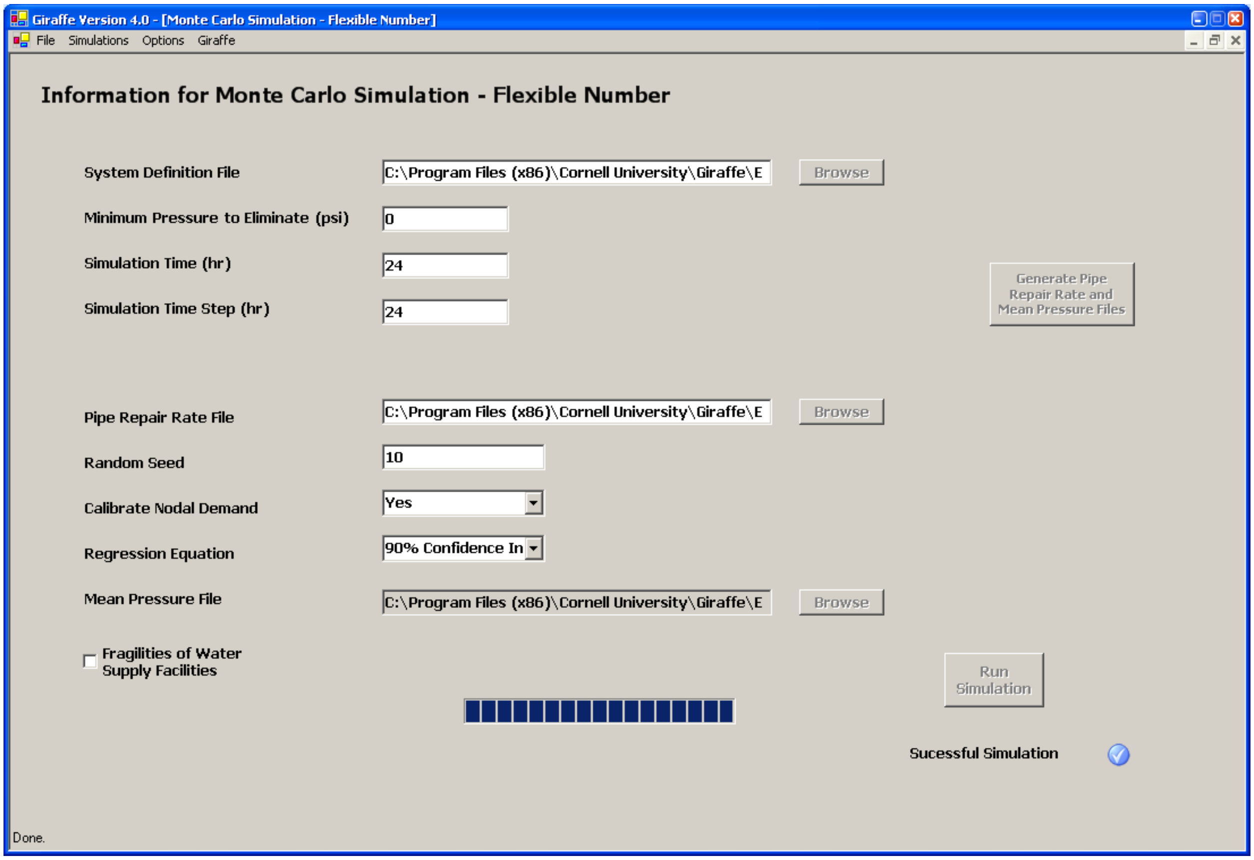
```
Node_ID  Demand  1     2     3     4      5      6     7     8     9      10      Node_Serviceability

3        100     100   100   100   100    100    100   100   100   100    100          1
5        100     0     100   100   100    100    100   100   100   100    100          0.9
9        100     100   100   100   100    100    100   100   100   100    100          1
11       100     100   100   100   100    100    100   100   100   100    100          1
13       100     100   100   100   100    100    100   100   100   100    100          1
15       100     0     0     100   0      100    0     0     0     0      0            0.2
17       100     0     100   100   0      100    100   100   100   0      0            0.6
19       100     0     0     100   0      0      0     0     0     0      0            0.1

Sum              0.5   0.75  1     0.625  0.875  0.75  0.75  0.75  0.625  0.625        0.725
```

7.5 Monte Carlo with Flexible Simulation Runs

Figure 7.9 shows the GIRAFFE GUI window with inputs for the Monte Carlo with flexible simulation runs. The same hydraulic network as shown in the previous section was analyzed by GIRAFFE. The earthquake demand associated with the distribution network damage is simulated using the 90% confidence level prediction. The input files, *rr.inp*, for pipe damage generation and, *Node_Pressure.inp*, for earthquake demand simulation are the same as those shown in Tables 7.16 and 7.17, respectively.



Information for Monte Carlo Simulation - Flexible Number

System Definition File: C:\Program Files (x86)\Cornell University\Giraffe\E
Minimum Pressure to Eliminate (psi): 0
Simulation Time (hr): 24
Simulation Time Step (hr): 24
Pipe Repair Rate File: C:\Program Files (x86)\Cornell University\Giraffe\E
Random Seed: 10
Calibrate Nodal Demand: Yes
Regression Equation: 90% Confidence In
Mean Pressure File: C:\Program Files (x86)\Cornell University\Giraffe\E
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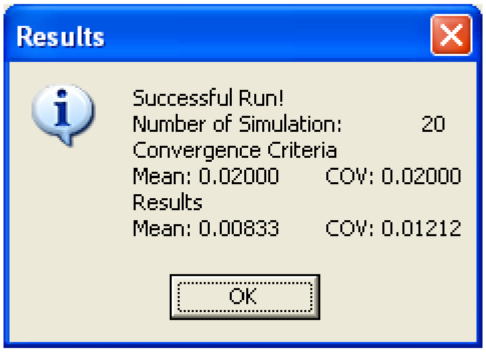
Sucessful Simulation ✓

Done.

Figure 7.9 Inputs for Monte Carlo Simulation with Flexible Simulation Times



Successful Run!
Number of Simulation: 20
Convergence Criteria
Mean: 0.02000 COV: 0.02000
Results
Mean: 0.00833 COV: 0.01212

Figure 7.10 Pop-Up Window with Results

The system serviceability is reported in Tables 7.21 and 7.22 for times 0 and 24, respectively. These tables show that 20 Monte Carlo simulations were performed. The calculations of the mean and COV of the system serviceability for the first 15 and the total 20 simulations show that the difference of the mean and COV from the two sets of simulations is less than 0.02. Thus the program terminated after 20 simulations using its self-termination algorithm. As shown in Figure 7.10, the number of simulations and associated convergence criteria appears in a pop-up window upon completion of the GIRAFFE run. By comparing Tables 7.19 with 7.21, and Table 7.20 with 7.22, it is found that the system serviceability of the first ten simulations is same for the two simulation options. This is because these two simulations used the same seed to generate random numbers.

Table 7.21 Serviceability of Monte Carlo Simulation with Flexible Simulation Runs at Time 0

Node_ID	Demand	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Node_Serviceability
3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1
5	100	0	100	100	100	100	100	100	100	100	100	0	0	100	100	100	100	0	100	100	100	0.8
9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1
11	100	100	100	100	100	100	100	100	100	100	100	0	100	100	100	100	100	100	100	100	100	0.95
13	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1
15	100	0	0	100	0	100	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0.15
17	100	0	100	100	0	100	100	100	100	100	0	100	0	0	100	100	0	0	0	100	100	0.6
19	100	0	0	100	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1
Sum		0.5	0.75	1	0.625	1	0.75	0.75	0.75	0.75	0.75	0.5	0.5	0.625	0.75	0.75	0.625	0.5	0.625	0.75	0.75	0.7

Table 7.22 Serviceability of Monte Carlo Simulation with Flexible Simulation Runs at Time 24

Node_ID	Demand	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Node_Serviceability
3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1
5	100	0	100	100	100	100	100	100	100	100	100	0	0	100	0	100	100	0	100	100	100	0.75
9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1
11	100	100	100	100	100	100	100	100	100	100	100	0	100	100	100	100	100	100	100	100	100	0.95
13	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1
15	100	0	0	100	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1
17	100	0	100	100	0	100	100	100	100	0	0	100	0	0	100	100	0	0	0	100	100	0.55
19	100	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05
Sum		0.5	0.75	1	0.625	0.875	0.75	0.75	0.75	0.625	0.625	0.5	0.5	0.625	0.625	0.75	0.625	0.5	0.625	0.75	0.75	0.675

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Wang, Yu. (2006). “Seismic Performance Evaluation of Water Supply Systems.” *Ph.D. Dissertation*, School of Civil & Environmental Engineering, Cornell University, Ithaca, NY.

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APPENDIX A
GIRAFFE QUICK START TUTORIAL

A.1 INTRODUCTION

This appendix provides a quick start tutorial on how to use GIRAFFE. The quick start tutorial will help first-time users become familiar with the core set of GIRAFFE features and should be used as a launching point to a more comprehensive understanding of GIRAFFE. Users are expected to have some knowledge of how to use the hydraulic network analysis software packages H2ONET and EPANET before starting to use GIRAFFE. Users can obtain this knowledge from the H2ONET Users Manual (MWH Soft, Inc., 1999) and the EPANET Users Manual (Rossman, 2000).

A.2 INSTALLING SOFTWARE

If the Microsoft Install Wizard does not automatically start upon inserting the GIRAFFE installation CD into your computer's CD drive, open the CD folder in Windows Explorer and double click on *Install_GiraffeV4.1.exe*. This will automatically install GIRAFFE Version 4.1, EPANET 2.0, Microsoft.NET Version 2.1, and a Matlab component. The default folder for GIRAFFE is **C:\Program Files\Cornell University\Giraffe**. After installing GIRAFFE, select this item from the Start menu and then double click on the *Giraffe.exe* icon in the GIRAFFE program folder to launch the program. The current version of GIRAFFE operates via a graphical user interface (GUI). When the user clicks the "Generate Pipe Repair Rate and Mean Pressure Files" button (see **Appendix C, Section 2**) in the Monte Carlo Fixed or Flexible simulations in GIRAFFE interface, the stochastic damage tool will be installed in **C:\Program Files\Cornell University\Appendix B**.

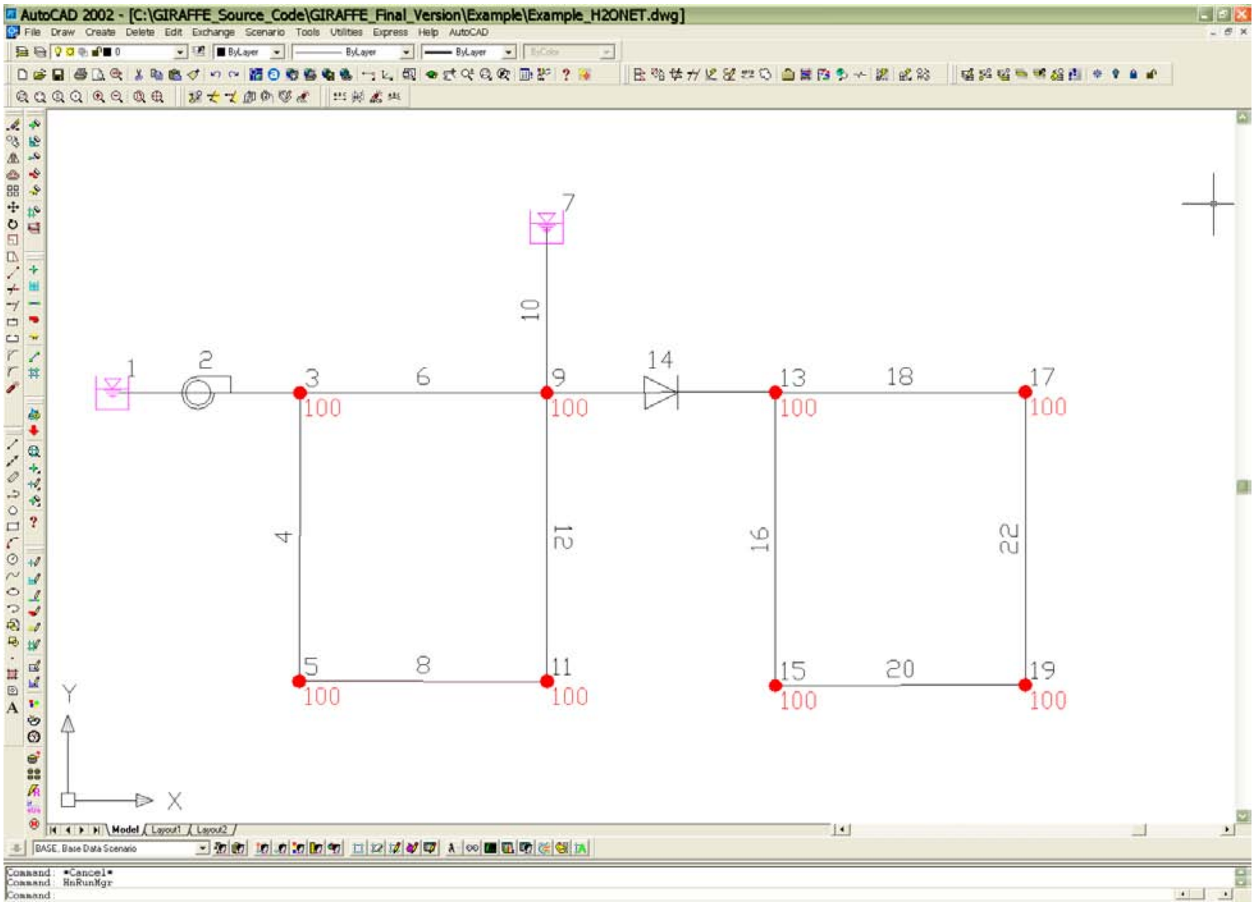
For Windows XP Professional x64 Edition, the GIRAFFE application will be installed in the 32-bit directory, **C:\Program Files (x86)\Cornell University\Giraffe**, and the stochastic damage tool (see **Appendix C, Section 2**) will be installed in the 64-bit directory, **C:\Program Files\Cornell University\Appendix B,** when the user clicks the "Generate Pipe Repair Rate and Mean Pressure Files" button in the GIRAFFE interface.

A.3 EXAMPLE NETWORK

Since the LADWP hydraulic network model works with the H2ONET software, this example also uses H2ONET to construct the hydraulic network model. Detailed procedures for constructing a hydraulic network model using H2ONET can be found in H2ONET Users Manual (MWH Soft, Inc., 1999). Figure A.1 shows the hydraulic network model constructed using H2ONET with component identifications (IDs) indicated as black characters and nodal demands indicated as red numbers.

The network contains 8 junctions with IDs 3, 5, 9, 11, 13, 15, 17, and 19, respectively. All the junctions have an elevation of 100 ft, except junctions 15 and 19, which have an elevation of 200 ft. The network contains 9 pipes with IDs, 4, 6, 8, 10, 12, 16, 18, 20, and 22, respectively. All pipes have a length of 3048 ft, diameter of 12 in., and roughness coefficient of 100. There is one reservoir with ID 1, one tank with ID 7, one pump with ID 2, and one PRV with ID 14 in the network. The reservoir has a hydraulic grade of 450 ft. The tank is a cylinder tank with a diameter of 30 ft, maximum water level of 120 ft, minimum water level of 0 ft, and bottom elevation of 450 ft from the datum. The tank is assumed to be full at the beginning of simulation time. The pump is a constant power pump, which supplies a power of 10 kw-hours. The valve is a pressure reducing valve with a pressure setting of 100 psi. Eight demand nodes are distributed around the network. Each demand node has a demand of 100 gpm.

Three simulations are performed to the network using GIRAFFE: deterministic, Monte Carlo with a fixed number of simulation runs, and Monte Carlo with a flexible number of simulation runs. For a deterministic simulation, GIRAFFE adds damage to the network deterministically and then performs a hydraulic analysis on the damaged network. For Monte Carlo with fixed simulation runs, users specify the number of Monte Carlo simulations to be performed. For Monte Carlo with flexible simulation runs, GIRAFFE determines how many



```
Command: *Cancel*
Command: HnRunMgr
Command:
```

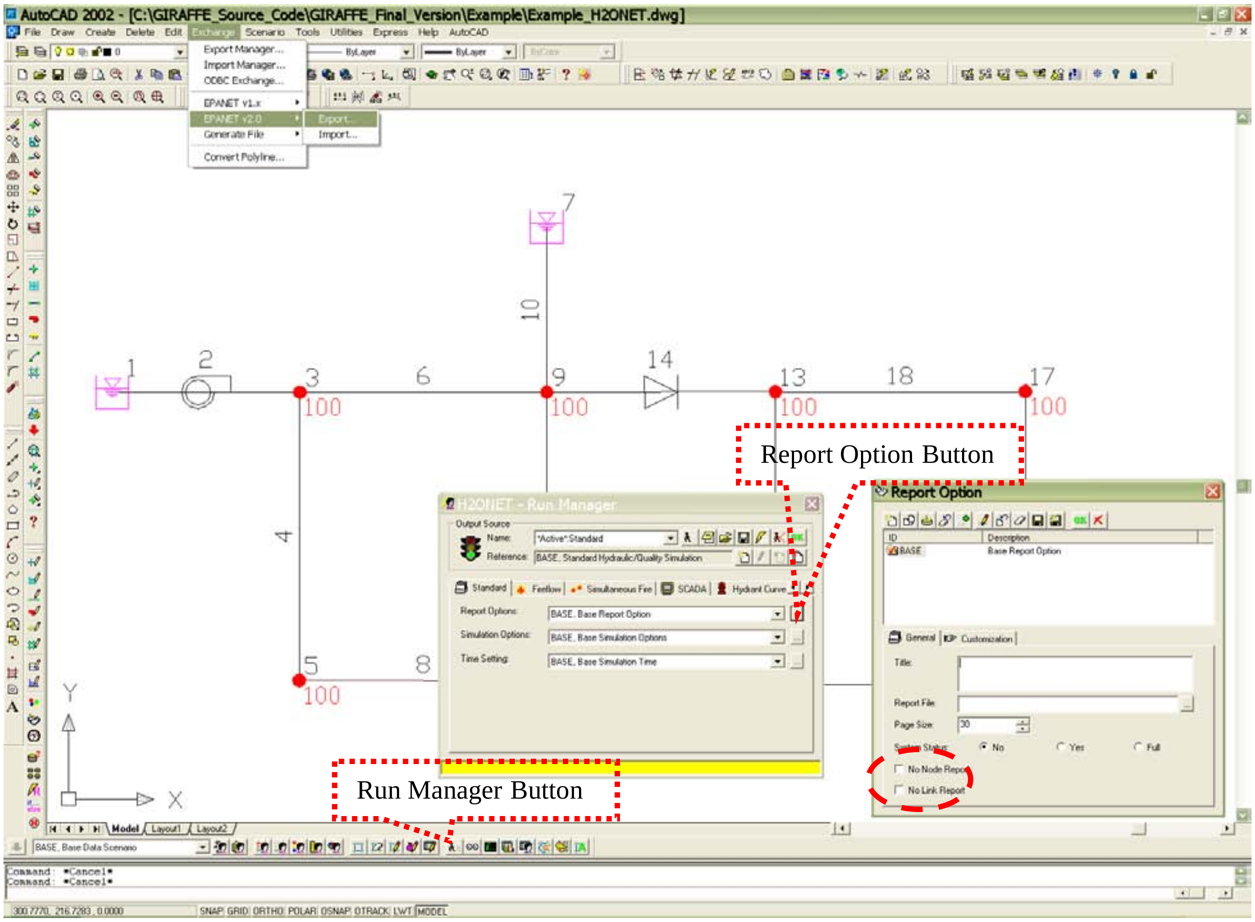
Figure A.1 Hydraulic Network Model Constructed by H2ONET

Monte Carlo simulations need to be performed to have statistically significant simulation results using a built-in self-termination algorithm. The self-termination algorithm is explained in the main text of the GIRAFFE Users Manual and Shi (2006). In each Monte Carlo simulation, GIRAFFE damages the system probabilistically and then analyzes the damaged network.

A.4 DETERMINISTIC SIMULATIONS

Step 1: Export EPANET File

GIRAFFE works with the EPANET format system definition file, which can be exported from H2ONET directly. To export the H2ONET model into EPANET format file:



Name: *Active* Standard
Reference: BASE, Standard Hydraulic/Quality Simulation
Report Options: BASE, Base Report Option
Simulation Options: BASE, Base Simulation Options
Time Setting: BASE, Base Simulation Time

BASE | Base Report Option

Title:
Report File:
Page Size: 30
System Status: ● No ○ Yes ○ Full
☐ No Node Report
☐ No Link Report

Command: *Cancel*
Command: *Cancel*

Figure A.2 Export H2ONET Model to EPANET Format File

- Click the **Run Manager** button at the bottom of the H2ONET GUI as shown in Figure A.2. A **Run Manager** dialogue box will appear.
- Click the **Report Option** button in the **Run Manager** dialogue box. A **Report Option** dialogue box will appear.
- Uncheck the **No Node Report** and **No Link Report** text boxes and then click the **OK** buttons to close the **Run Manager** and **Report Option** dialogue boxes. If these two boxes have already been unchecked, leave them unchecked and close the **Run Manager** dialogue box and **Report Option** dialogue box.
- Go to the **Exchange | EPANET v2.0 | Export** menu in the top of H2ONET GUI, specify the directory and name of the export file, and then click **Export** button. In this example, the EPANET file is saved as *Example_1.inp* in the accompanying Users Manual CD.

Step 2: Check EPANET File

It is important to double check that the EPANET format file can be analyzed by the EPANET engine. The EPANET format file, *Example_1.inp*, is shown in Table A.1. In general, the EPANET file needs to include the following sections.

- Section [TITLE]
- Sections defining physical components in the hydraulic network, including [JUNCTIONS], [RESERVOIRS], [TANKS], [PIPES], [PUMPS], and [VALVES].
- Sections defining operational components, including [DEMANDS], [CURVES], [PATTERNS], [STATUS], and [CONTROLS]
- Sections defining water quality simulation parameters, including [SOURCES], [QUALITY], and [REACTIONS].
- Sections defining simulation and report options, including [ENERGY], [OPTIONS], and [REPORT]. Users need to make sure that the report option for node and link is “ALL”.
- Sections defining the locations of network components, including [COORDINATES] and [VERTICES].
- Section [End]

It is possible that there are no records in some sections. In this case, users still need to keep the title of that section. It is recommended that users load the EPANET file into EPANET to verify that the file can be analyzed by EPANET. To load the file into EPANET and run the file:

- Go to **File | Import | Network** menu in the EPANET GUI as shown in Figure A.3.
- Browse to the file, *Example_1.inp*, and click it to load it into EPANET.
- Click **Project | Run Analysis** menu.

A message box will pop up to report the **Run Status**. If it reports “Run was successful” as shown in Figure A.3, then EPANET could analyze the file and it can be analyzed further in GIRAFFE. If the run was unsuccessful, EPANET will report error messages. Users need to correct the errors in the *.inp* file following directions given by the error messages. Due to several incompatibilities between EPANET and H20NET, the input file may have errors regarding H20NET control features that are not supported by EPANET. Modifications should be made within the H20NET model to rectify these errors, and then the new file can be exported as an input file.

Note to LADWP:

Adjustments were made in the LADWP-Cornell model to eliminate approximately 400 negative pressure nodes. This was accomplished by decreasing the node elevations such that the nodal pressures were increased to 5psi. Most elevation adjustments were less than 10 ft. From a comparison standpoint, it is recommended you make these adjustments for consistency between models. After performing a simulation within H20Net, look at the output pressures for all nodes, and copy all negative pressure nodes into excel (copy NodeID, Output Elevation, Output Grade and Output Pressure for each). For each negative pressure node create a column called "New Elevation" and perform the following calculation to find what the new elevation would need to be to create a nodal pressure of 5psi:

Output Elevation (ft) – [5 – Ouptut Pressure (psi)] * 2.3067 ft/psi

Within the H20Net model, go to "Edit Database Tables" and replace node elevations with these new elevation values. Rerun the simulation and double check that there are no longer any negative pressure nodes.

Table A.0 lists modifications that were made to various control features that either contained typographical errors or were not compatible with EPANET. All pipe flows and node pressures were checked after these modifications and results were either identical to or within 1% of the original values.

Table A.0. Control Modifications

FCV

CC7090	Control
CC7110	
CC7210	
CC7380	
GH7250	
GH7310	
GH7320	
H6170	
HP6060	Control
MW6140	Control
SY6330	
VF6270	Control
VF6280	Control
VF6290	Control
VF6380	
VF6390	
VF6400	
VF6830	Control
VF6840	Control
VF6910	
VF6930	
VF6940	
VF6960	Control
VF6970	
WS6960	Control
WS7210	

TCV

CC6420	Curves	35	
CC7230			
CC7240	Control		
CC7290			
CC7300	Curves	10000	
CC7330	Curves	4.2209091	
CC7340	Curves	261.818	Disable Control
CC7350	Curves	10000	
GH7020			
GH7040			
GH7370			
HH6200			
HH6210			
HH6280	Curves	0.25	
MW6070	Curves	0.25	Setting 556
MW6410	Control+Curves	63.360108	
MW6420	Curves		0.25
MW6430	Curves	656.92	Setting 0
VF6580			
VF6730			
VF6850	Curves	888	Setting 0
VF7102			
VF7112			
VF7122			
VF7132			
WS7100	Curves	597.2	Setting 0
WS7120	Curves	0.25	
WS7150	Curves	597.2	Setting 0
WS7170	Curves	0.25	
WS7180	Curves	0.25	
WS7190	Curves	0.25	
WS7250	Curves	597.2	Setting 0
WS7260	Curves	597.2	Setting 0

Curves

VF101	delete last row
MW17	delete first row

Link

EH656	initial status
GH824	

Tanks

CC4220	Curves: starting from 0	
MW4100	Curves: starting from 0	
HP4030	Curves: starting from 0	
HP4060	Curves: starting from 0	

Fixed Head Reservoir

VF5690
VF4180
VF4010

Misc.

Remove Secondary demand pattern at HH775

Table A.1 EPANET Format File Exported from H2ONET

```
[TITLE]

[JUNCTIONS]
//ID     Elevation(ft)     Pattern//
3          100.000000
5          100.000000
9          100.000000
11         100.000000
13         100.000000
15         200.000000
17         100.000000
19         200.000000

[RESERVOIRS]
//ID          Head(ft)//
1          450.000000

[TANKS]
//ID      Elev(ft)      InitialLevel(ft)   MinLevel(ft)     MaxLevel(ft)     Dia.(ft)      MinVol(ft^3)   VolCurve//
7         450.000000   120.000000          0.000000          120.000000      30.000000     0.000000

[PIPES]
//ID   FromNode     ToNode    Length(ft)       Diameter(in)  Roughness         MinorLoss       CheckValve//
10         7            9       3048.00000       12.00000    100.000000        0.000000
12         9            11      3048.00000       12.00000    100.000000        0.000000
16         13           15      3048.00000       12.00000    100.000000        0.000000
18         13           17      3048.00000       12.00000    100.000000        0.000000
20         15           19      3048.00000       12.00000    100.000000        0.000000
22         17           19      3048.00000       12.00000    100.000000        0.000000
4          3            5       3048.00000       12.00000    100.000000        0.000000
6          3            9       3048.00000       12.00000    100.000000        0.000000
8          5            11      3048.00000       12.00000    100.000000        0.000000

[PUMPS]
//ID   FromNode       ToNode          Parameter(kw-hr)//
2              1            3         POWER 10.000000

[VALVES]
//ID     FromNode      ToNode       Diameter(in)     Type      Setting(psi)      MinorLoss//
14             9            13          4.000000      PRV      100.000000        0.000000

[DEMANDS]
//ID     Demand(gpm)//
3          100.000000
5          100.000000
9          100.000000
11         100.000000
13         100.000000
15         100.000000
17         100.000000
19         100.000000
```

Headline added by the author to help users understand the meaning of the parameters. Must not have headlines when loading the file into EPANET or analyzing it using GIRAFFE

Headline

Headline

Headline

Headline

Headline

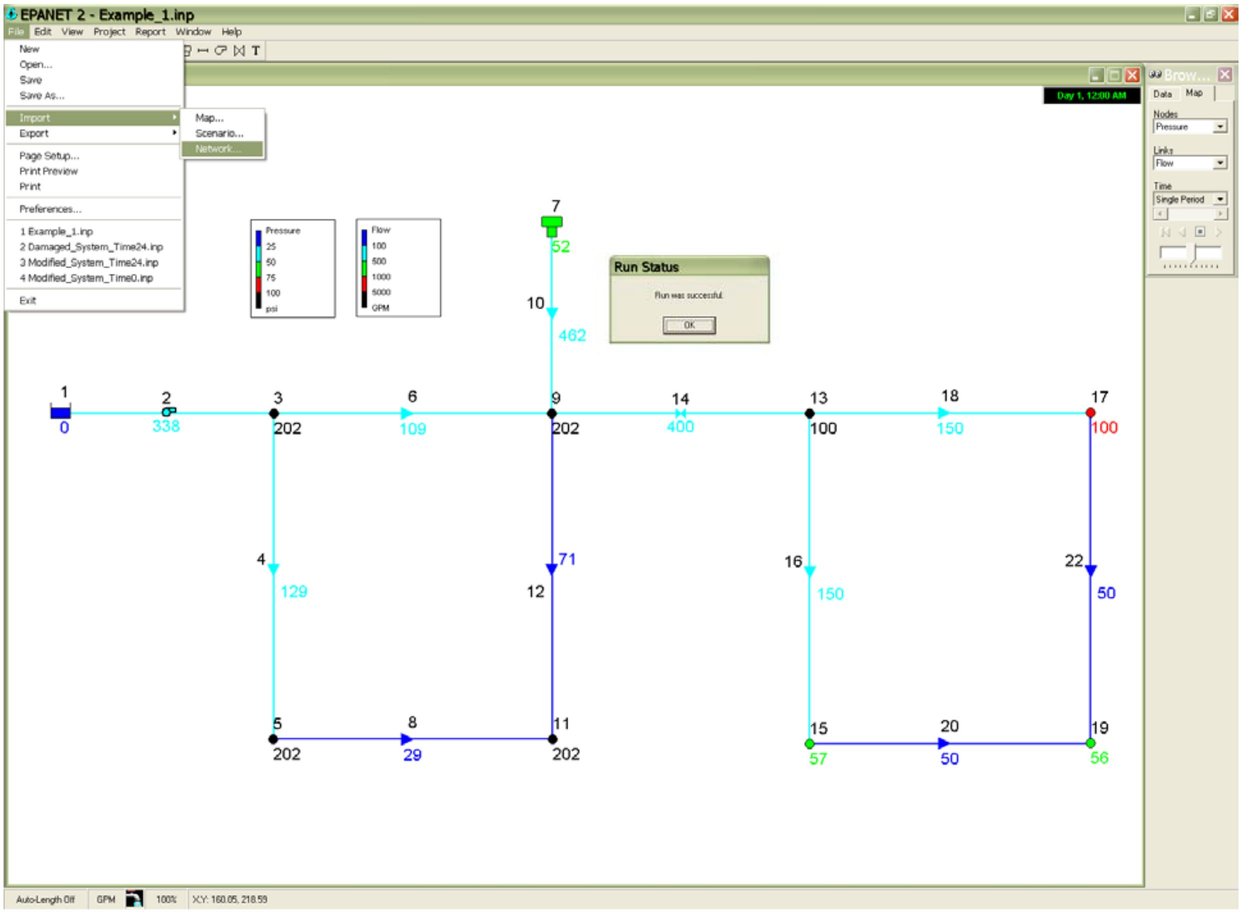
Headline

Table A.1 Continued

```
[CURVES]

[PATTERNS]
PATN1  1.000000         1.000000         1.000000         1.000000         1.000000         1.000000
PATN1  1.000000         1.000000         1.000000         1.000000         1.000000

[STATUS]

[CONTROLS]

[SOURCES]

[QUALITY]

[REACTIONS]
GLOBAL BULK 0.000000
GLOBAL WALL 0.000000

[ENERGY]

[OPTIONS]
UNITS GPM
HEADLOSS H-W
VISCOSITY 1.1e-005
DIFFUSIVITY 1.3e-008
SPECIFIC GRAVITY 1.000000
TRIALS 40
ACCURACY 0.001
DEMAND Multiplier 1.000000

[REPORT]
PAGESIZE 30
STATUS NO
NODE ALL
LINK ALL

[COORDINATES]
//ID          x(ft)          y(ft)//
1        140.726688      174.581772
3        169.667221      174.431972
5        169.576993      130.595466
7        207.220708      199.588372
9        207.220708      174.450158
11       207.252760      130.579090
13       241.998111      174.517132
15       241.998111      129.944774
17       280.016223      174.565669
19       280.016223      130.044299

[VERTICES]

[End]
```

Must use ALL

Headline



EPANET 2 - Example_1.inp

Run Status

Run was successful

Day 1, 12:00 AM

Nodes: Pressure

Links: Flow

Time: Single Period

Auto-Length Off | GPM | 100% | XY: 160.05, 218.59

Figure A.3 Loading EPANET File into EPANET

Step 3: Construct Pipe Damage Input File

For a deterministic simulation, users need to specify the location of each pipe break and leak, as well as the opening area of each leak. In this example, it is assumed that damage occurs in two pipes, 12 and 22, as illustrated in Figure A.4. One break occurs at point *D* in pipe 12. The location of the damage is defined by a length ratio, which is the ratio of the pipe length, measured from the pipe upstream node to the damage location, to the original pipe length. It is assumed that point *D* is at the middle of pipe 12, as such the length ratio for the break in pipe 12 is 0.5. Three locations of damage occurs in pipe 22: one break at point *A* with a length ratio of 0.3, one leak at point *B* with a length ratio of 0.6 and leak diameter of 2 inch, and one break at point *C* with a length ratio of 0.9.

The pipe damage input file is a text file, which can be constructed by entering the parameters by hand, by using the GIRAFFE GUI input window, or by opening a Manifold System project and selecting the desired pipes. The following section describes how to create the pipe damage input file using each of the three methods. If creating the file by hand, users can use Microsoft Word, Excel, or Notepad to construct the file and save it as a tab-delimited text file with the extension *.inp*. Users may also create a pipe damage file via the GIRAFFE GUI input window for a deterministic simulation. All three methods for creating the file are discussed in this section. In this example, the pipe damage input file is saved as *Pipe_damage.inp*, which is shown in Table A.2. The input file consists of two blocks with one storing pipe break information and the other storing pipe leak information.

Constructing Pipe Damage File using Microsoft Word, Excel or Notepad

The block storing pipe break information starts with the line [Pipe_Break_Information]. Users need to copy this exact line into their input file and not leave any space before [Pipe_Break_Information], otherwise the program will not run correctly. The second line is a headline describing the type of values in each column in the pipe break records that follow. It is recommended that users copy the headline into their input file. The headline terms in the pipe break records are explained in Table A.3. Following the headline and a blank line are the three records for the breaks at points A and C in pipe 22, and the break at point D in pipe 12, respectively.

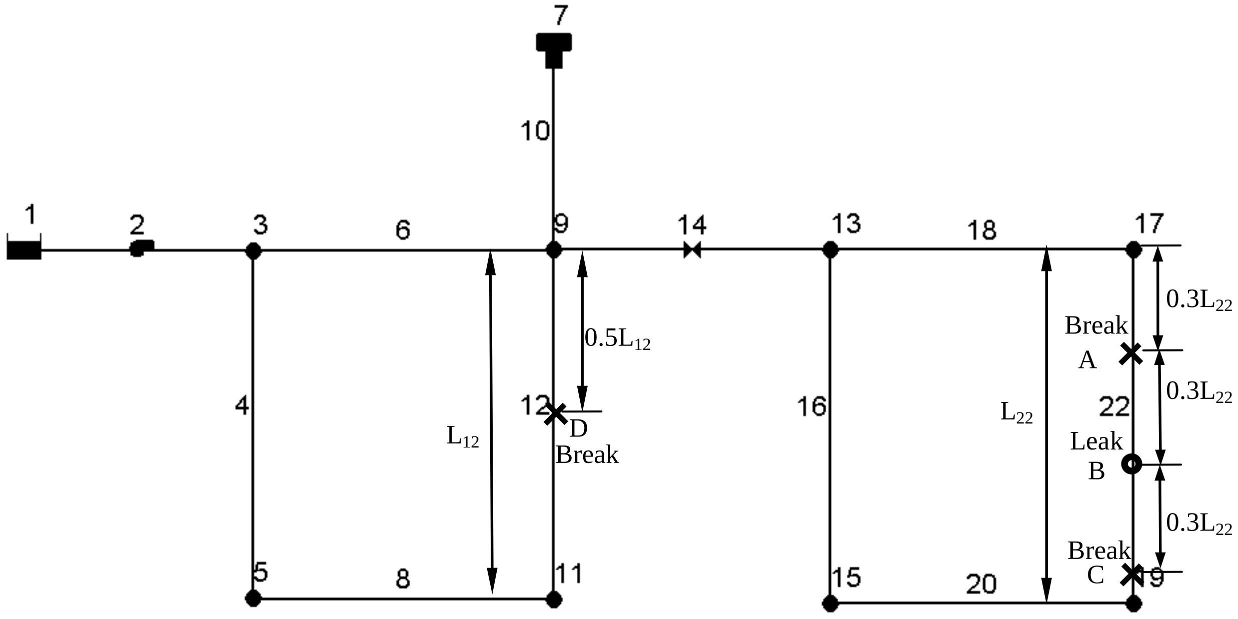


Figure A.4 Illustration for Pipe Damage

Table A.2 Pipe Damage Input File for Deterministic Simulation

```
[Pipe_Break_Information]
PipeID     PreRatio     BreakRatio     RepairNo     BreakNo     LeakNo     PreIndex

22         0            0.3            3            1           0          0
22         0.6          0.9            3            2           1          0
12         0            0.5            1            1           0          0


[Pipe_Leak_Information]
PipeID     LeakD     PreRatio     LeakRatio     RepairNo     BreakNo     LeakNo     PreIndex

22         2         0.3          0.6           3            1           1          1
```

The block storing pipe leak information starts with the line [Pipe_Leak_Information]. Users need to copy this exact line into their input file and not leave any space before [Pipe_Leak_Information], otherwise the program will not run correctly. The next line is a headline describing the type of values in each column in the pipe leak records that follow. It is recommended that users copy the headline into their input file. The headline terms in the pipe leak records are explained in Table A.4. Following the headline and a blank line is the record for the leak at point B in pipe 22.

Table A.3 Description of Columns in Pipe Break Section

Name	Type	Explanation
PipeID	char	The ID of the pipe which users want to break.
PreRatio	float	The length ratio of the previous location of pipe damage, either break or leak, in the same pipeline. If the current break is the first location of damage in the pipeline, then the PreRatio is set to 0.
BreakRatio	float	The length ratio of the location of the current pipe break.
RepairNo	int	The total number of locations of pipe damage, including breaks and leaks, in the pipeline. For example, there are three locations of damage in pipe 22, including two breaks and one leak. As such, the RepairNo is 3 for all the records associated with pipe 22. There is one location of damage, which is a break, in pipe 12. As such, the RepairNo is 1 for the break record associated with pipe 12.
BreakNo	int	The number of locations of breaks in the upstream of the current location of pipe break in the same pipeline. The current location of pipe break is counted. For example, for the first pipe break record, which is for the break at point A in pipe 22, the BreakNo is 1 because it is the first break in pipe 22. For the second pipe break record, which is for the break at point C in pipe 22, the BreakNo is 2 because it is the second break in pipe 22.
LeakNo	int	The number of locations of leaks in the upstream of the current location of pipe break in the same pipeline. For example, for the first pipe break record, which is for the break at point A in pipe 22, the LeakNo is 0 because there is no leak upstream of point A in pipe 22. For the second pipe break record, which is for the break at point C in pipe 22, the LeakNo is 1 because there is 1 leak at point B, which is located upstream of point C in pipe 22.
PreIndex	int	The type of the previous location of pipe damage immediately upstream

		of the current break in the same pipeline: 0 for leak and 1 for break. If the current break is the first location of pipe damage in the pipeline. The PreIndex is set to 0.

Table A.4 Description of Columns in Pipe Leak Section

Name	Type	Explanation
PipeID	char	The ID of the pipe which users want to add the leak. Maximum length 30 characters
LeakD	float	Equivalent orifice diameter of the leak in inches.
PreRatio	float	The length ratio of the previous location of pipe damage, either break or leak, in the same pipeline. If the current leak is the first location of damage in the pipeline, then the PreRatio is set to 0.
LeakRatio	float	The length ratio of the location of the current leak.
RepairNo	int	The total number of locations of pipe damage, including breaks and leaks, in the pipeline.
BreakNo	int	The number of locations of breaks in the upstream of the current location of pipe leak in the same pipeline. For example, for the leak record in Table A.2, which is for the leak at point B in pipe 22, the BreakNo is 1 because there is one break at point A, which is located in the upstream of point B in pipe 22.
LeakNo	int	The number of locations of leaks in the upstream of the current location of pipe leak in the same pipeline. The current location of pipe leak is counted. For example, for the leak record in Table A.2, which is for the leak at point B in pipe 22, the LeakNo is 1 because it is the first leak in pipe 22.
PreIndex	int	The type of the previous location of pipe damage immediately upstream of the current leak in the same pipeline: 0 for leak and 1 for break. If the current leak is the first location of pipe damage in the pipeline. The Preindex is set to 0.

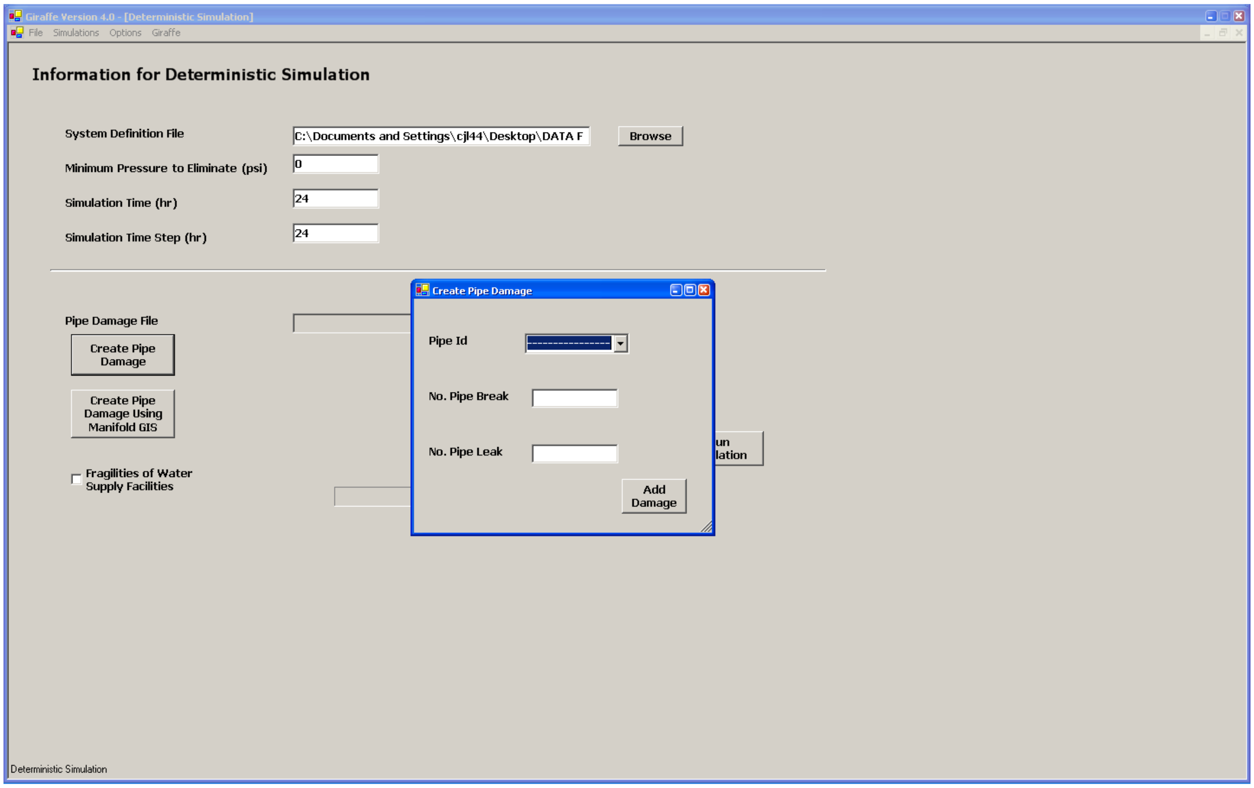
Constructing a Pipe Damage File using GIRAFFE GUI

Users can be guided through the creation of a pipe damage file by the GIRAFFE GUI. To create pipe damage in GIRAFFE, select “Deterministic” from the screen that appears when GIRAFFE is first opened, or go to Simulations | Deterministic in the main GIRAFFE toolbar. There are two alternatives for creating pipe damage in the deterministic GUI: using only GIRAFFE to assign damage based on pipe IDs (“Create Pipe Damage”) or using Manifold System to spatially assign damage (“Create Pipe Damage Using Manifold GIS”). Both of these methods will be discussed in this section.

The first method, which only uses GIRAFFE to assign damage, is shown in Figure A.5. After loading the system definition file (in this case, *Example1.inp*) and clicking on the “Create Pipe Damage” button in the deterministic GUI, a pop-up window appears so that the user can select a pipe from a drop down menu and enter the number of breaks and leaks associated with that pipe. To create the same example pipe damage file used previously in this section, the user should select Pipe ID 22 from the drop down menu. There are 2 breaks and 1 leak associated with this pipe, so the user should enter 2 for “No. of Pipe Breaks” and 1 for “No. of Pipe Leaks” and then click the “Add Damage” button. Figure A.6 shows the “Pipe Details” window that opens, prompting the user to enter in the break ratio for the first pipe break. After entering 0.3 for the break ratio and selecting the “Save” button, the user is prompted to enter the break ratio for the second pipe break. The user should enter 0.9 for the second break ratio and hit “Save”.

The next prompt, shown in Figure A.7, asks the user to enter the leak ratio and leak diameter, in inches, for the pipe leak associated with pipe 22. Entering the values and hitting “Save” will take the user back to the original “Create Pipe Damage” window (shown in Figure A.5) where another pipe ID can be selected to repeat the process and add additional damage to the system. Once all pipe breaks and leaks have been entered, the user simply closes the “Create Pipe Damage” window by clicking on the X at the top of the window The pipe damage file is automatically saved as *Pipe_Damage_temp.inp* in the GIRAFFE program folder once the

"Create Pipe Damage" window is closed. The newly created pipe damage file automatically populates the "Pipe Damage File" box in the GIRAFFE GUI. This file can be used to view the breaks and leaks entered via the GUI, but any changes to this text file will not be recognized by the GIRAFFE engine when it performs the simulation because the *Pipe_Damage_temp.inp* file is only a temporary file for viewing. If changes need to be made to values already entered, the user must re-enter all of the pipe breaks and leaks via the GUI. (To avoid repeating the entire GUI process when an entry mistake has occurred, the user may copy, rename and alter the *Pipe_Damage_temp.inp* file and then select this new file from the "Browse" button by the "Pipe Damage File" input box.)


Giraffe Version 4.0 - [Deterministic Simulation]

Information for Deterministic Simulation

System Definition File: C:\Documents and Settings\cjl44\Desktop\DATA F

Minimum Pressure to Eliminate (psi): 0

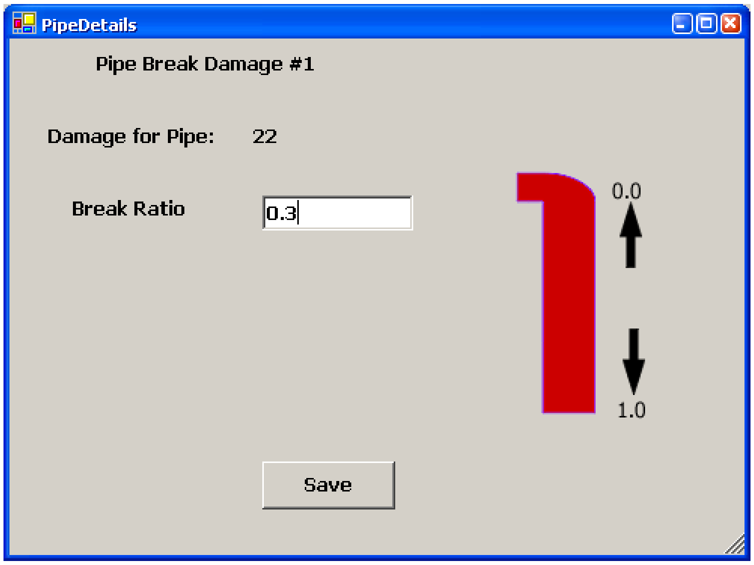
Simulation Time (hr): 24

Simulation Time Step (hr): 24

Pipe Id: ---------------

Deterministic Simulation

Figure A.5 Creating a Pipe Damage File via the GIRAFFE GUI – Entering the number of pipe breaks and leaks associated with a Pipe ID

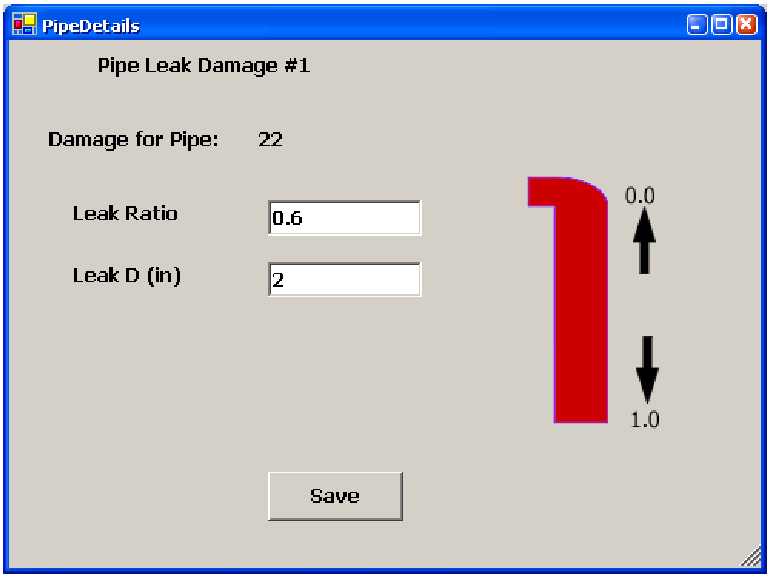

PipeDetails

Pipe Break Damage #1

Damage for Pipe: 22

Break Ratio: 0.3

Figure A.6 Creating a Pipe Damage File via the GIRAFFE GUI – Entering the break ratio associated with each pipe break


PipeDetails

Pipe Leak Damage #1

Damage for Pipe: 22

Leak Ratio: 0.6

Leak D (in): 2

Figure A.7 Creating a Pipe Damage File via the GIRAFFE GUI – Entering the leak ratio and leak diameter associated with each pipe leak

The second method for assigning pipe damage uses the Manifold System application (Figure A.8). Note that this example uses the entire LADWP water distribution system rather than the small system example. This tool will open a Manifold project and allow the user to select the pipes from a spatial representation of the pipe network. However, before clicking the “Create Pipe Damage Using Manifold GIS”, the user must first add the tool to Manifold’s custom controls. To do this, go to the **Manifold Tools** folder in the GIRAFFE program folder and copy the contents of the folder (two folders, **LADWP** and **Damage**, and an *.xml* file). Then paste the files in the **Config** folder hierarchy for Manifold (normally **C:\Program Files\Manifold System\Config**).

After clicking on the "Create Pipe Damage Using Manifold GIS" button in the deterministic GUI, a pop-up window appears asking the user to select a saved Manifold project (in this example, *Deterministic_damage.map*) as shown in Figure A.9. After pressing OK, the project will open and the pipes can be selected (Figure A.10). The saved project should contain a shapefile representing all pipes in the system (*epa_pipes.shp*). It is also helpful to create ID labels for the pipes and overlay them in a map as was done in the example map (right-click in the Project pane and select Create | Labels). A sample Manifold project (*Deterministic_damage.map*) has been included in the GIRAFFE program file in the folder **Example_Files | Appendix A**, which includes the required files in the appropriate format. Before running the tool in Manifold, the user should select the desired pipes, either specific pipes or a large section of pipes. Note that the layer in which the pipes are being selected must be named *Epa_pipes* and it must contain a column called **[ID 2]**, which contains the unique identification numbers for each pipe in the system (see Figure C.2). After the pipes have been selected, click on the pipe damage tool in the toolbar. If the toolbar is not visible, go to **Tools | Add-Ins | Add-In Manager** and check the box next to "Create Pipe Damage." Restart Manifold as directed.

Clicking the Create Pipe Damage tool will cause a pop-up window to appear, which asks for the output file location (Figure A.11). The next window asks for the type and amount of damage to each of the selected pipes (Figure A.12). After these data have been entered, the window then asks for the break ratio or leak ratio and leak diameter for each incidence of damage (Figures A.13(a) and (b)). When the last incidence of damage has been added, a pop-up window will identify the output location specified in the beginning of the process and then Manifold will close automatically. The pipe damage file automatically populates the "Pipe Damage File" box in the GIRAFFE GUI.

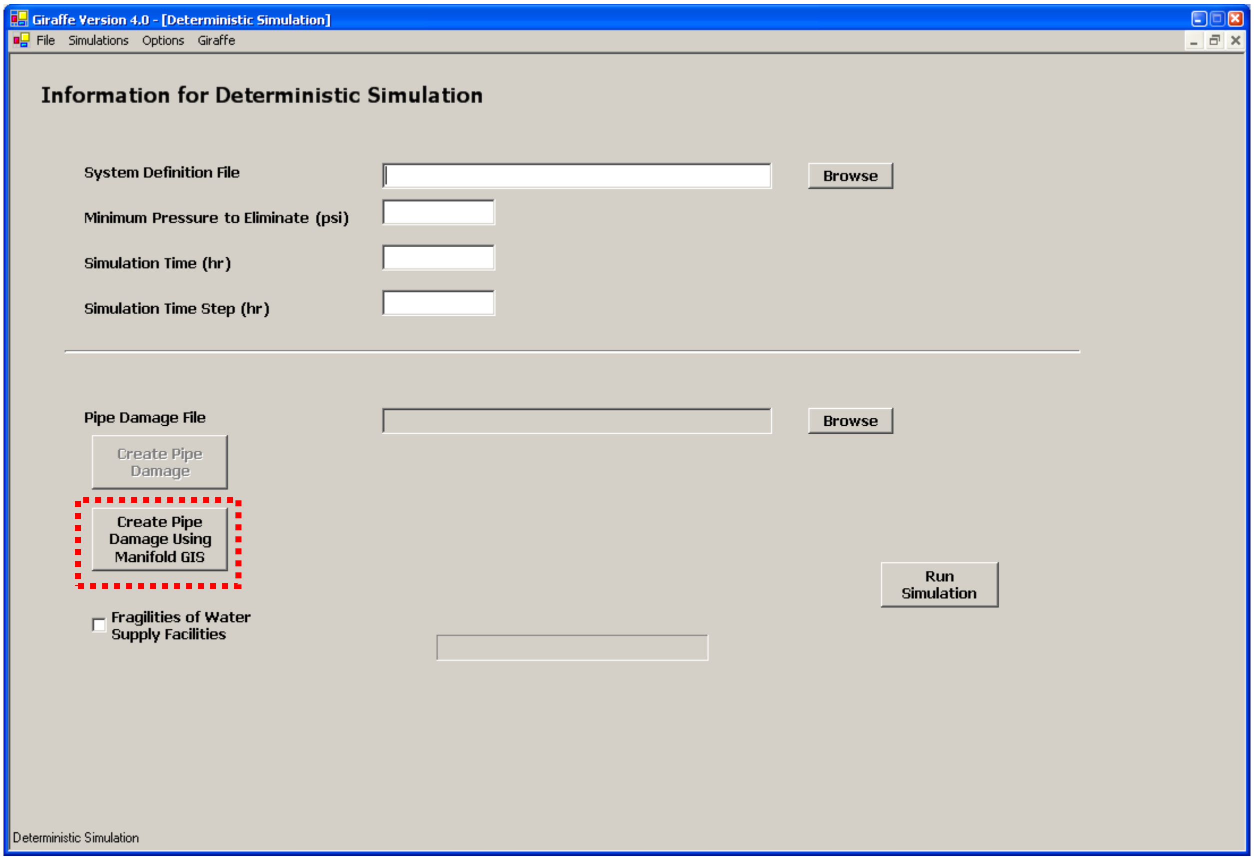
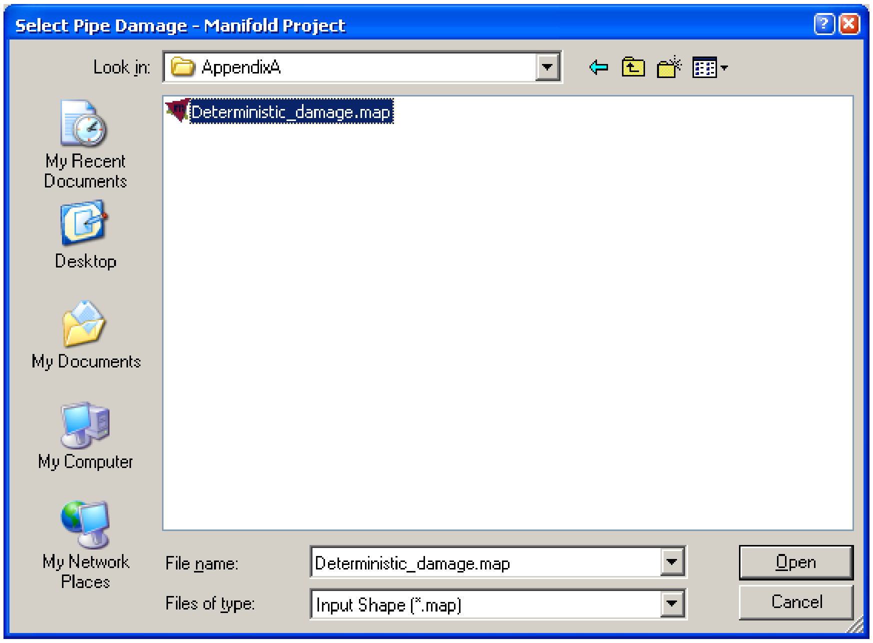


Figure A.8. Creating a Pipe Damage File via the GIRAFFE-Manifold GUI



Look in: AppendixA

File name: Deterministic_damage.map

Files of type: Input Shape (*.map)

Figure A.9. Creating a Pipe Damage File via the GIRAFFE-Manifold GUI – Selecting the Manifold Project.

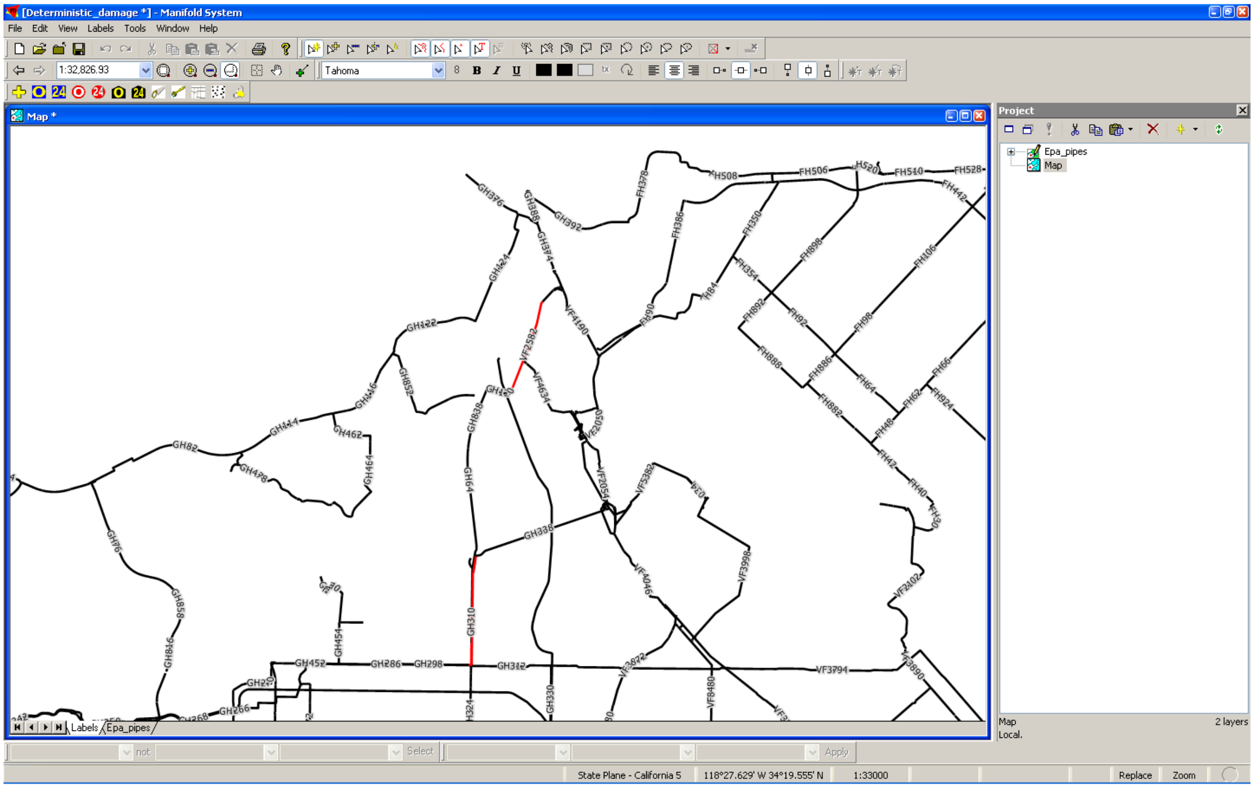


Figure A.10 Creating a Pipe Damage File via the GIRAFFE-Manifold GUI – Selecting the Pipes.

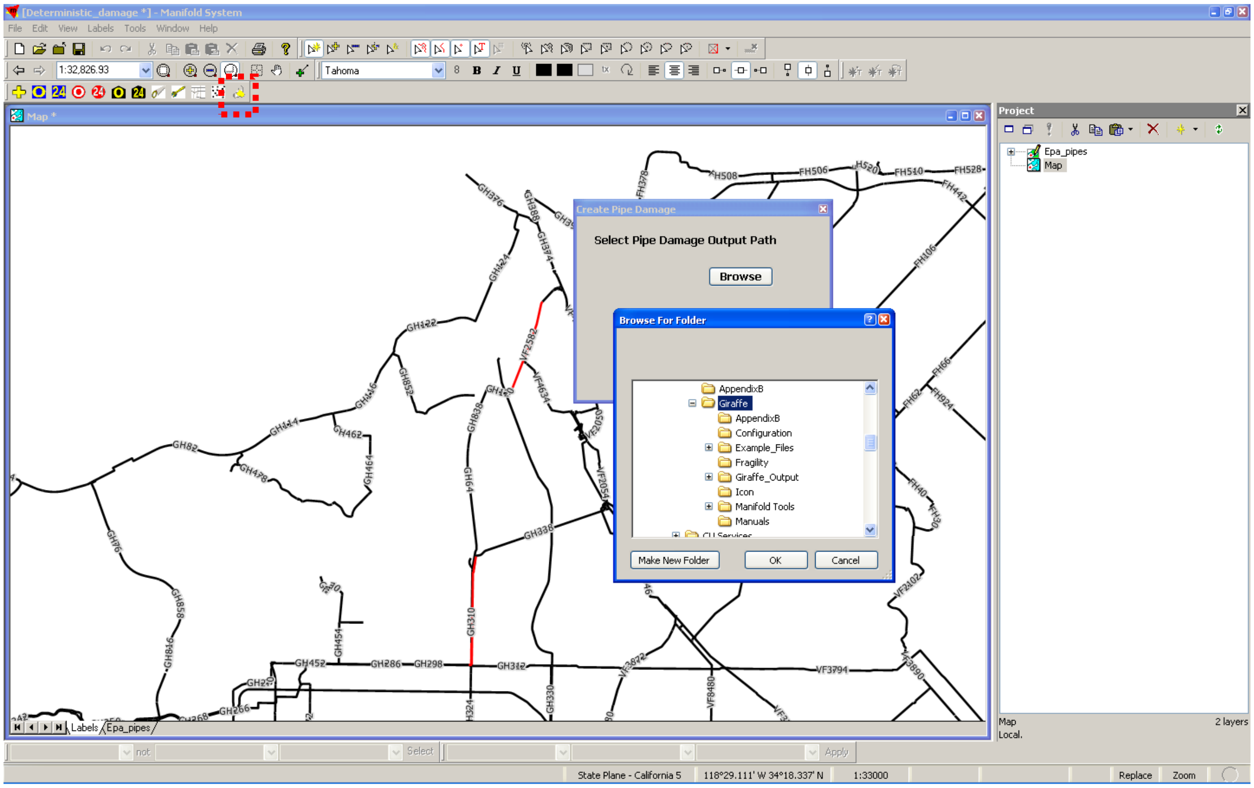
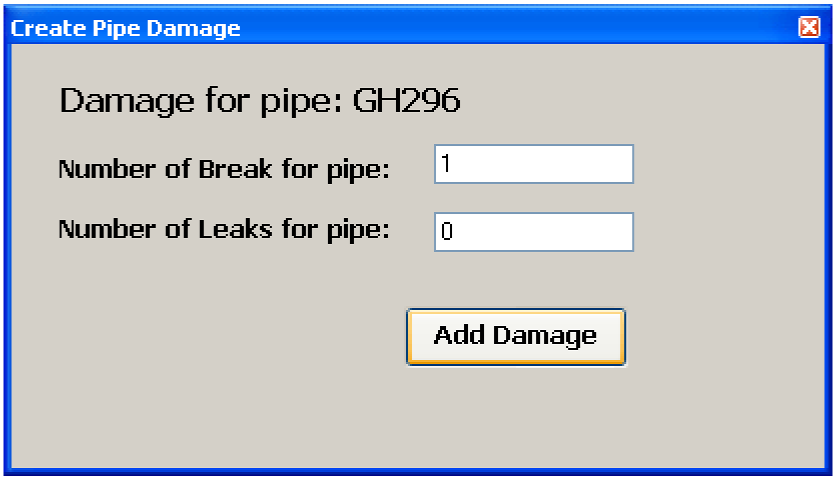


Figure A.11 Creating a Pipe Damage File via the GIRAFFE-Manifold GUI – Using the Pipe Damage Tool and Selecting the Output File Location.

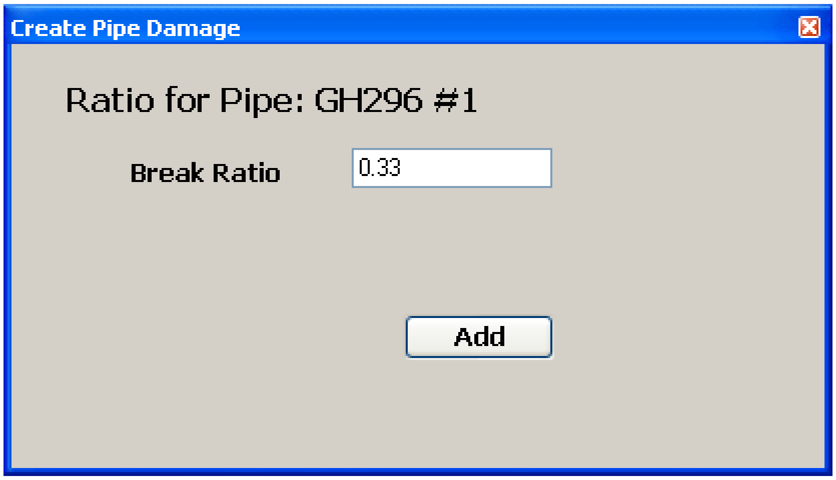


Damage for pipe: GH296

Number of Break for pipe: 1

Number of Leaks for pipe: 0

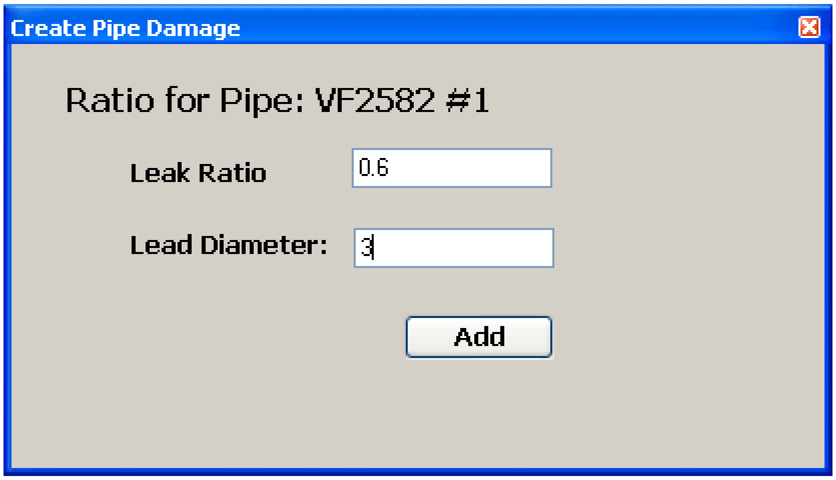
Figure A.12 Creating a Pipe Damage File via the GIRAFFE-Manifold GUI – Assigning Damage to Selected Pipes.



Ratio for Pipe: GH296 #1

Break Ratio 0.33

Figure A.13(a) Creating a Pipe Damage File via the GIRAFFE-Manifold GUI – Specifying Amount of Damage to Selected Pipes.



Ratio for Pipe: VF2582 #1

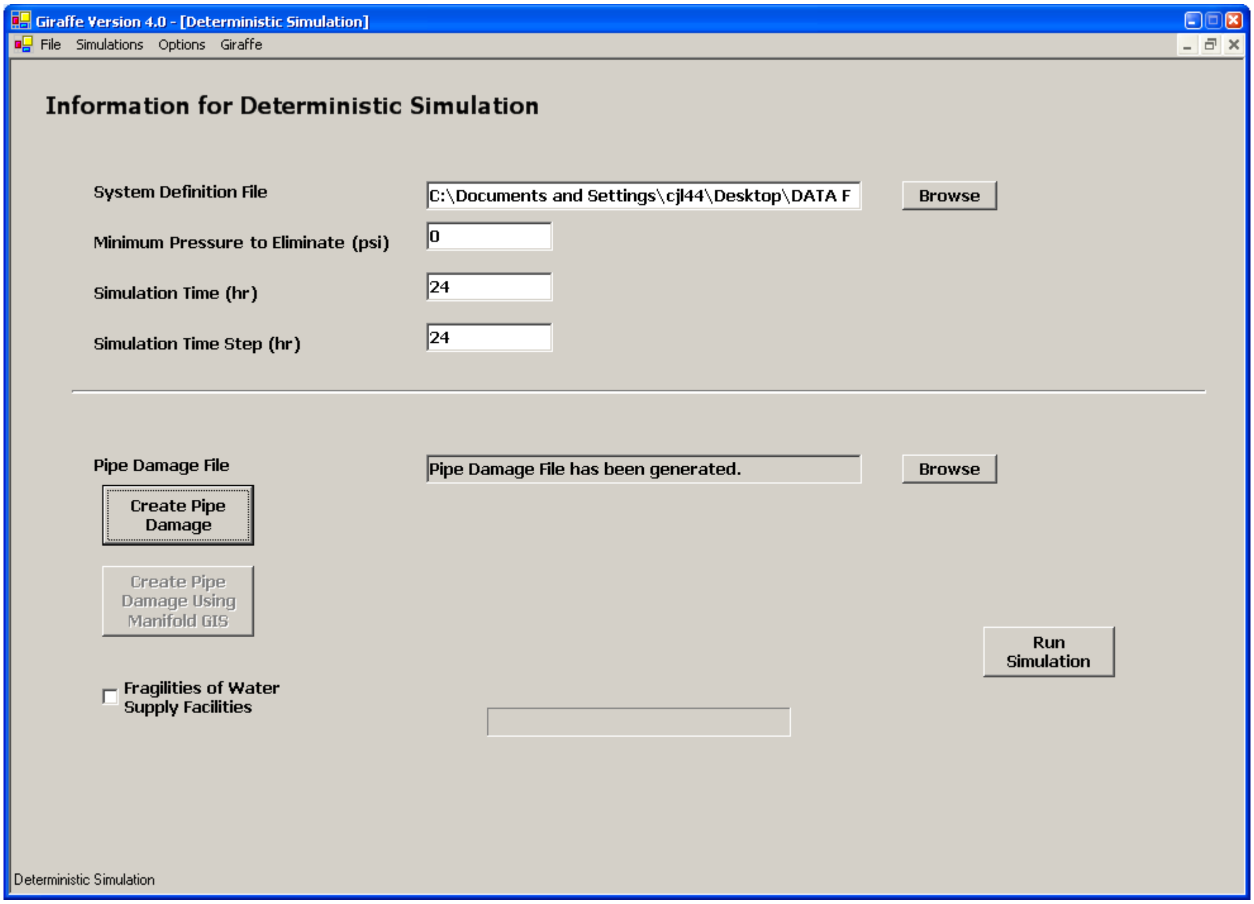
Leak Ratio: 0.6

Lead Diameter: 3

Figure A.13(b) Creating a Pipe Damage File via the GIRAFFE-Manifold GUI – Specifying Amount of Damage to Selected Pipes.

Step 4: Input Parameters in GIRAFFE GUI Window

Figure A.14 shows the GUI window with the required inputs for a deterministic simulation. The meaning of each entry for a deterministic simulation is explained in Table A.5.



Information for Deterministic Simulation

System Definition File: C:\Documents and Settings\cjl44\Desktop\DATA F

Minimum Pressure to Eliminate (psi): 0

Simulation Time (hr): 24

Simulation Time Step (hr): 24

Pipe Damage File: Pipe Damage File has been generated.

☐ Fragilities of Water Supply Facilities

Figure A.14 GUI Window with Inputs for Deterministic Simulation

Table A.5 GIRAFFE Input Parameters for Deterministic Simulation

Name	Description
System Definition File	Name of the EPANET system definition file with the extension of *.inp, .txt or .dat.*. File name may have a maximum length of 80 characters.
Minimum Pressure to Eliminate	Pressure limit, in psi, below which GIRAFFE eliminates the node and connected links from the system. Typically 0 for negative pressure elimination.
Simulation Time	Total length of simulation time in hours to update tank water levels. 0 for steady state simulation.
Simulation Time Step	The time step in hours to update tank water levels. 1 for steady state simulation.
Pipe Damage File	Name of input file for pipe damage generation. The file name may have a maximum length of 80 characters.

Step 5: Perform Simulation

After GIRAFFE receives the inputs, it performs the deterministic simulation according to the following procedures:

1) Damage the network and output the damaged system, *Damage_System_Time0.inp*.
2) Apply the EPANET engine to perform hydraulic network analysis to the damaged system and an iterative approach to eliminate negative pressures. The elimination process continues until no negative pressures exist in the network.
3) Output the system definition file, *Modified_System_Time0.inp,* and report the results of each type of physical component in the files, *JunctionResults_Time0.out*, *TankResults_Time0.out*, *PipeResults_Time0.out*, *PumpResults_Time0.out,* and *ValveResults_Time0.out*.

4) Calculate the system serviceability at time 0 and report the system serviceability in the file, *Serviceability0.out*.
5) Read the *TankResults_Time0.out*, determine the outflow of each tank, and update the tank water levels according to the initial tank water levels, tank cross-sectional areas, tank outflows, and the time step. In this example, GIRAFFE updates the water level of tank with ID 7 once after 24 hours of tank running.
6) Output the damaged system, *Damage_System_Time24.inp*.
7) Apply the EPANET engine to perform hydraulic network analysis to the system with tank water level updated, and the iterative approach to eliminate negative pressures. The elimination process continues until no negative pressures exist in the network.
8) Output the system definition file, *Modified_System_Time24.inp*, and report the hydraulic simulation results of each type of physical component in the files, *JunctionResults_Time24.out*, *TankResults_Time24.out*, *PipeResults_Time24.out*, *PumpResults_Time24.out*, and *ValveResults_Time24.out*.
9) Calculate the system serviceability at time 24 and report the system serviceability in the file, *Serviceability24.out*.

Step 6: View Simulation Results

After the GIRAFFE simulation, the result files can be viewed and checked. The simulation results are saved in the **Giraffe_Output** folder which is located in the same location as the GIRAFFE application.

- **View damaged system at time 0**. The damaged system is saved in the file, *Damage_System_Time0.inp*, as shown for the small system example in Table A.6. The added components associated with pipeline damage are described in red text boxes. The *Damage_System_Time0.inp* can be loaded into EPANET and can be visualized using the EPANET GUI, as shown in Figure A.15. Users need to check if GIRAFFE adds the pipeline damage correctly.

- **View simulation results at time 0.** The hydraulic simulation results associated with each type of component including junctions, tanks, pipes, pumps, and valves, are shown in Tables A.7 to A.11. The system serviceability at time 0 is shown in Table A.12. The simulation results can be visualized using the EPANET GUI as shown in Figure A.16 by loading the *Modified_System_Time0.inp* into EPANET and running the simulation.
- **View damaged system at time 24**. The damaged system at time 24 is saved in the file, *Damage_System_Time24.inp*, shown in Table A.13. The *Damage_System_Time24.inp* can be loaded into EPANET to be visualized as shown in Figure A.17.
- **View simulation results at time 24**. The hydraulic simulation results associated with each type of component, including junctions, tanks, pipes, pumps, and valves, are shown in Tables A.14 to A.18. The system serviceability at time 24 is shown in Table A.19. The simulation results can be visualized using the EPANET GUI as shown in Figure A.18 by loading the *Modified_System_Time24.inp* into EPANET and running the simulation.

Table A.6 Damaged System at Time 0

```
[TITLE]

[JUNCTIONS]
A1J22   160
3       100.000000
5       100.000000
9       100.000000
11      100.000000
13      100.000000
15      200.000000
17      100.000000
19      200.000000

[RESERVOIRS]
A1R22   130
A2R22   130
A4R22   190
A5R22   190
A1R12   100
A2R12   100
A3R22   160
1       450.000000

[TANKS]
7       450.000000      120.000000      0.000000        120.000000      30.000000       0.000000

[PIPES]
A1O22      17      A1R22     914.4           12              100             1               CV
A3O22      A1J22   A4R22     914.4           12              100             1
A4O22      19      A5R22     304.8           12              100             1               CV
A1O12       9      A1R12     1524            12              100             1               CV
A2O12      11      A2R12     1524            12              100             1               CV
A2O22      A1J22   A2R22     914.4           12              100             1               CV
A1L22      A1J22   A3R22     0.5             2               1e+006          1               CV
10         7       9         3048.00000      12.00000        100.000000      0.000000
16         13      15        3048.00000      12.00000        100.000000      0.000000
18         13      17        3048.00000      12.00000        100.000000      0.000000
20         15      19        3048.00000      12.00000        100.000000      0.000000
4          3       5         3048.00000      12.00000        100.000000      0.000000
6          3       9         3048.00000      12.00000        100.000000      0.000000
8          5       11        3048.00000      12.00000        100.000000      0.000000

[PUMPS]

2       1       3       POWER       10.000000

[VALVES]
14      9       13      4.000000        PRV     100.000000      0.000000
```

Added junction to model leak in pipe 22

Added empty reservoirs to model two breaks in pipe 22, 1 leak in pipe 22, and 1 break in pipe

Original pipe 22 is replaced with pipes A1O22, A2O22, A3O22, and A4O22. Original pipe 12 is replaced with pipes A1O12 and A2O12. One pipe A1L22 is added to model the leak occurred in pipe 22

Table A.6 Continued

```
[DEMANDS]
3           100.000000
5           100.000000
9           100.000000
11          100.000000
13          100.000000
15          100.000000
17          100.000000
19          100.000000

[CURVES]

[PATTERNS]
PATN1  1.000000        1.000000        1.000000        1.000000        1.000000        1.000000
PATN1  1.000000        1.000000        1.000000        1.000000        1.000000

[STATUS]
A3O22   Closed

[CONTROLS]

[SOURCES]

[QUALITY]

[REACTIONS]
GLOBAL BULK 0.000000
GLOBAL WALL 0.000000

[ENERGY]

[OPTIONS]
UNITS GPM
HEADLOSS H-W
VISCOSITY 1.1e-005
DIFFUSIVITY 1.3e-008
SPECIFIC GRAVITY 1.000000
TRIALS 40
ACCURACY 0.001
DEMAND Multiplier 1.00000011

[REPORT]
PAGESIZE 30
STATUS NO
NODE ALL
LINK ALL
```

Table A.6 Continued

```
[COORDINATES]
A1R22   284.468 163.435
A2R22   284.468 158.983
A4R22   284.468 136.723
A5R22   284.468 132.27
A1R12   211.622 154.711
A2R12   211.625 150.324
A1J22   280.016 147.853
A3R22   284.468 147.853
1          140.726688        174.581772
3          169.667221        174.431972
5          169.576993        130.595466
7          207.220708        199.588372
9          207.220708        174.450158
11         207.252760        130.579090
13         241.998111        174.517132
15         241.998111        129.944774
17         280.016223        174.565669
19         280.016223        130.044299
```

Added coordinates for new reservoirs and junctions

```
[VERTICES]
A1O22   280.016 163.435
A3O22   280.016 136.723
A4O22   280.016 132.27
A1O12   207.235 154.708
A2O12   207.238 150.321
A2O22   280.016 158.983

[End]
```

Added vertices for new pipes

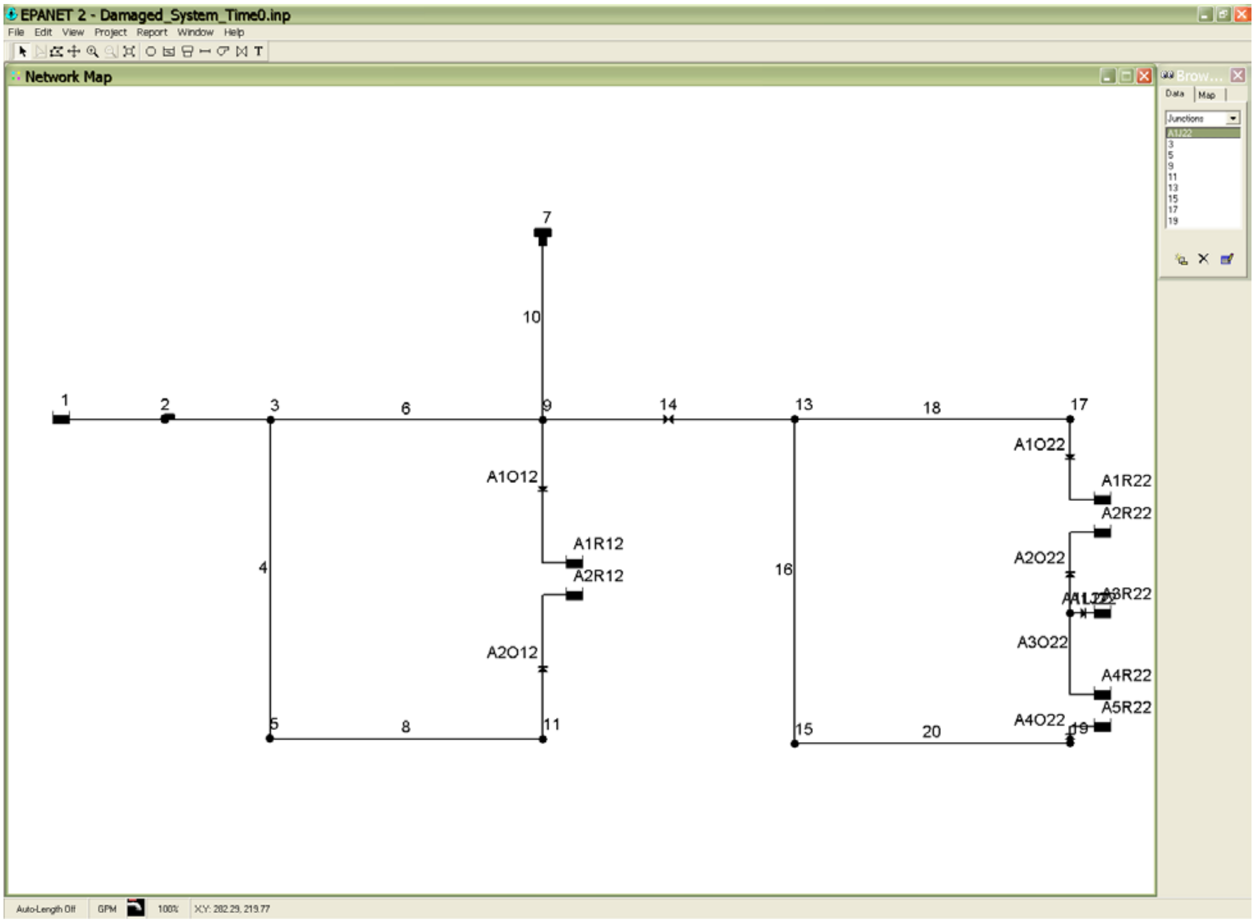


Figure A.15 Damaged System with Node and Link IDs at Time 0

Table A.7 Junction Results at Time 0

Node_ID	Demand_gpm	Head_ft	Pressure_psi
3	100	454.92	153.79
5	100	307.92	90.09
9	100	278.8	77.47
11	100	168.05	29.49
13	100	278.8	77.47
15	100	278.62	34.07
17	100	163.86	27.67
19	0	0	0

Table A.8 Tank Results at Time 0

Tank_ID	Demand_gpm	Head_ft	Pressure_psi
1	-8036.31	450	0
7	-5459.8	570	52

Table A.9 Pipe Results at Time 0

Pipe_ID	Flow_gpm	Velocity_fps	Headloss_/1000ft
10	5459.8	15.49	95.54
12	0	0	0
16	100	0.28	0.06
18	3305.09	9.38	37.71
20	0	0	0
22	0	0	0
4	3774.68	10.71	48.23
6	4161.63	11.81	57.78
8	3674.68	10.42	45.89

Table A.10 Pump Results at Time 0

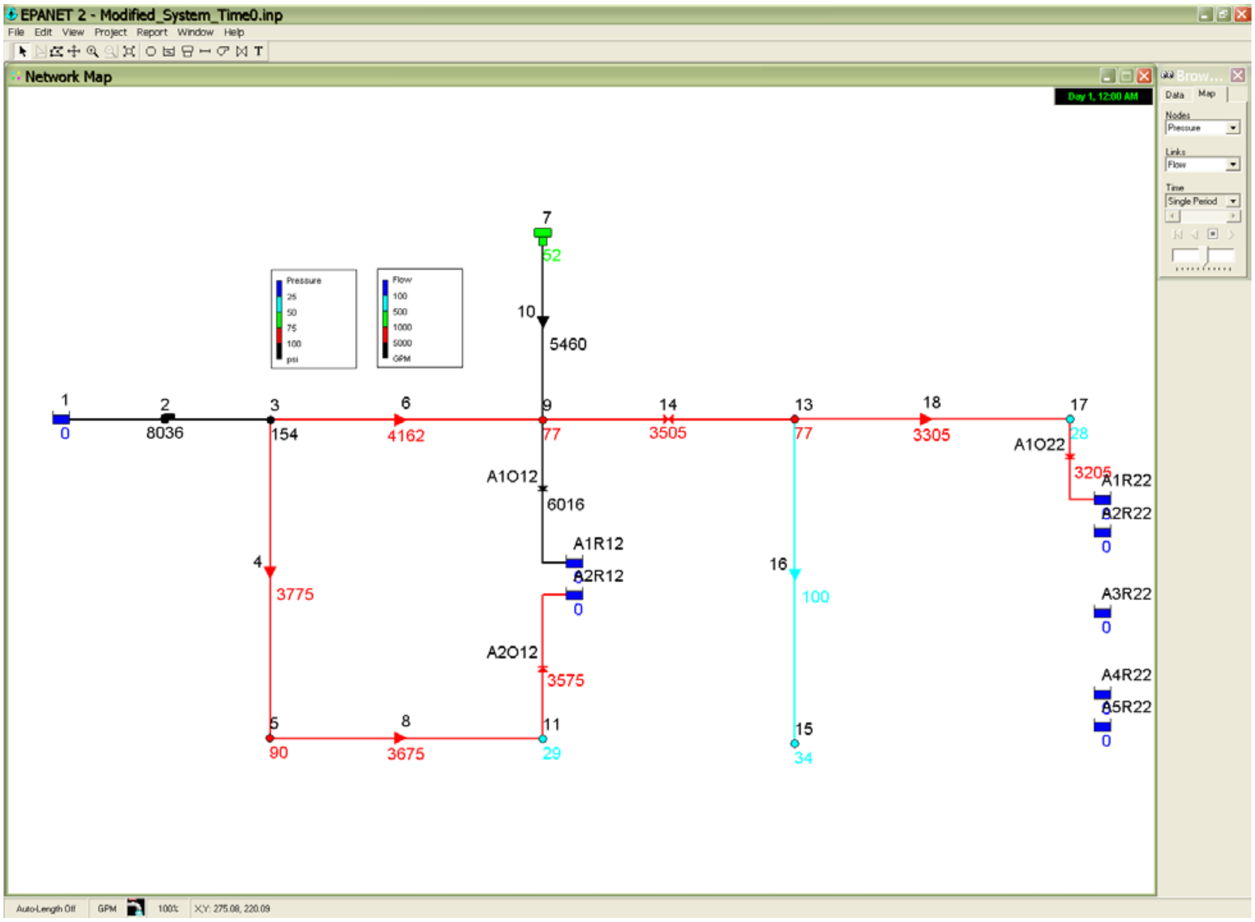
Pump_ID	Flow_gpm	Velocity_fps	Headloss_/1000ft
2	8036.31	0	-4.92

Table A.11 Valve Results at Time 0

Valve_ID	Flow_gpm	Velocity_fps	Headloss_/1000ft
14	3505.09	9.94	0

Table A.12 Serviceability at Time 0

Node_ID	Demand	1	Node_Serviceability
3	100	100	1
5	100	100	1
9	100	100	1
11	100	100	1
13	100	100	1
15	100	100	1
17	100	100	1
19	100	0	0
Sum		0.875	0.875



Nodes: Pressure

Links: Flow

Time: Single Period

Figure A.16 Simulation Results at Time 0

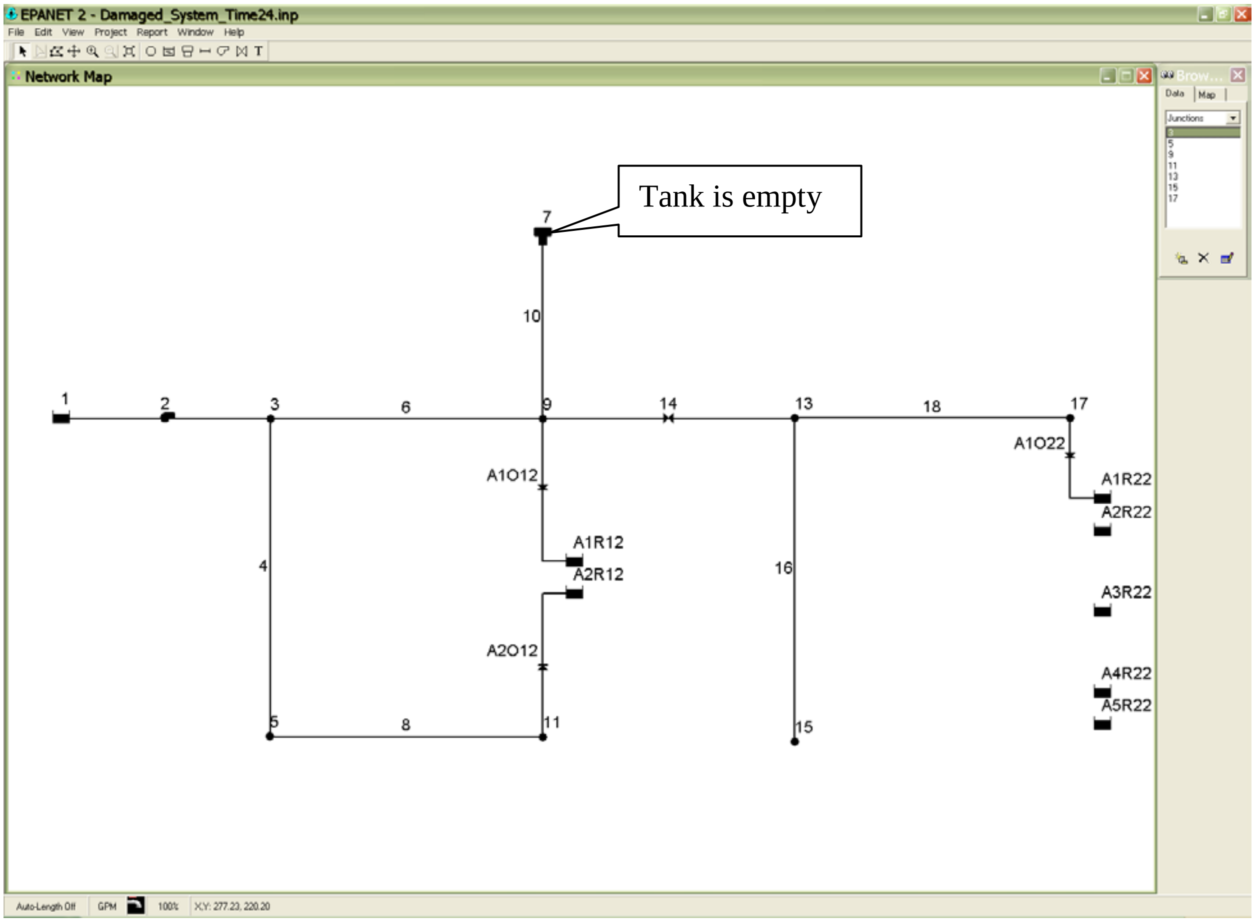
Table A.13 Damaged System at Time 24

```
[TITLE]

[JUNCTIONS]
3       100.000000
5       100.000000
9       100.000000
11      100.000000
13      100.000000
15      200.000000
17      100.000000

[RESERVOIRS]
A1R22   130
A2R22   130
A4R22   190
A5R22   190
A1R12   100
A2R12   100
A3R22   160
1       450.000000

[TANKS]
7           450         0           0           120         30          0

[PIPES]
A1O22   17      A1R22       914.4           12          100         1       CV
A1O12   9       A1R12       1524            12          100         1       CV
A2O12   11      A2R12       1524            12          100         1       CV
10      7       9           3048.00000      12.00000    100.000000  0.000000
16      13      15          3048.00000      12.00000    100.000000  0.000000
18      13      17          3048.00000      12.00000    100.000000  0.000000
4       3       5           3048.00000      12.00000    100.000000  0.000000
6       3       9           3048.00000      12.00000    100.000000  0.000000
8       5       11          3048.00000      12.00000    100.000000  0.000000

[PUMPS]
2       1       3       POWER 10.000000

[VALVES]
14      9       13      12.000000       PRV     100.000000      0.000000

[DEMANDS]
3       100.000000
5       100.000000
9       100.000000
11      100.000000
13      100.000000
15      100.000000
17      100.000000

[CURVES]
```

Tank water level is updated.
Tank is empty in this example.

Table A.13 Continued

```
[STATUS]

[CONTROLS]

[SOURCES]

[QUALITY]

[REACTIONS]
GLOBAL BULK 0.000000
GLOBAL WALL 0.000000

[ENERGY]

[OPTIONS]
UNITS GPM
HEADLOSS H-W
VISCOSITY 1.1e-005
DIFFUSIVITY 1.3e-008
SPECIFIC GRAVITY 1.000000
TRIALS 40
ACCURACY 0.001
DEMAND Multiplier 1.000000

[REPORT]
PAGESIZE 30
STATUS NO
NODE ALL
LINK ALL

[COORDINATES]
A1R22   284.468 163.435
A2R22   284.468 158.983
A4R22   284.468 136.723
A5R22   284.468 132.27
A1R12   211.622 154.711
A2R12   211.625 150.324
A3R22   284.468 147.853
1       140.726688      174.581772
3       169.667221      174.431972
5       169.576993      130.595466
7       207.220708      199.588372
9       207.220708      174.450158
11      207.252760      130.579090
13      241.998111      174.517132
15      241.998111      129.944774
17      280.016223      174.565669

[VERTICES]
A1O22   280.016 163.435
A1O12   207.235 154.708
A2O12   207.238 150.321

[End]
```



Tank is empty

Figure A.17 Damaged System at Time 24

Table A.14 Junction Results at Time 24

Node_ID	Demand_gpm	Head_ft	Pressure_psi
3	100	454.27	153.5
5	100	307.53	89.92
9	100	168.69	29.76
11	100	167.92	29.43
13	100	168.69	29.76
15	0	0	0
17	100	138.36	16.62
19	0	0	0

Table A.15 Tank Results at Time 24

Tank_ID	Demand_gpm	Head_ft	Pressure_psi
1	-9273.55	450	0
7	0	450	0

Table A.16 Pipe Results at Time 24

Pipe_ID	Flow_gpm	Velocity_fps	Headloss_/1000ft
10	0	0	0
12	0	0	0
16	0	0	0
18	1609.71	4.57	9.95
20	0	0	0
22	0	0	0
4	3770.99	10.7	48.14
6	5402.57	15.33	93.69
8	3670.99	10.41	45.8

Table A.17 Pump Results at Time 24

Pump_ID	Flow_gpm	Velocity_fps	Headloss_/1000ft
2	9273.55	0	-4.27

Table A.18 Valve Results at Time 24

Valve_ID	Flow_gpm	Velocity_fps	Headloss_/1000ft
14	1709.71	4.85	0

Table A.19 Serviceability at Time 24

Node_ID	Demand	1	Node_Serviceability
3	100	100	1
5	100	100	1
9	100	100	1
11	100	100	1
13	100	100	1
15	100	0	0
17	100	100	1
19	100	0	0
Sum		0.75	0.75

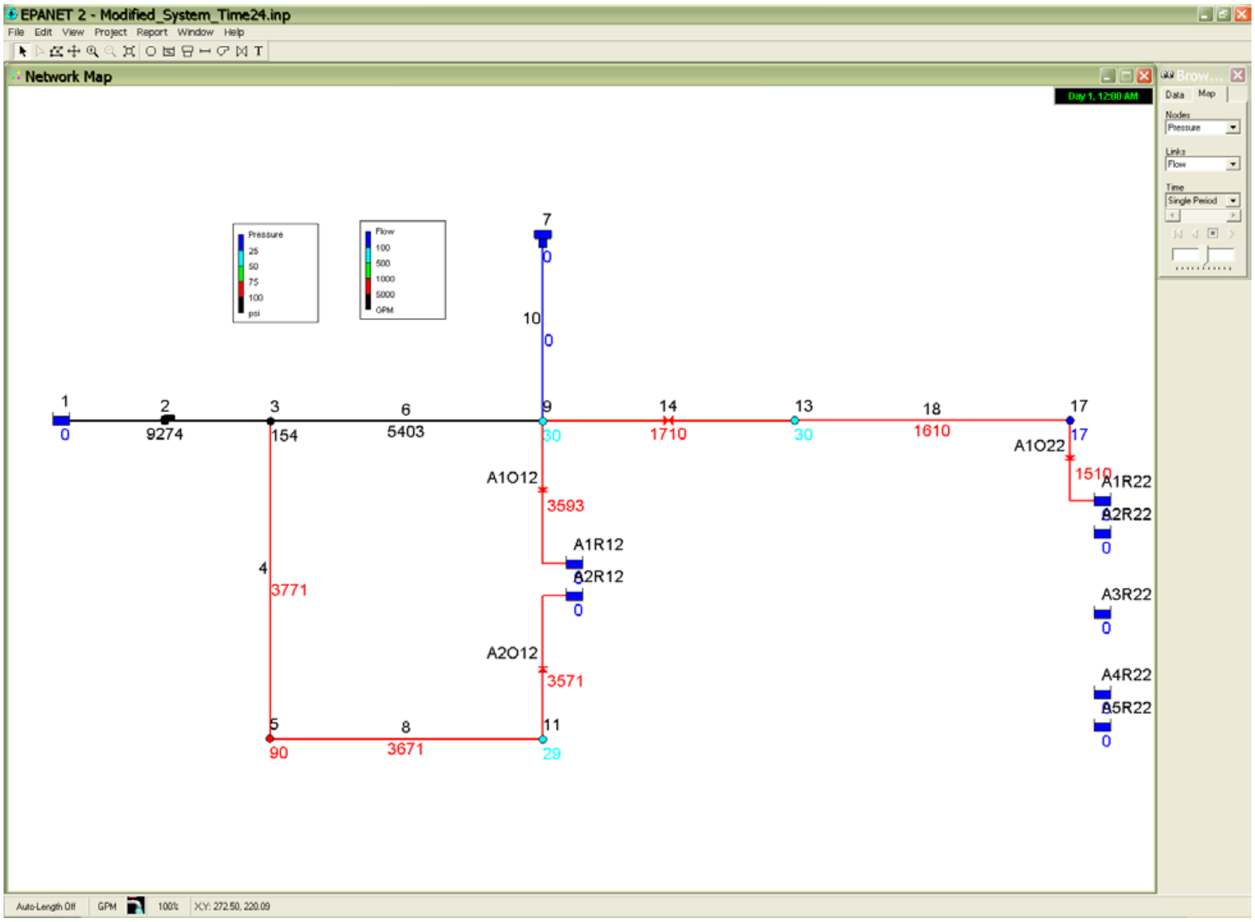


Figure A.18 Simulation Results at Time 24

A.5 MONTE CARLO WITH FIXED SIMULATION RUNS

Step 1: Export EPANET Format File

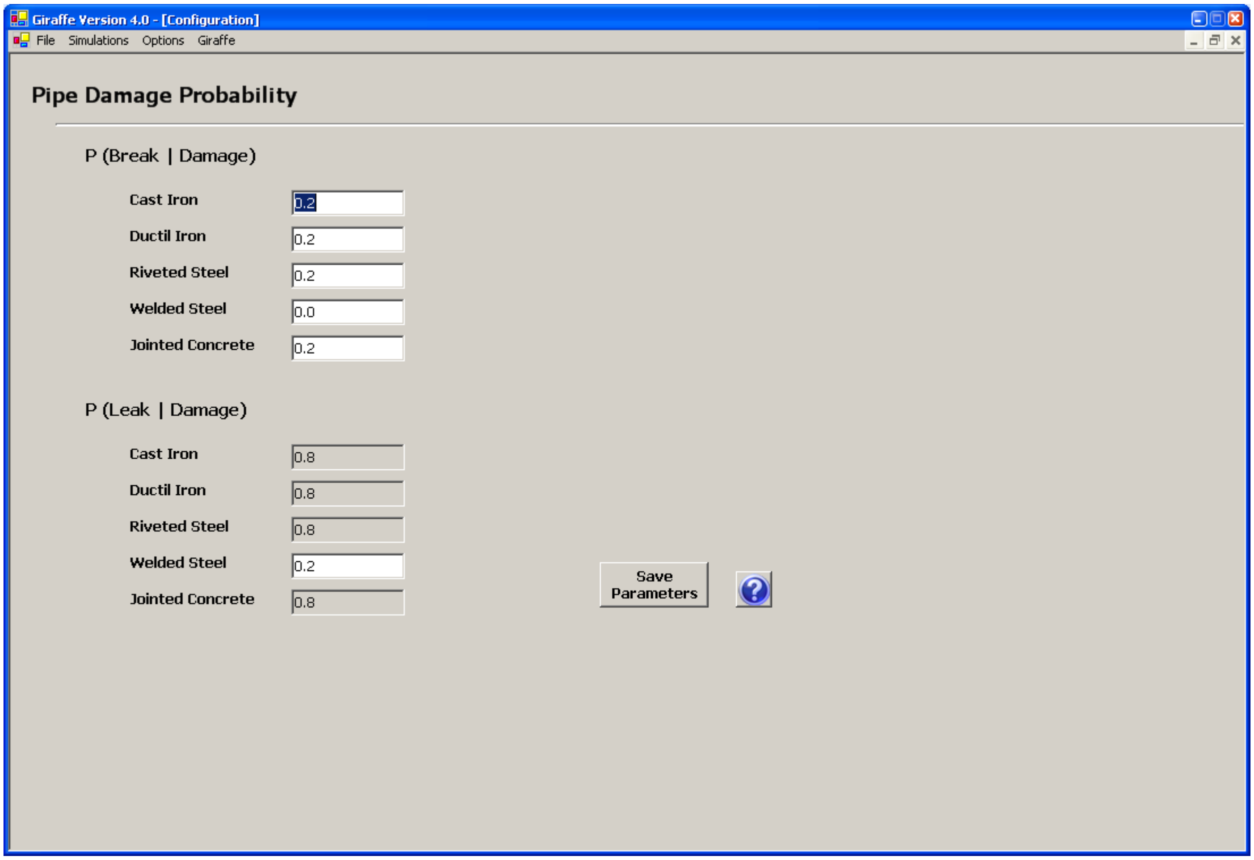
Export the hydraulic network model from H2ONET to the EPANET file format following the same approach as described in Section A.4, Step 1. The exported file, *Example_1.inp*, is installed along with the GIRAFFE program and resides in the folder: Example Files\Appendix A.

Step 2: Review EPANET File

Check the EPANET format file following the same procedures as described in Section A.4, Step 2.

Step 3: Construct Files for Pipe Damage Generation and Earthquake Demand Simulation

The probabilistic implementation generates randomly distributed pipeline breaks and leaks in the system according to pipeline repair rate, *RR*, length, *L*, and the conditional probability of pipe break, P_{bk} , given that damage occurs. In addition, the probabilistic implementation determines the type of each leak according to the probability of that leak type for different types of pipelines. The probabilistic implementation includes three steps: generating pipe damage, deciding on damage states (leak or break), and determining leak type. Its detailed methodology can be found in the GIRAFFE Users Manual main text and Shi (2006). The main inputs from users for probabilistic pipe damage generation are the repair rate (*RR*), length (*L*), and material of each pipeline. The conditional probability of pipe break, P_{bk}, and the probability for each leak type for different types of pipelines have default values that can be changed by clicking on **Options | Configuration | Pipe Damage Probability** in the GIRAFFE toolbar. Figures A.19 and A.20 show the default values for the Pipe Damage Probability and the Pipe Leakage Model. These default values of 20% breaks and 80% leaks are based on pipeline damage repair data from a seismic event in the Seattle area. Data associated with the 1994 Northridge earthquake, however, seems to suggest a 5% break rate and 95% leak occurrence is better suited to a Los Angeles area seismic event. Therefore, the user may decide to change the default values in order to better model the characteristics of the study area.



Pipe Damage Probability

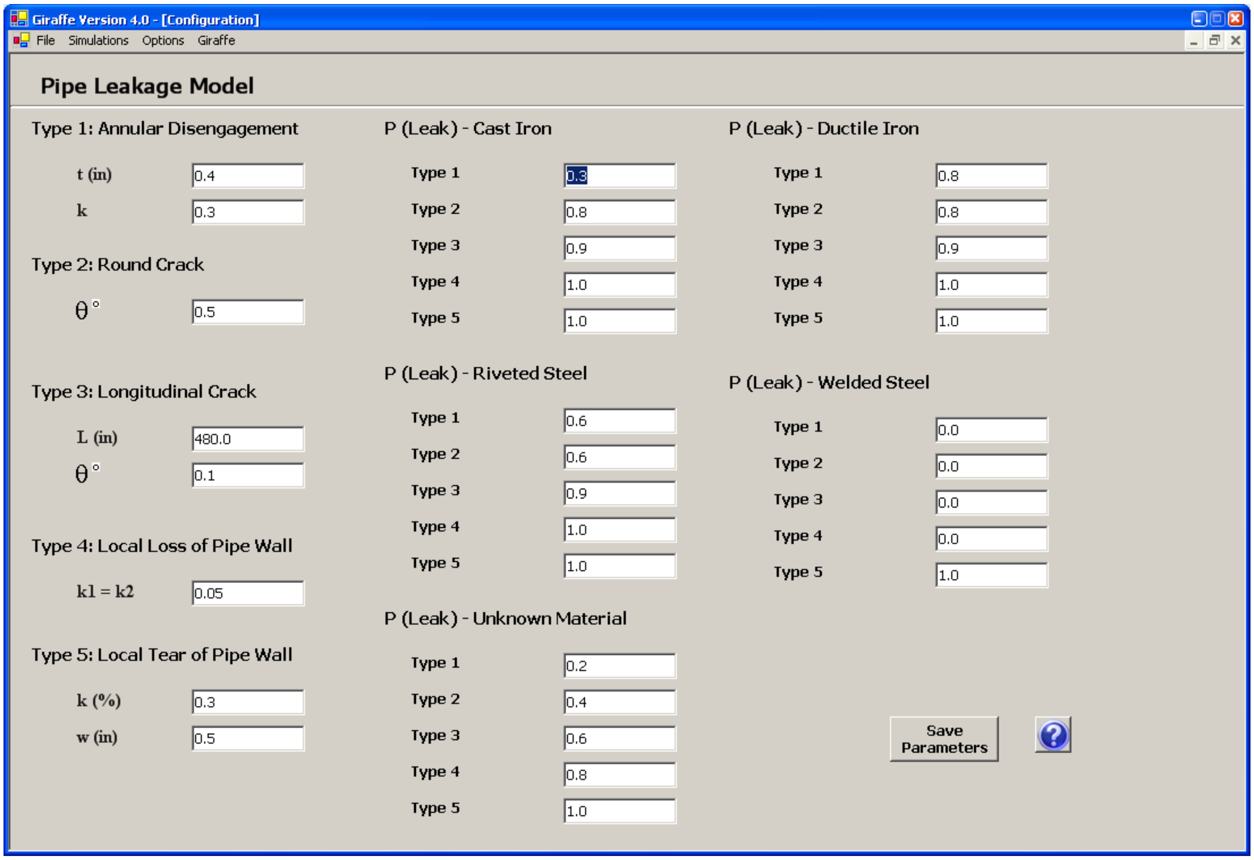
P (Break | Damage)

Cast Iron	0.2
Ductil Iron	0.2
Riveted Steel	0.2
Welded Steel	0.0
Jointed Concrete	0.2

P (Leak | Damage)

Cast Iron	0.8
Ductil Iron	0.8
Riveted Steel	0.8
Welded Steel	0.2
Jointed Concrete	0.8

Figure A.19 Default values for Pipe Damage Probability



Pipe Leakage Model

Type 1: Annular Disengagement

t (in)	0.4
k	0.3

Type 2: Round Crack

θ °	0.5

Type 3: Longitudinal Crack

L (in)	480.0
θ °	0.1

Type 4: Local Loss of Pipe Wall

k1 = k2	0.05

Type 5: Local Tear of Pipe Wall

k (%)	0.3
w (in)	0.5

P (Leak) - Cast Iron

Type 1	0.3
Type 2	0.8
Type 3	0.9
Type 4	1.0
Type 5	1.0

P (Leak) - Riveted Steel

Type 1	0.6
Type 2	0.6
Type 3	0.9
Type 4	1.0
Type 5	1.0

P (Leak) - Unknown Material

Type 1	0.2
Type 2	0.4
Type 3	0.6
Type 4	0.8
Type 5	1.0

P (Leak) - Ductile Iron

Type 1	0.8
Type 2	0.8
Type 3	0.9
Type 4	1.0
Type 5	1.0

P (Leak) - Welded Steel

Type 1	0.0
Type 2	0.0
Type 3	0.0
Type 4	0.0
Type 5	1.0

Figure A.20 Default values for Pipe Leakage Model

The input file for probabilistic pipe damage generation is shown in Table A.20. This file is a text file and users can use Microsoft Word, Excel, or Notepad to construct it and save it as a tab-delimited text file with the extension *.inp*. The probabilistic pipe damage input file starts with a headline, followed by the record of each pipeline. It is recommended that users copy the headline to their own files. The headline terms in the pipe damage generation input file are explained in Table A.21.

It is assumed that each pipe has a repair rate, *RR*, equal to repair/km in this example. The determination of RR for each pipeline for a given earthquake scenario involves spatial manipulation which is performed by GIS (see Appendices B and C for detailed methodology and explanations). The pipe length and material information can be obtained from the hydraulic network model database.

The input file for earthquake demand simulation is shown in Table A.22. This is also a text file which users can create using Microsoft Word, Excel, or Notepad, and save as a tab-delimited text file with the extension *.inp*. The input file starts with a headline, followed by the record of each demand node. The headline terms in the earthquake demand simulation input file are explained in Table A.23.

It is assumed that each demand has a RR = 1 repair/km in this example. The determination of RR for each demand node for a given earthquake scenario involves in spatial manipulation which is performed by GIS. It is further assumed that the network is divided into two pressure zones, one upstream from pressure reducing valve 14, including junctions 3, 5, 9, and 11, and the other downstream from pressure reducing valve 14, including junctions, 13, 15, 17, and 19. The mean pressure of each pressure zone is calculated by averaging the pressures at the junctions inside the pressure zone for the undamaged system. Then the mean pressure is assigned to each demand node inside the pressure zone. The pressure at each junction for the undamaged system is shown in Figure A.2.

Table A.20 Pipe Damage Input File for Monte Carlo Simulation with Fixed Simulation Times *(rr.inp)*

```
PipeID          Length_km          RR          Material

10              1                  1           CI
12              1                  1           CI
16              1                  1           DI
18              1                  1           DI
20              1                  1           CON
22              1                  1           CON
4               1                  1           RV
6               1                  1           RV
8               1                  1           STL
```

Table A.21 Description of Columns in Probabilistic Pipe Damage Input File

Name	Type	Description
PipeID	char	The ID of the pipe which users want to damage. Users have to make sure this pipe is in the system definition file otherwise the program cannot run correctly. Maximum length 30 characters
Length	float	The length of the pipe in km. The length of each pipe can be obtained from the system definition file.
RR	float	Pipe repair rate in repairs per kilometer of pipe length, which is correlated with seismic hazard parameters, such as peak ground velocity and permanent ground deformation. The determination of repair rate for each pipeline involves spatial manipulation, which is conducted using GIS.
Material	char	The material of the pipeline. CI: cast iron pipeline; DI: ductile iron pipeline, RS: riveted steel pipeline; CON: concrete pipeline; STL: welded steel pipeline, and N/A: other types of pipelines beside the abovementioned five types of pipeline.

Table A.22 Input File for Earthquake Demand Simulation

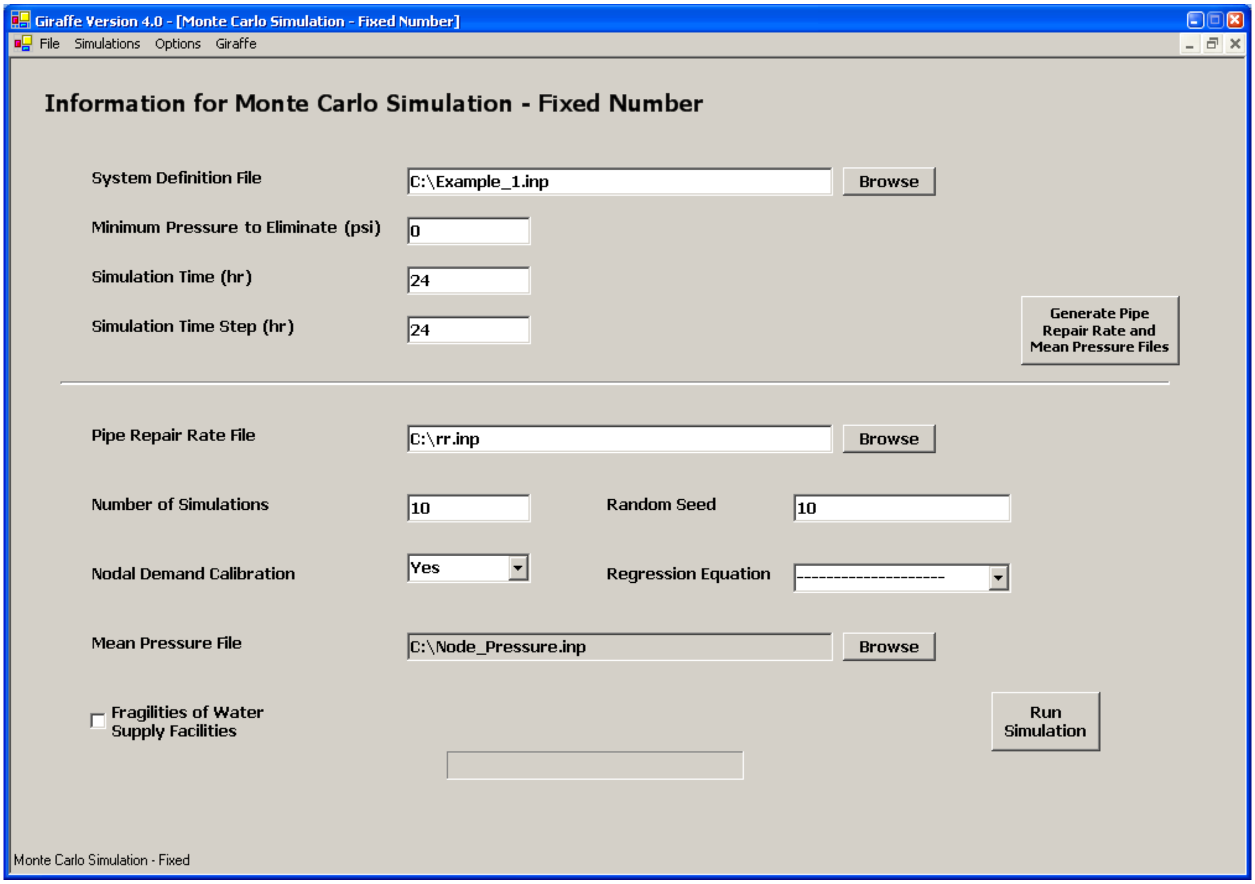
```
ID                     G_RR               Ave_PRESSURE
3                        1                    202
5                        1                    202
9                        1                    202
11                       1                    202
13                       1                    78
15                       1                    78
17                       1                    78
19                       1                    78
```

Table A.23 Description of Columns in Earthquake Demand Simulation Input File

Name	Type	Description
ID	char	The ID of the demand node. Users have to make sure this demand node is in the system definition file otherwise the program cannot run correctly. Maximum length 30 characters.
G_RR	float	Pipe repair rate in repairs per kilometer of pipe length, which is correlated with seismic hazard parameters, such as peak ground velocity and permanent ground deformation. The determination of repair rate for each pipeline involves spatial manipulation, which is conducted using GIS.
Ave_PRESSURE	float	The average nodal pressure of the pressure zone, in which the demand node is located.

Step 4: Input Parameters in GUI Window

Figure A.15 shows the GUI window with the required inputs for a Monte Carlo simulation with a fixed number of simulation runs. Users may select “Monte Carlo Fixed” from the screen that appears when first opening GIRAFFE, or by going to Simulations | Monte Carlo Fixed in the main GIRAFFE toolbar. The meaning of each entry for a deterministic simulation is explained in Table A.24.



Information for Monte Carlo Simulation - Fixed Number

System Definition File: C:\Example_1.inp

Minimum Pressure to Eliminate (psi): 0

Simulation Time (hr): 24

Simulation Time Step (hr): 24

Pipe Repair Rate File: C:\rr.inp

Number of Simulations: 10

Random Seed: 10

Nodal Demand Calibration: Yes

Regression Equation: ---------------------

Mean Pressure File: C:\Node_Pressure.inp

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Figure A.21 GUI Window with Input for a Monte Carlo Simulation with Fixed Simulation Runs

Table A.24 Input Parameters for Monte Carlo Fixed Simulation

Name	Description
System Definition File	Name of the EPANET system definition file with the extension of *.inp*.. File name may have a maximum length of 80 characters.
Minimum Pressure to Eliminate	Pressure limit, in psi, below which GIRAFFE eliminates the node and connected links from the system. Typically input 0 for negative pressure elimination.
Simulation Time	Total length of simulation time in hours to update tank water levels. 0 for steady state simulation.
Simulation Time Step	The time step in hours to update tank water levels. 1 for steady state simulation.
Pipe Repair Rate File	Name of the input file for probabilistic pipe damage generation. File name may have a maximum length of 80 characters.
Number of Simulations	Monte Carlo simulation time ranging from 1 to 100
Random Seed	Seed for random number generation.
Nodal Demand Calibration	Options to choose to simulate the earthquake demand or not: “Yes” for simulated and “No” for not simulated.
Regression Equation	(If “Yes” was selected for “Nodal Demand Calibration”, this value is required.) Options for earthquake demand simulation: “Mean Prediction Plus Noise Terms” or “90% Confidence Level Prediction”.
Mean Pressure File	(If “Yes” was selected for “Nodal Demand Calibration”, this value is required.) Name of the input file for earthquake demand assessment. File name may have a maximum length of 80 characters.

Step 5: Perform Simulation

GIRAFFE analyzes the network following the same procedures described in the deterministic simulation for 10 Monte Carlo runs in the User Manual, Section 7.4.

Step 6: View Results

GIRAFFE saves the damaged system definition file, *Damage_Info_Dert*.inp*, and the component results for each Monte Carlo simulation run. The *Damage_Info_Dert*.inp* files contain the pipe break and leak information for each simulation run and have the same format as the input file for deterministic pipeline damage generation, as shown Table A.2. The files associated with each simulation run are bundled in separate folders and saved with a similar naming convention as that used in the deterministic simulation. These files can be found in the "Giraffe_Output" folder that exists in the same directory where the GIRAFFE application is installed. The damaged system and modified system files are appended with a number indicating which simulation run they are associated with, e.g. *Damage_System_Time09*.inp is the damaged system file at time 0 for simulation run 9, and *Modified_System_Time245.inp* is the modified system file at time 24 for simulation run 5. Besides the results for each simulation run, GIRAFFE reports the serviceability at times 0 and 24 for all simulation runs. The simulation results users need to check are:

- Damaged system at time 0, *Damage_System_Time0.inp*, as shown in Table A.25, for the 10th simulation run. Users need to check if the demands are updated if they choose the simulation option to perform earthquake demand simulation.
- System serviceability at times 0 and 24, in files *Serviceability0.out* and *Serviceability24.out*, respectively. These files are shown in Tables 7.19 and 7.20. In these tables, the system serviceability is reported in a matrix format. For each Monte Carlo simulation, the serviceability is reported for each demand node and for the entire system. The mean of the nodal and system serviceability for all Monte Carlo simulations is also calculated and reported.

Table A.25 Damaged System for the Last Run of Monte Carlo Simulation

```
[TITLE]

[JUNCTIONS]
A1J10   440.746
A2J10   344.961
A1J12   100
A1J16   105.151
A2J16   126.669
A1J22   147.075
A1J4    100
A2J4    100
3       100.000000
5       100.000000
9       100.000000
11      100.000000
13      100.000000
15      200.000000
17      100.000000
19      200.000000

[RESERVOIRS]
A2R12   100
A3R12   100
A2R22   153.127
A3R22   153.127
A1R10   440.746
A2R10   344.961
A1R12   100
A1R16   105.151
A2R16   126.669
A1R22   147.075
A1R4    100
A2R4    100
1       450.000000

[TANKS]
7       450.000000     120.000000     0.000000       120.000000     30.000000      0.000000

[PIPES]
A2O12    A1J12     A2R12     4.28195 12       100      1        CV
A3O12    11        A3R12     1874.56 12       100      1        CV
A2O22    A1J22     A2R22     184.441 12       100      1        CV
A3O22    19        A3R22     1428.7  12       100      1        CV
A1O10     7        A1J10     80.5885 12       100      0
A1L10     A1J10    A1R10     0.5     1.58533 1e+006   1        CV
A2O10     A1J10    A2J10     834.149 12       100      0
A2L10     A2J10    A2R10     0.5     1.2      1e+006   1        CV
A3O10     A2J10    9   2133.26 12    100      0
A1O12     9        A1J12     1169.15 12       100      0
A1L12     A1J12    A1R12     0.5     2.4      1e+006   1        CV
A1O16     13       A1J16     156.993 12       100      0
A1L16     A1J16    A1R16     0.5     2.4      1e+006   1        CV
A2O16     A1J16    A2J16     655.89  12       100      0
A2L16     A2J16    A2R16     0.5     2.4      1e+006   1        CV
```

Table A.25 Continued

```
A3O16      A2J16      15          2235.12          12              100             0
A1O22      17         A1J22      1434.86          12              100             0
A1L22      A1J22      A1R22      0.5              2.4             1e+006          1               CV
A1O4       3          A1J4       737.49           12              100             0
A1L4       A1J4       A1R4       0.5              3.57771         1e+006          1               CV
A2O4       A1J4       A2J4       1120.94          12              100             0
A2L4       A2J4       A2R4       0.5              3.57771         1e+006          1               CV
A3O4        A2J4      5          1189.57          12              100             0
18         13         17         3048.00000       12.00000        100.000000      0.000000
20         15         19         3048.00000       12.00000        100.000000      0.000000
6          3          9          3048.00000       12.00000        100.000000      0.000000
8          5          11         3048.00000       12.00000        100.000000      0.000000

[PUMPS]

2          1          3          POWER 10.000000

[VALVES]
14         9          13         12.000000        PRV      100.000000       0.000000

[DEMANDS]
3                     921.02
5                     921.02
9                     921.02
11                    921.02
13                    422.54
15                    422.54
17                    422.54
19                    422.54

[CURVES]

[PATTERNS]
PATN1  1.000000        1.000000        1.000000        1.000000        1.000000        1.000000
PATN1  1.000000        1.000000        1.000000        1.000000        1.000000

[STATUS]

[CONTROLS]

[SOURCES]


[QUALITY]

[REACTIONS]
GLOBAL BULK 0.000000
GLOBAL WALL 0.000000

[ENERGY]

[OPTIONS]
UNITS GPM
HEADLOSS H-W
```

Demands are changed to consider the effects of earthquake damage to distribution network

Table A.25 Continued

```
VISCOSITY 1.1e-005
DIFFUSIVITY 1.3e-008
SPECIFIC GRAVITY 1.000000
TRIALS 40
ACCURACY 0.001
DEMAND Multiplier 1.000000

[REPORT]
PAGESIZE 30
STATUS NO
NODE ALL
LINK ALL

[COORDINATES]
A2R12   211.619 159.757
A3R12   211.622 155.37
A2R22   284.468 153.139
A3R22   284.468 148.687
A1J10   207.221 198.924
A1R10   209.735 198.924
A2J10   207.221 192.044
A2R10   209.735 192.044
A1J12   207.233 157.622
A1R12   211.62  157.628
A1J16   241.998 172.221
A1R16   246.455 172.221
A2J16   241.998 162.63
A2R16   246.455 162.63
A1J22   280.016 153.607
A1R22   284.468 153.607
A1J4    169.645 163.825
A1R4    165.262 163.843
A2J4    169.612 147.704
A2R4    165.229 147.722
1       140.726688      174.581772
3       169.667221      174.431972
5       169.576993      130.595466
7       207.220708      199.588372
9       207.220708      174.450158
11      207.252760      130.579090
13      241.998111      174.517132
15      241.998111      129.944774
17      280.016223      174.565669
19      280.016223      130.044299

[VERTICES]
A2O12   207.231 159.754
A3O12   207.235 155.367
A2O22   280.016 153.139
A3O22   280.016 148.687

[End]
```

Table A.26 Serviceability of Monte Carlo Simulation with Fixed Simulation Times at Time 0

Node_ID	Demand	1	2	3	4	5	6	7	8	9	10	Node_Serviceability
3	100	100	100	100	100	100	100	100	100	100	100	1
5	100	0	100	100	100	100	100	100	100	100	100	0.9
9	100	100	100	100	100	100	100	100	100	100	100	1
11	100	100	100	100	100	100	100	100	100	100	100	1
13	100	100	100	100	100	100	100	100	100	100	100	1
15	100	0	0	100	0	100	0	0	0	0	100	0.3
17	100	0	100	100	0	100	100	100	100	100	0	0.7
19	100	0	0	100	0	100	0	0	0	0	0	0.2
Sum		0.5	0.75	1	0.625	1	0.75	0.75	0.75	0.75	0.75	0.7625

System Serviceability of Each Monte Carlo

Mean Node Serviceability for All Monte Carlo Runs

Mean System Serviceability for All Monte Carlo Runs

Table A.27 Serviceability of Monte Carlo Simulation with Fixed Simulation Times at Time 24

Node_ID	Demand	1	2	3	4	5	6	7	8	9	10	Node_Serviceability
3	100	100	100	100	100	100	100	100	100	100	100	1
5	100	0	100	100	100	100	100	100	100	100	100	0.9
9	100	100	100	100	100	100	100	100	100	100	100	1
11	100	100	100	100	100	100	100	100	100	100	100	1
13	100	100	100	100	100	100	100	100	100	100	100	1
15	100	0	0	100	0	100	0	0	0	0	0	0.2
17	100	0	100	100	0	100	100	100	100	0	0	0.6
19	100	0	0	100	0	0	0	0	0	0	0	0.1
Sum		0.5	0.75	1	0.625	0.875	0.75	0.75	0.75	0.625	0.625	0.725

A.6 MONTE CARLO SIMULATION WITH FLEXIBLE SIMULATION RUNS

Step 1: Export EPANET Format File

Export the hydraulic network model from H2ONET to EPANET format file, Ex*ample_1.inp,* following the same approach as described in Section A.4, Step 1.

Step 2: Check EPANET File

Check the EPANET format file, *Example_1.inp*, following the same procedures described in Section A.4, Step 2.

Step 3: Construct Files for Pipe Damage Generation and Earthquake Demand Simulation

Construct the input files, *rr.inp,* for pipe damage generation and, *Node_Pressure.inp*, for earthquake demand simulation, using the same format as shown in Tables A.20 and A.22, respectively. The files must be in tab-delimited format.

Step 4: Input Parameters

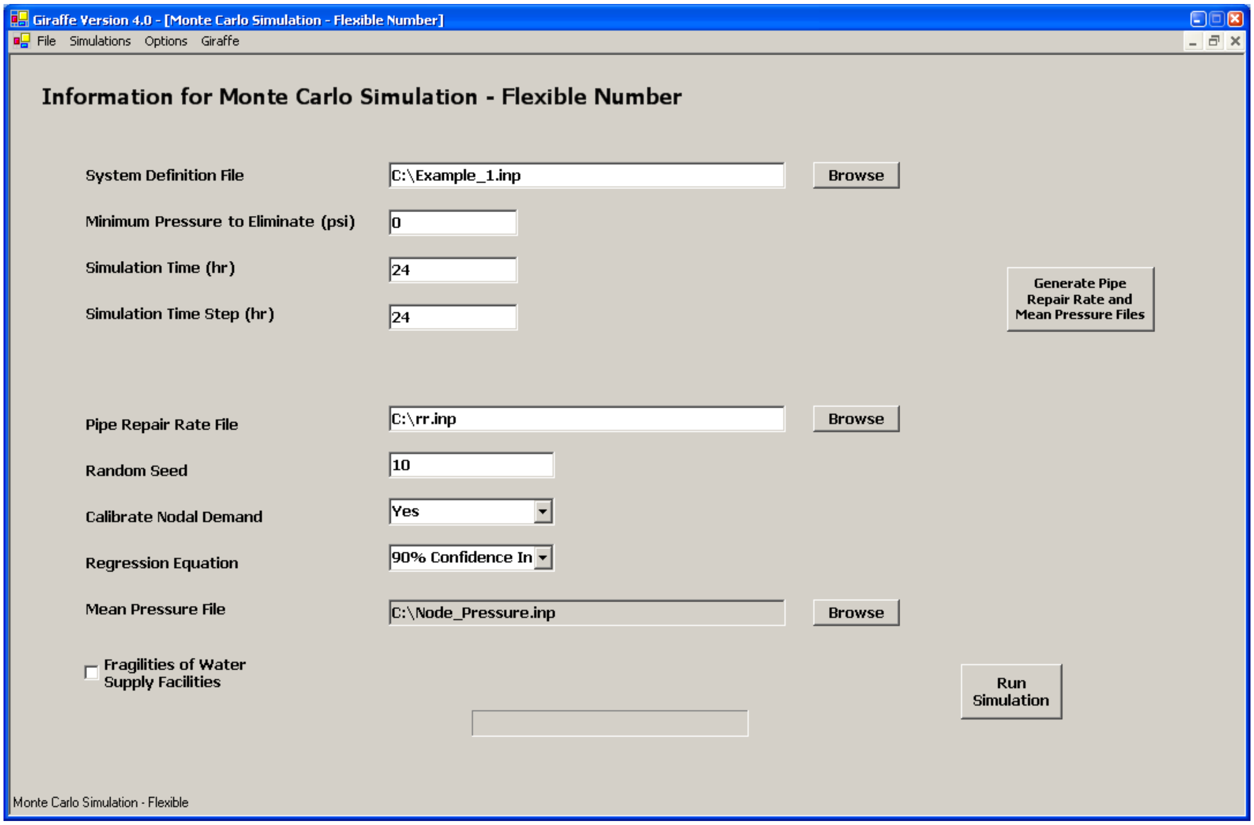
Selecting a Monte Carlo Flexible simulation in GIRAFFE produces a GUI window as shown in Figure A.16. All the entries in this GUI window have the same meaning and format as those shown in Figure A.15 and described in Table A. 24.

Step 5: GIRAFFE Performs Simulation

GIRAFFE analyzes the network following the same processes described in the deterministic simulation and determines how many Monte Carlo simulation runs are needed to have statistically significant results using the built-in algorithm.

Step 6: View Results

GIRAFFE saves the damaged system definition file and the component results for each Monte Carlo simulation and saves the serviceability at times 0 and 24 for all simulation runs. The system serviceability is reported in Tables A.28 and A.29 for times 0 and 24, respectively. In total, 20 runs of Monte Carlo simulations are performed in this example.



Information for Monte Carlo Simulation - Flexible Number

System Definition File: C:\Example_1.inp

Minimum Pressure to Eliminate (psi): 0

Simulation Time (hr): 24

Simulation Time Step (hr): 24

Pipe Repair Rate File: C:\rr.inp

Random Seed: 10

Calibrate Nodal Demand: Yes

Regression Equation: 90% Confidence In

Mean Pressure File: C:\Node_Pressure.inp

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Figure A.22 Inputs for Monte Carlo Simulation with Flexible Simulation Runs

Table A.28 Serviceability of Monte Carlo Simulation with Flexible Simulation Runs at Time 0

Node_ID	Demand	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Node_Serviceability
3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1
5	100	0	100	100	100	100	100	100	100	100	100	0	0	100	100	100	100	0	100	100	100	0.8
9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1
11	100	100	100	100	100	100	100	100	100	100	100	0	100	100	100	100	100	100	100	100	100	0.95
13	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1
15	100	0	0	100	0	100	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0.15
17	100	0	100	100	0	100	100	100	100	100	0	100	0	0	100	100	0	0	0	100	100	0.6
19	100	0	0	100	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1
Sum		0.5	0.75	1	0.625	1	0.75	0.75	0.75	0.75	0.75	0.5	0.5	0.625	0.75	0.75	0.625	0.5	0.625	0.75	0.75	0.7

Table A.29 Serviceability of Monte Carlo Simulation with Flexible Simulation Runs at Time 24

Node_ID	Demand	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Node_Serviceability
3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1
5	100	0	100	100	100	100	100	100	100	100	100	0	0	100	0	100	100	0	100	100	100	0.75
9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1
11	100	100	100	100	100	100	100	100	100	100	100	0	100	100	100	100	100	100	100	100	100	0.95
13	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1
15	100	0	0	100	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1
17	100	0	100	100	0	100	100	100	100	0	0	100	0	0	100	100	0	0	0	100	100	0.55
19	100	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05
Sum		0.5	0.75	1	0.625	0.875	0.75	0.75	0.75	0.625	0.625	0.5	0.5	0.625	0.625	0.75	0.625	0.5	0.625	0.75	0.75	0.675

A.7 USING DETERMINISTIC RESULTS AS INPUT FOR MONTE CARLO SIMULATION RUNS

The primary utility of running a deterministic simulation is that it allows the user to explicitly specify damage to the system and then view the effects of that damage. This is especially useful when experts can predict regions of permanent ground deformation where damage is likely to occur. A useful application of GIRAFFE is the ability to combine a stochastic simulation and a deterministic simulation. The deterministic simulation allows users to specify damage due to permanent ground deformation and results from this simulation can be fed into a stochastic simulation where additional damage will be applied to the system based on the selected earthquake scenario. Note that this can be done with both fixed and flexible Monte Carlo simulations.

Step 1: Start a Deterministic Simulation

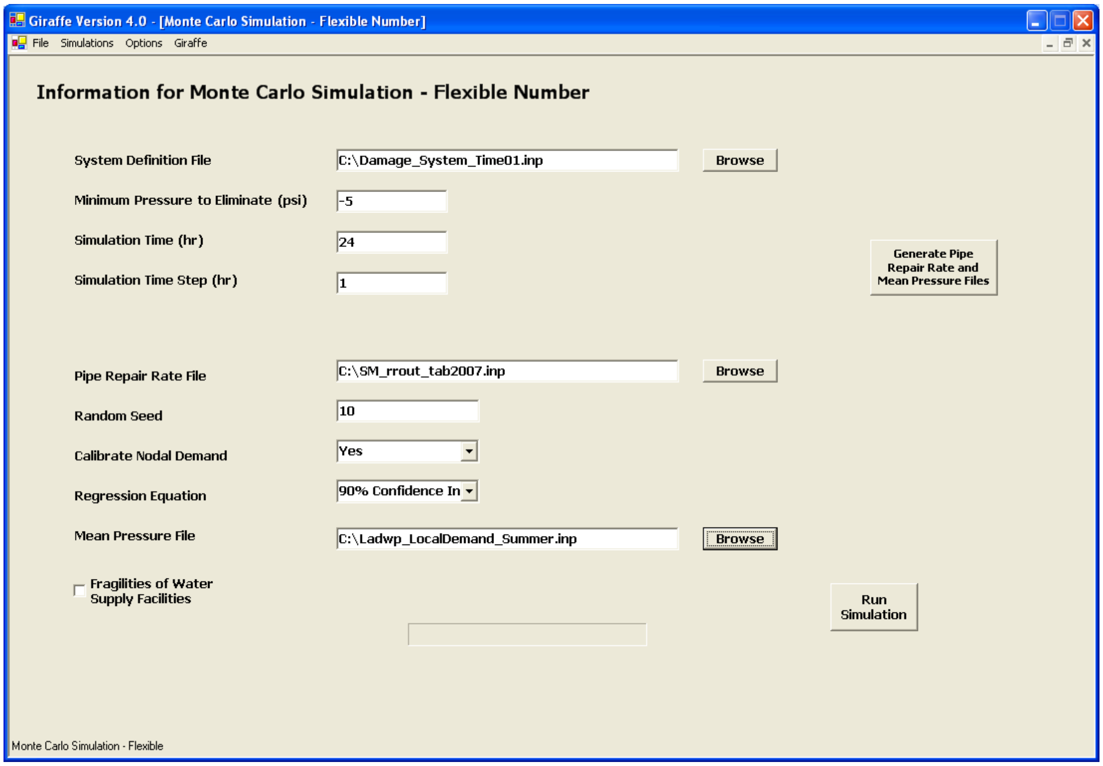
Run the deterministic simulation, adding damage to pipes as described in **Section A.4 DETERMINISTIC SIMULATIONS.** When the simulation is complete, there will be a file called *Damage_System_Time01.inp* in the “Giraffe_Output” folder of results. This file is in the same format as the original system definition file, but it includes damage to the system that was specified in the deterministic simulation. (Please note that the user should use the *Damage_System_Time01* file and not the *Modified_System_Time01* file. The *Modified_System_Time01* file will have been through hydraulic analysis and negative pressures and corresponding model elements will have been removed. For accurate results, the user needs to use the *Damage_System_Time01* file for the next step, so all model elements are present at the start of the stochastic simulation). Using the *Damage_System_Time01.inp* file as the system definition file for a Monte Carlo simulation, the user can have additional damage (created by the stochastic simulation) imposed with the damage explicitly applied via the deterministic simulation module.

Step 2: Run Monte Carlo Simulation Using Deterministic Results

Open up the GIRAFFE GUI to begin a Monte Carlo Simulation (either Flexible or Fixed). Use the *Damage_System_Time01.inp* file as the system definition file (you may want to rename this file as something more descriptive). At this point, the user can choose to incur additional trunk line damage via the Monte Carlo simulation by selecting a pipe repair rate file (*SM_rrout.inp*) for a particular scenario earthquake. Damage to the distribution network will be simulated if the user chooses “Yes” for “Calibrate Nodal Demand” and then selects the appropriate mean pressure file. If desired, the tank fragility module can be applied. Figure A.23 shows what the inputs would look like for this type of a simulation.

In some cases, a user will not want to incur any additional trunk line damage (i.e. only include the damage that has been applied deterministically), but would still like to have damage simulated for the distribution network. This can be accomplished by creating a pipe repair rate file with zeros for all of the pipe repair rates (as shown in Figure A.24). The user can then select “Yes” for “Calibrate Nodal Demand” and selects a mean pressure file and distribution line damage will occur. If desired, the tank fragility module can be applied.

Once the inputs are in place, the user can run a Monte Carlo simulation and view results. The output files will include the effects of both deterministic and stochastic damage to the system.



Information for Monte Carlo Simulation - Flexible Number

System Definition File: C:\Damage_System_Time01.inp
Minimum Pressure to Eliminate (psi): -5
Simulation Time (hr): 24
Simulation Time Step (hr): 1
Pipe Repair Rate File: C:\SM_rrout_tab2007.inp
Random Seed: 10
Calibrate Nodal Demand: Yes
Regression Equation: 90% Confidence In
Mean Pressure File: C:\Ladwp_LocalDemand_Summer.inp
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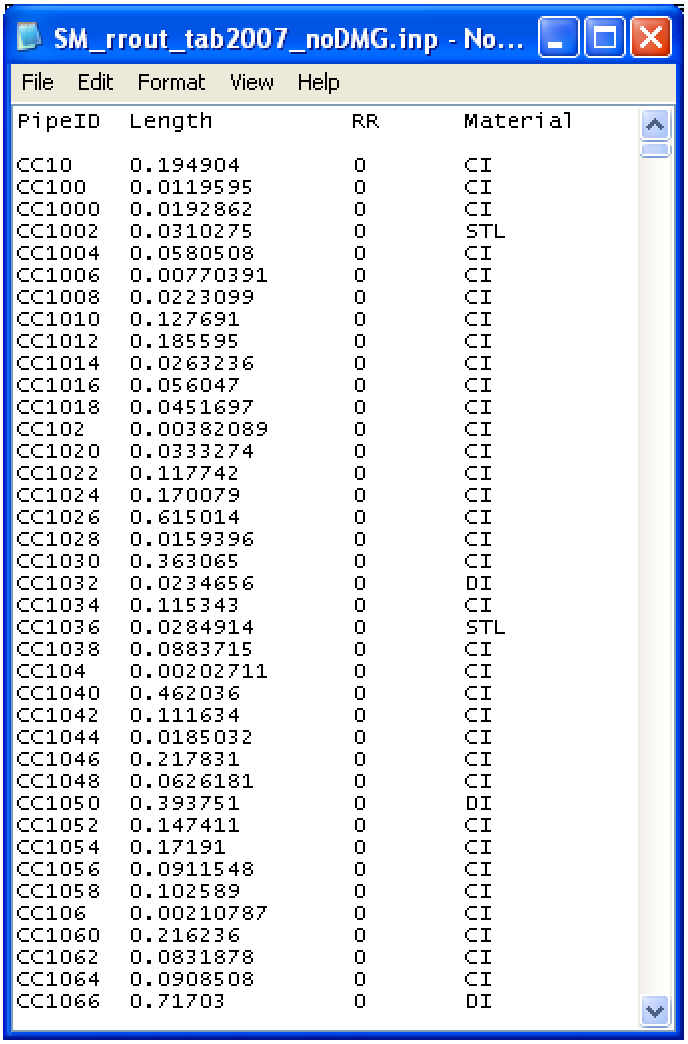
Figure A.23. Example of Monte Carlo Simulation Using a Deterministic Simulation-Generated System Definition File.



```
PipeID  Length          RR      Material

CC10    0.194904        0       CI
CC100   0.0119595       0       CI
CC1000  0.0192862       0       CI
CC1002  0.0310275       0       STL
CC1004  0.0580508       0       CI
CC1006  0.00770391      0       CI
CC1008  0.0223099       0       CI
CC1010  0.127691        0       CI
CC1012  0.185595        0       CI
CC1014  0.0263236       0       CI
CC1016  0.056047        0       CI
CC1018  0.0451697       0       CI
CC102   0.00382089      0       CI
CC1020  0.0333274       0       CI
CC1022  0.117742        0       CI
CC1024  0.170079        0       CI
CC1026  0.615014        0       CI
CC1028  0.0159396       0       CI
CC1030  0.363065        0       CI
CC1032  0.0234656       0       DI
CC1034  0.115343        0       CI
CC1036  0.0284914       0       STL
CC1038  0.0883715       0       CI
CC104   0.00202711      0       CI
CC1040  0.462036        0       CI
CC1042  0.111634        0       CI
CC1044  0.0185032       0       CI
CC1046  0.217831        0       CI
CC1048  0.0626181       0       CI
CC1050  0.393751        0       DI
CC1052  0.147411        0       CI
CC1054  0.17191         0       CI
CC1056  0.0911548       0       CI
CC1058  0.102589        0       CI
CC106   0.00210787      0       CI
CC1060  0.216236        0       CI
CC1062  0.0831878       0       CI
CC1064  0.0908508       0       CI
CC1066  0.71703         0       DI
```

Figure A.24 Example of a Pipe Repair Rate file for No Trunk Line Damage

REFERENCES

MWH Soft, Inc. (1999). *H2ONET Users Guide*. Pasadena, CA.

Rossman, L.A. (2000). *EPANET 2 Users Manual*. National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, OH.

Shi, P. (2006). “Seismic Response Modeling of Water Supply Systems.” *Ph.D. Dissertation*, School of Civil & Environmental Engineering, Cornell University, Ithaca, NY.

APPENDIX B
GIRAFFE INPUT PREPARATION

B.1 INTRODUCTION

This appendix provides a demonstration on how to prepare input files for GIRAFFE simulations. To simulate the performance of a damaged water system, GIRAFFE needs two types of input files: a system definition file in EPANET format defining the intact water system and some system damage files describing damage scenarios. GIRAFFE can perform both deterministic and stochastic simulations. Depending on whether the simulation is deterministic or stochastic, GIRAFFE asks for different system damage files. This appendix focuses on preparing system damage files for stochastic simulations by a series of manipulations and spatial analyses using H2ONET, ESRI ArcGIS, and Microsoft Excel. The preparation of the system definition file and system damage file for deterministic simulations are described in detail in **Section A.4 DETERMINISTIC SIMULATIONS** of Appendix A. Although the thought process of the input file preparation applies to other GIS and hydraulic analysis software, this demonstration uses ESRI ArcGIS 8.3 and H2ONET 3.5 in particular, and usage of other similar GIS and/or hydraulic analysis software may lead to slight variations of the procedures. Users should be familiar with GIRAFFE, EPANET, H2ONET, ESRI ArcGIS, and Microsoft Excel before the GIRAFFE input file preparation. For more information on EPANET, H2ONET, and ESRI ArcGIS, users can refer to the EPANET User Manual (Rossman, 2000), H2ONET User Manual (MWH Soft, Inc., 1999), and ESRI User Manual (Booth and Mitchell, 2001).

This appendix is tailored to the seismic performance evaluation of the Los Angeles water supply system, which is operated by Los Angeles Department of Water and Power (LADWP). For the details of the evaluation process, please refer to Wang (2006) and Shi (2006). The appendix starts with a brief description of LADWP seismic hazard characterization, followed by H2ONET analysis of the LADWP water supply system. Then, it proceeds to the GIS manipulations and spatial analysis and Excel spreadsheet calculations for the preparation of input files in the GIRAFFE format.

B.2 LADWP SEISMIC HAZARD CHARACTERIZATION

The seismic hazard characterization for the LADWP water supply system was developed by approximating the aggregate seismic hazard in the area that takes into account all currently identified, potential seismic sources in a probabilistic context. This was accomplished by examining 59 scenario earthquakes that were selected to provide probability of exceedance characteristics for strong ground motion similar to those for all currently identified potential seismic sources in the area (Lee et al. 2005; and Wang 2006). Table B.1 summarizes information about the 59 scenario earthquakes.

For each of the 59 scenario earthquakes, several strong ground motion parameters at equivalent rock sites, i.e., peak ground acceleration (PGA), peak ground velocity (PGV), and spectral acceleration with 5% damping at T = 0.2 sec ($S_{A0.2}$), and T = 1.0 sec (S_{A1}), respectively, are generated at 572 points in a grid with uniform separation of points and interval of 0.03° longitude and latitude covering the LADWP water supply system. The grid is shown in Figure B.1, superimposed by the LADWP trunk line system.

For each strong ground motion parameter at the 572 grid points, strong motion data are generated corresponding to both the mean and mean $\pm \sigma$, where σ is the total standard error for the strong ground motion. Table B.2 shows an illustration of strong ground motion for scenario earthquake 175 (Verdugo, $M_w = 6.9$). The first column indicates the scenario ID, which is defined in Table B.1. The second and third columns define the geographic coordinates for the grid points. The fourth, fifth, and sixth columns show the mean, mean + σ, and mean - σ PGA, respectively. In a similar fashion, the remaining columns show the mean, mean + σ, and mean - σ PGV, $S_{A0.2}$, and S_{A1}, respectively. Please note: due to limited space, only 41 of 572 grid points are shown in Table B.2.

Table B.1. Characteristics of 59 Scenario Earthquakes

Scenario ID	Scenario Name	Magnitude Mw	Annual Occurrence Frequency
12	el15	6.8	3.60E-03
18	SAF - Mojave	7.3	4.13E-03
19	SAF - Carrizo	7.4	2.28E-03
21	SAF-All southern segments	8.1	3.00E-03
22	SAF - 1857	7.8	9.61E-03
23	SAF - Southern 2 segments	7.7	3.37E-03
118	Holser	6.5	1.66E-04
119	Hollywood	6.4	6.64E-06
120	Raymond	6.5	7.41E-04
122	Clamshell-Sawpit	6.5	1.06E-03
141	Newport-Inglewood offshore	7.1	2.56E-03
145	Coronado Bank	7.6	1.75E-03
159	Newport-Inglewood	7.1	8.10E-04
160	Newport-Inglewood	6.6	2.37E-03
161	Newport-Inglewood	6.6	5.58E-04
162	Newport-Inglewood	6.6	1.50E-04
166	Sierra Madre	7.2	7.45E-04
167	Sierra Madre	6.7	4.40E-03
168	Sierra Madre	6.7	2.21E-04
169	San Gabriel	7.2	1.53E-03
170	San Gabriel	6.7	9.97E-05
171	San Gabriel	6.7	1.27E-03
173	Malibu Coast	6.7	2.70E-06
174	Santa Monica	6.6	5.23E-04
175	Verdugo	6.9	9.65E-04
176	Verdugo	6.4	1.57E-05
177	Verdugo	6.4	2.84E-06
189	Oak Ridge-onshore	7	4.13E-03
191	Oak Ridge-onshore	6.5	3.86E-03
195	San Cayetano	7	6.86E-03
196	San Cayetano	6.5	6.03E-03
198	Santa Susana	6.7	3.01E-03
202	Simi-Santa Rosa	7	6.35E-04
203	Simi-Santa Rosa	6.5	2.87E-04
219	Anacapa-Dume	7.5	9.36E-04

Table B.1. (Continued)

Scenario ID	**Scenario Name**	**Magnitude Mw**	**Annual Occurrence Frequency**
220	Anacapa-Dume	7	5.70E-04
221	Anacapa-Dume	7	9.43E-04
222	Anacapa-Dume	6.5	1.29E-06
370	Northridge	7	1.43E-03
371	Northridge	6.5	2.88E-04
372	Northridge	6.5	2.37E-05
378	Channel Island Thrust	7.5	5.12E-04
388	Upper Elysian Park	6.4	6.13E-05
397	Puente Hills blind thrust	7.1	8.63E-04
398	Puente Hills blind thrust	6.6	1.04E-05
399	Puente Hills blind thrust	6.6	8.21E-05
440	Cucamonga	6.9	6.18E-03
443	Sierra Madre-San Fernando	6.7	9.41E-04
444	Palos Verdes	7.3	1.05E-03
446	Palos Verdes	6.8	8.20E-04
447	Palos Verdes	6.8	6.24E-04
451	Palos Verdes	6.3	3.27E-03
452	Palos Verdes	6.3	1.44E-03
453	Palos Verdes	6.3	2.07E-03
454	Palos Verdes	6.3	2.17E-03
559	Background Source	7	1.05E-03
560	Background Source	7	7.75E-04
561	Background Source	7	1.29E-03
562	Background Source	7	7.63E-04

The standard error, $\sigma_{\text{inter-event}}$, associated with inter-event variability to account for only the "source" effects (Wang 2006) is estimated as 0.31 for PGA, PGV, and S_{A1}, and 0.35 for $S_{A0.2}$ (Lee et al. 2005). Since the $\sigma_{\text{inter-event}}$ is the standard deviation of the natural log of the strong ground motion, the strong motion data corresponding to mean ± $\sigma_{\text{inter-event}}$, can be calculated from the mean strong motion data by:

$$mean \pm \sigma_{inter-event} = mean \times \exp(\pm \sigma_{inter-event}) \tag{B.1}$$

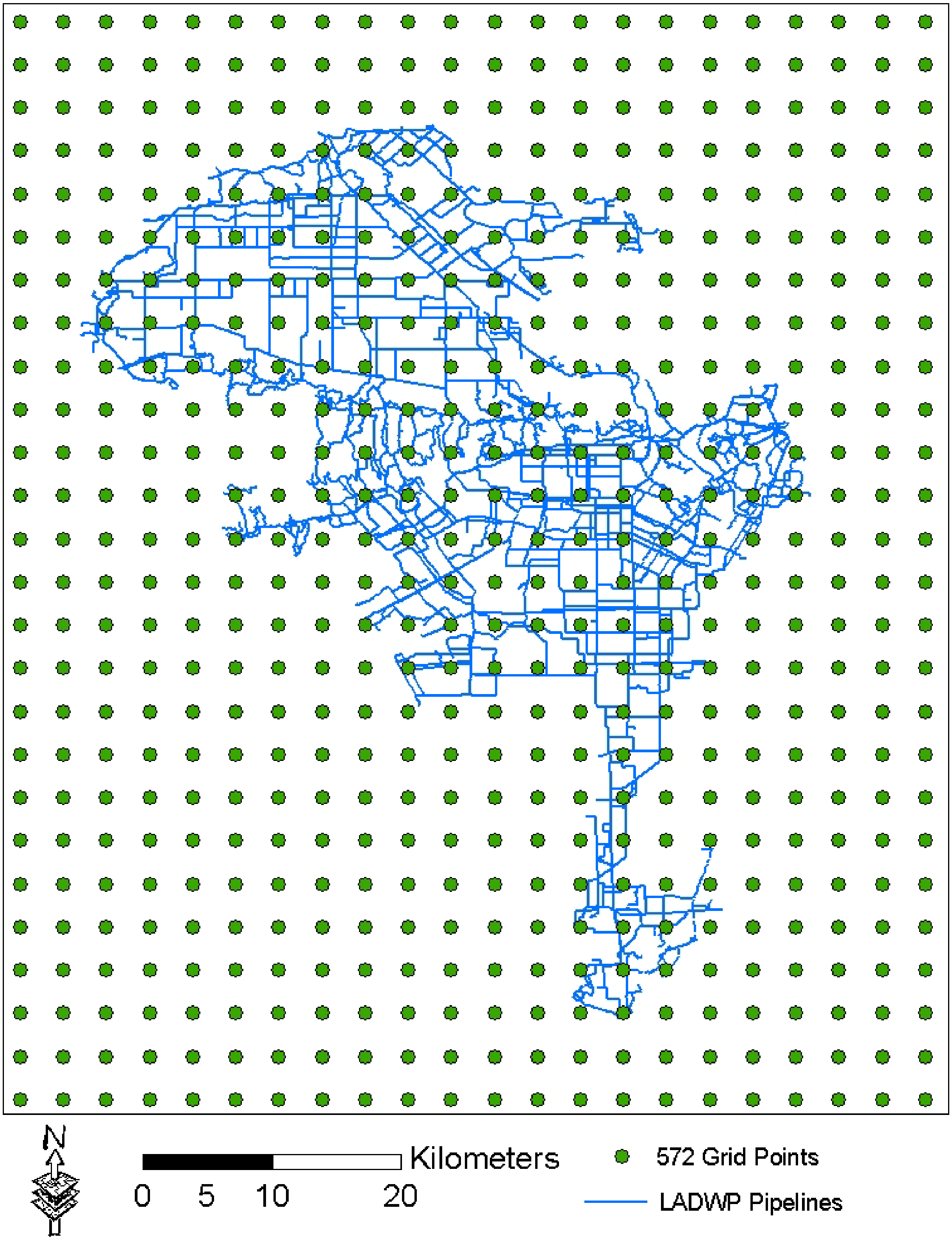
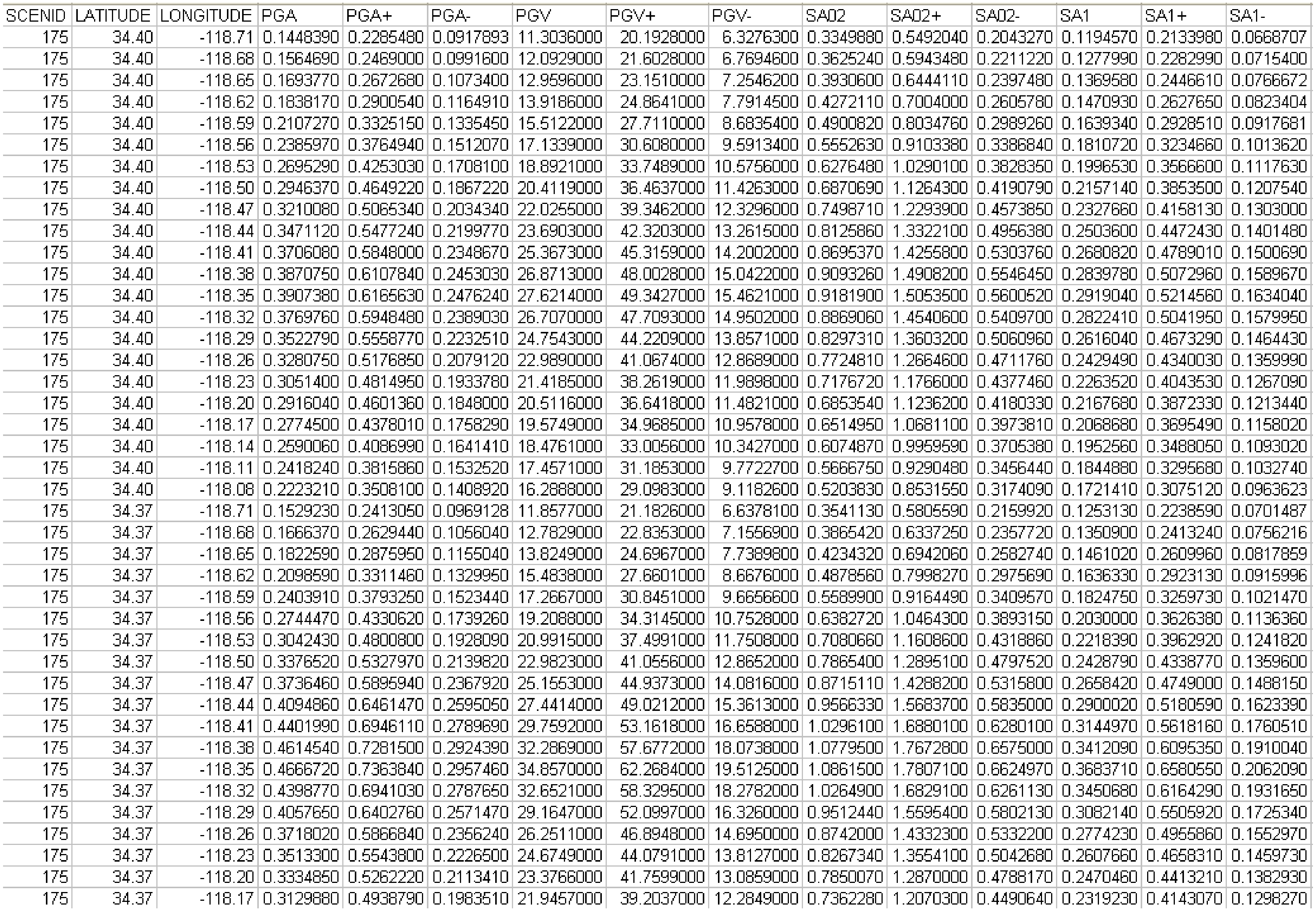


Figure B.1. Spatial Distribution of 572 Grid Points for Strong Motion Data

Table B.2. Illustration of Strong Ground Motion Data for Scenario Earthquake 175



SCENID	LATITUDE	LONGITUDE	PGA	PGA+	PGA-	PGV	PGV+	PGV-	SA02	SA02+	SA02-	SA1	SA1+	SA1-
175	34.40	-118.71	0.1448390	0.2285480	0.0917893	11.3036000	20.1928000	6.3276300	0.3349880	0.5492040	0.2043270	0.1194570	0.2133980	0.0668707
175	34.40	-118.68	0.1564690	0.2469000	0.0991600	12.0929000	21.6028000	6.7694600	0.3625240	0.5943480	0.2211220	0.1277990	0.2282990	0.0715400
175	34.40	-118.65	0.1693770	0.2672680	0.1073400	12.9596000	23.1510000	7.2546200	0.3930600	0.6444110	0.2397480	0.1369580	0.2446610	0.0766672
175	34.40	-118.62	0.1838170	0.2900540	0.1164910	13.9186000	24.8641000	7.7914500	0.4272110	0.7004000	0.2605780	0.1470930	0.2627650	0.0823404
175	34.40	-118.59	0.2107270	0.3325150	0.1335450	15.5122000	27.7110000	8.6835400	0.4900820	0.8034760	0.2989260	0.1639340	0.2928510	0.0917681
175	34.40	-118.56	0.2385970	0.3764940	0.1512070	17.1339000	30.6080000	9.5913400	0.5552630	0.9103380	0.3386840	0.1810720	0.3234660	0.1013620
175	34.40	-118.53	0.2695290	0.4253030	0.1708100	18.8921000	33.7489000	10.5756000	0.6276480	1.0290100	0.3828350	0.1996530	0.3566600	0.1117630
175	34.40	-118.50	0.2946370	0.4649220	0.1867220	20.4119000	36.4637000	11.4263000	0.6870690	1.1264300	0.4190790	0.2157140	0.3853500	0.1207540
175	34.40	-118.47	0.3210080	0.5065340	0.2034340	22.0255000	39.3462000	12.3296000	0.7498710	1.2293900	0.4573850	0.2327660	0.4158130	0.1303000
175	34.40	-118.44	0.3471120	0.5477240	0.2199770	23.6903000	42.3203000	13.2615000	0.8125860	1.3322100	0.4956380	0.2503600	0.4472430	0.1401480
175	34.40	-118.41	0.3706080	0.5848000	0.2348670	25.3673000	45.3159000	14.2002000	0.8695370	1.4255800	0.5303760	0.2680820	0.4789010	0.1500690
175	34.40	-118.38	0.3870750	0.6107840	0.2453030	26.8713000	48.0028000	15.0422000	0.9093260	1.4908200	0.5546450	0.2839780	0.5072960	0.1589670
175	34.40	-118.35	0.3907380	0.6165630	0.2476240	27.6214000	49.3427000	15.4621000	0.9181900	1.5053500	0.5600520	0.2919040	0.5214560	0.1634040
175	34.40	-118.32	0.3769760	0.5948480	0.2389030	26.7070000	47.7093000	14.9502000	0.8869060	1.4540600	0.5409700	0.2822410	0.5041950	0.1579950
175	34.40	-118.29	0.3522790	0.5558770	0.2232510	24.7543000	44.2209000	13.8571000	0.8297310	1.3603200	0.5060960	0.2616040	0.4673290	0.1464430
175	34.40	-118.26	0.3280750	0.5176850	0.2079120	22.9890000	41.0674000	12.8689000	0.7724810	1.2664600	0.4711760	0.2429490	0.4340030	0.1359990
175	34.40	-118.23	0.3051400	0.4814950	0.1933780	21.4185000	38.2619000	11.9898000	0.7176720	1.1766000	0.4377460	0.2263520	0.4043530	0.1267090
175	34.40	-118.20	0.2916040	0.4601360	0.1848000	20.5116000	36.6418000	11.4821000	0.6853540	1.1236200	0.4180330	0.2167680	0.3872330	0.1213440
175	34.40	-118.17	0.2774500	0.4378010	0.1758290	19.5749000	34.9685000	10.9578000	0.6514950	1.0681100	0.3973810	0.2068680	0.3695490	0.1158020
175	34.40	-118.14	0.2590060	0.4086990	0.1641410	18.4761000	33.0056000	10.3427000	0.6074870	0.9959590	0.3705380	0.1952560	0.3488050	0.1093020
175	34.40	-118.11	0.2418240	0.3815860	0.1532520	17.4571000	31.1853000	9.7722700	0.5666750	0.9290480	0.3456440	0.1844880	0.3295680	0.1032740
175	34.40	-118.08	0.2223210	0.3508100	0.1408920	16.2888000	29.0983000	9.1182600	0.5203830	0.8531550	0.3174090	0.1721410	0.3075120	0.0963623
175	34.37	-118.71	0.1529230	0.2413050	0.0969128	11.8577000	21.1826000	6.6378100	0.3541130	0.5805590	0.2159920	0.1253130	0.2238590	0.0701487
175	34.37	-118.68	0.1666370	0.2629440	0.1056040	12.7829000	22.8353000	7.1556900	0.3865420	0.6337250	0.2357720	0.1350900	0.2413240	0.0756216
175	34.37	-118.65	0.1822590	0.2875950	0.1155040	13.8249000	24.6967000	7.7389800	0.4234320	0.6942060	0.2582740	0.1461020	0.2609960	0.0817859
175	34.37	-118.62	0.2098590	0.3311460	0.1329950	15.4838000	27.6601000	8.6676000	0.4878560	0.7998270	0.2975690	0.1636330	0.2923130	0.0915996
175	34.37	-118.59	0.2403910	0.3793250	0.1523440	17.2667000	30.8451000	9.6656600	0.5589900	0.9164490	0.3409570	0.1824750	0.3259730	0.1021470
175	34.37	-118.56	0.2744470	0.4330620	0.1739260	19.2088000	34.3145000	10.7528000	0.6382720	1.0464300	0.3893150	0.2030000	0.3626380	0.1136360
175	34.37	-118.53	0.3042430	0.4800800	0.1928090	20.9915000	37.4991000	11.7508000	0.7080660	1.1608600	0.4318860	0.2218390	0.3962920	0.1241820
175	34.37	-118.50	0.3376520	0.5327970	0.2139820	22.9823000	41.0556000	12.8652000	0.7865400	1.2895100	0.4797520	0.2428790	0.4338770	0.1359600
175	34.37	-118.47	0.3736460	0.5895940	0.2367920	25.1553000	44.9373000	14.0816000	0.8715110	1.4288200	0.5315800	0.2658420	0.4749000	0.1488150
175	34.37	-118.44	0.4094860	0.6461470	0.2595050	27.4414000	49.0212000	15.3613000	0.9566330	1.5683700	0.5835000	0.2900020	0.5180590	0.1623390
175	34.37	-118.41	0.4401990	0.6946110	0.2789690	29.7592000	53.1618000	16.6588000	1.0296100	1.6880100	0.6280100	0.3144970	0.5618160	0.1760510
175	34.37	-118.38	0.4614540	0.7281500	0.2924390	32.2869000	57.6772000	18.0738000	1.0779500	1.7672800	0.6575000	0.3412090	0.6095350	0.1910040
175	34.37	-118.35	0.4666720	0.7363840	0.2957460	34.8570000	62.2684000	19.5125000	1.0861500	1.7807100	0.6624970	0.3683710	0.6580550	0.2062090
175	34.37	-118.32	0.4398770	0.6941030	0.2787650	32.6521000	58.3295000	18.2782000	1.0264900	1.6829100	0.6261130	0.3450680	0.6164290	0.1931650
175	34.37	-118.29	0.4057650	0.6402760	0.2571470	29.1647000	52.0997000	16.3260000	0.9512440	1.5595400	0.5802130	0.3082140	0.5505920	0.1725340
175	34.37	-118.26	0.3718020	0.5866840	0.2356240	26.2511000	46.8948000	14.6950000	0.8742000	1.4332300	0.5332200	0.2774230	0.4955860	0.1552970
175	34.37	-118.23	0.3513300	0.5543800	0.2226500	24.6749000	44.0791000	13.8127000	0.8267340	1.3554100	0.5042680	0.2607660	0.4658310	0.1459730
175	34.37	-118.20	0.3334850	0.5262220	0.2113410	23.3766000	41.7599000	13.0859000	0.7850070	1.2870000	0.4788170	0.2470460	0.4413210	0.1382930
175	34.37	-118.17	0.3129880	0.4938790	0.1983510	21.9457000	39.2037000	12.2849000	0.7362280	1.2070300	0.4490640	0.2319230	0.4143070	0.1298270

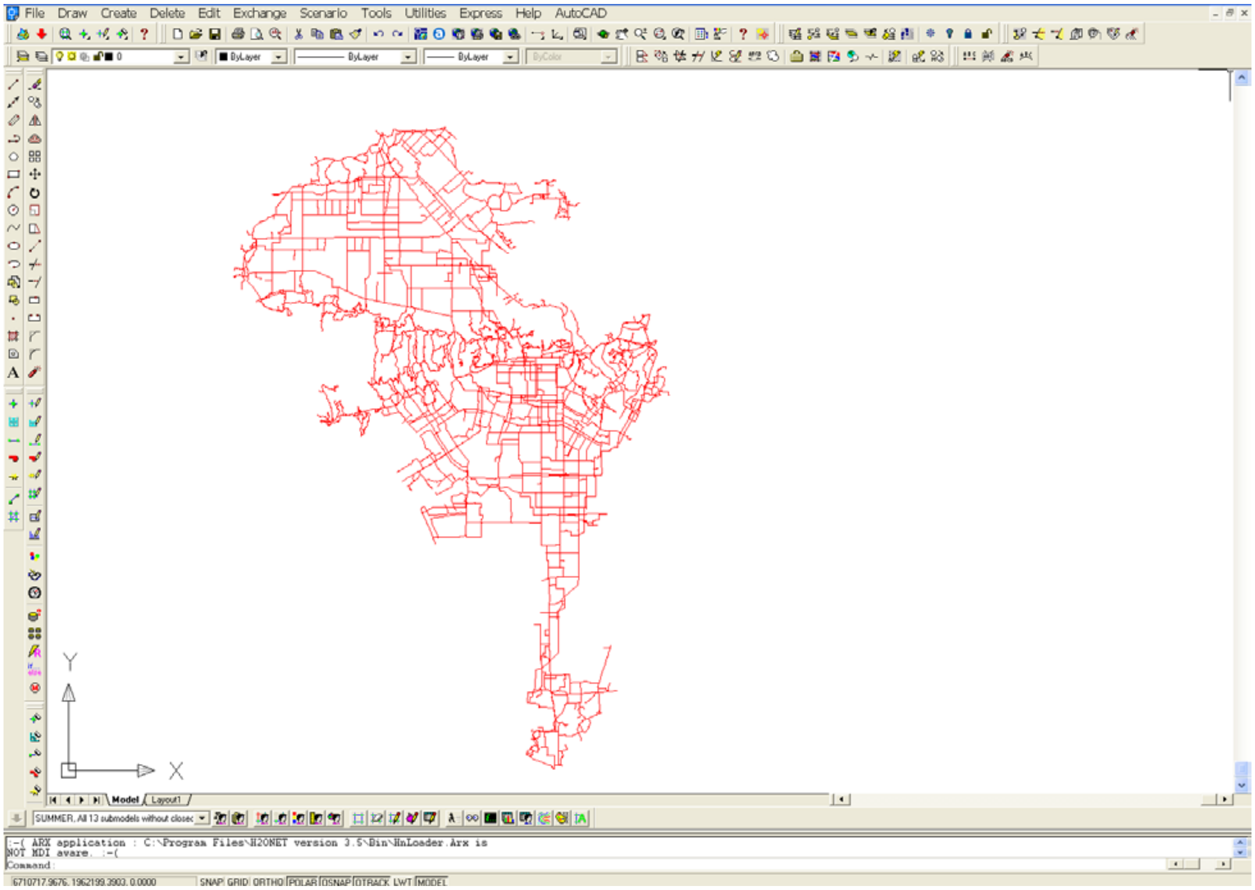
B.3 H2ONET ANALYSIS OF LADWP WATER SUPPLY SYSTEM

The system characteristics of the LADWP water supply system have been consolidated into a hydraulic network model (LADWP 2002) by LADWP engineers using a commercial software, H2ONET (MWH Soft, Inc. 1999). H2ONET is an interactive, multi-application software program for the modeling of water distribution piping systems. It combines a point and click interface for network construction, drawing, and database management. It contains highly advanced and computationally efficient hydraulic and water quality simulation modules based on EPANET (EPA 2005), and a graphical interface running within AutoCAD (Autodesk 2005) for the Windows environment. H2ONET not only is capable of construction and maintenance of the water supply system data inventory with reference to spatial coordinates, but also offers flexible data exchange with other software, such as EPANET and GIS, enabling integration with other relevant information and data.

The components in the H2ONET hydraulic network analysis can be divided into two broad categories: link-type components, such as pipelines, and node-type components, such as demand nodes. For stochastic simulations, GIRAFFE needs damage information for both the link-type and node-type components. This section describes how to export data from H2ONET to GIS for both the link-type and node-type components, after a brief description of the LADWP water supply system.

B.3.1 System Description

Figure B.2 shows the LADWP water supply system in H2ONET. The system provides water to about 3.8 million people in a service area of approximately 1,200 km^2. The total water consumption of the LADWP system in a typical summer and winter day is about 2.5×10^6 and 1.2×10^6 m^3, respectively. The water is distributed primarily by gravity flow from north to south throughout the LADWP service area. The H2ONET hydraulic network model contains 9,287 nodes and 10,665 links, representing about 2,186 km of pipelines, 1,052 demand nodes, 591 control valves, 110 tanks and reservoirs, 151 local groundwater wells, and 284 pumps.



```
:-( ARX application : C:\Program Files\H2ONET version 3.5\Bin\HnLoader.Arx is
NOT MDI aware. :-(
Command:
```

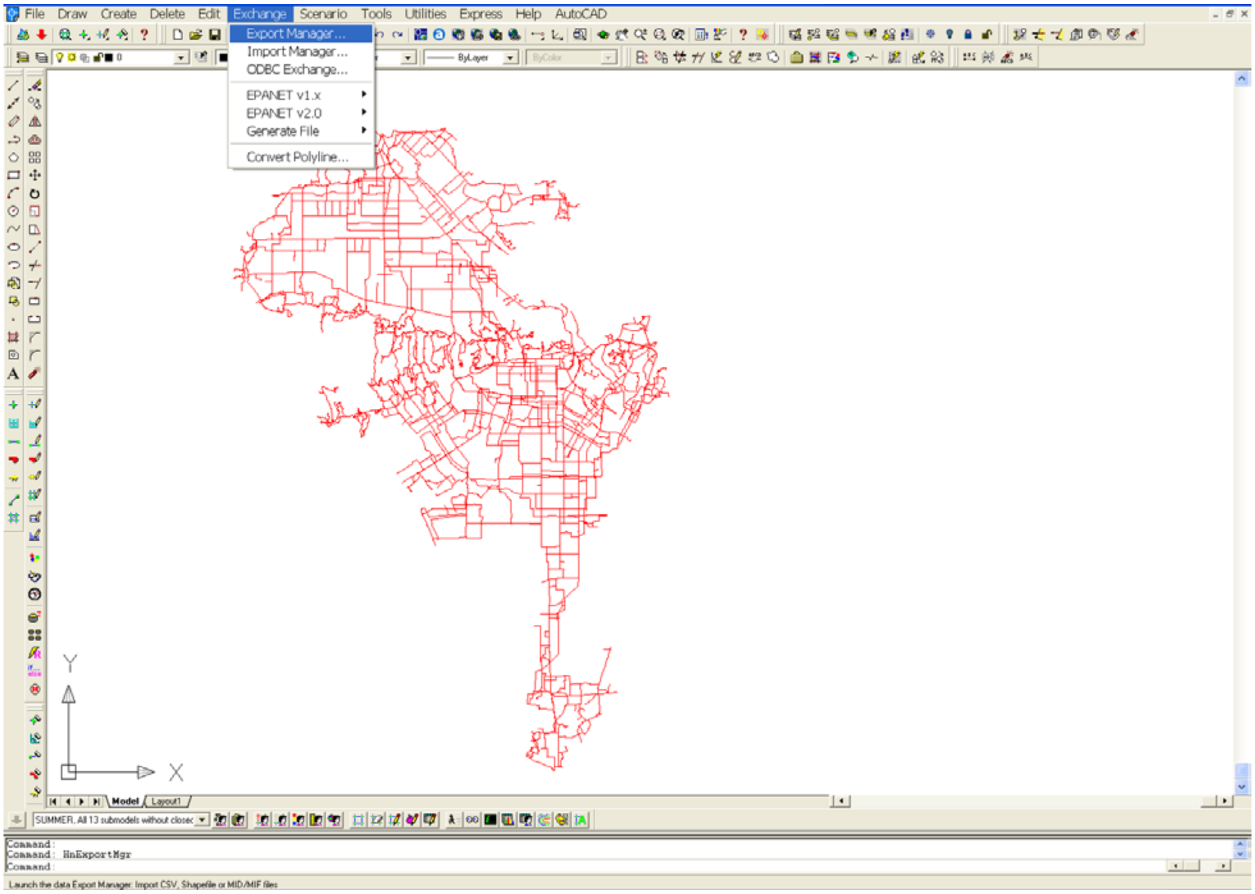
```
6710717.9676, 1962199.3903, 0.0000
```

Figure B.2. Overview of LADWP Water Supply System in H2ONET

B.3.2 Exporting Link-type Component Data to GIS

The procedures to export link-type component data from H2ONET to GIS are illustrated in this section using the pipe data as an example. To export the data from H2ONET to GIS,

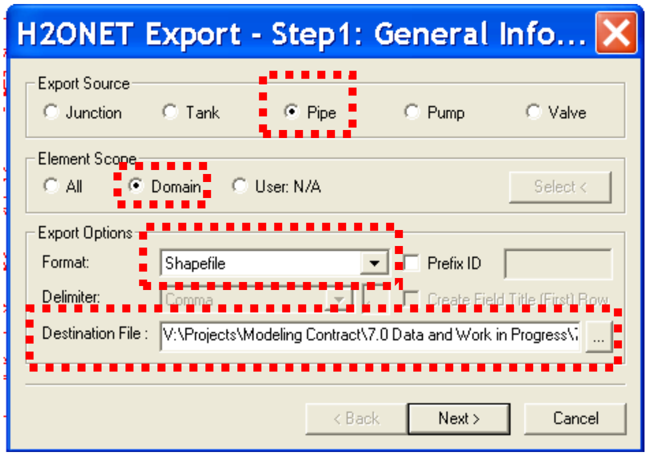
- go to the H2ONET drop-down menu **Exchange | Export Manager…**and click on it, as shown in Figure B.3
- a H2ONET Export window will open, select **Pipe** in **Export Source**, **Domain** in **Element Scope**, **Shapefile** in **Format**, name your file and specify your destination to store the file.
- Click **Next** button, and another window will open
- Click **Next** button, and another window will open
- Click **Finish** button



```
Command:
Command:  HnExportMgr
Command:
```

Launch the data Export Manager: Import CSV, Shapefile or MID/MIF files

(a) Step 1



Export Source: ○ Junction ○ Tank ● Pipe ○ Pump ○ Valve

Element Scope: ○ All ● Domain ○ User: N/A

Export Options

Format: Shapefile

☐ Prefix ID

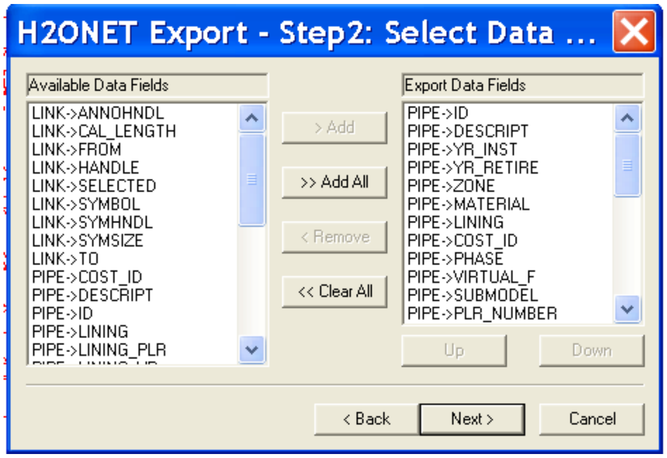
Delimiter: Comma

☐ Create Field Title (First) Row

Destination File : V:\Projects\Modeling Contract\7.0 Data and Work in Progress\

(b) Step 2

Figure B.3. Exporting Pipe Data from H2ONET to GIS



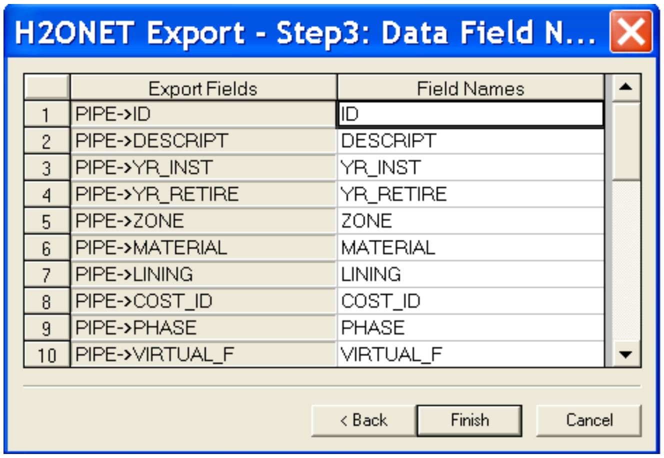
Available Data Fields:

LINK->ANNOHNDL
LINK->CAL_LENGTH
LINK->FROM
LINK->HANDLE
LINK->SELECTED
LINK->SYMBOL
LINK->SYMHNDL
LINK->SYMSIZE
LINK->TO
PIPE->COST_ID
PIPE->DESCRIPT
PIPE->ID
PIPE->LINING
PIPE->LINING_PLR

Export Data Fields:

PIPE->ID
PIPE->DESCRIPT
PIPE->YR_INST
PIPE->YR_RETIRE
PIPE->ZONE
PIPE->MATERIAL
PIPE->LINING
PIPE->COST_ID
PIPE->PHASE
PIPE->VIRTUAL_F
PIPE->SUBMODEL
PIPE->PLR_NUMBER

(c) Step 3



	Export Fields	Field Names
1	PIPE->ID	ID
2	PIPE->DESCRIPT	DESCRIPT
3	PIPE->YR_INST	YR_INST
4	PIPE->YR_RETIRE	YR_RETIRE
5	PIPE->ZONE	ZONE
6	PIPE->MATERIAL	MATERIAL
7	PIPE->LINING	LINING
8	PIPE->COST_ID	COST_ID
9	PIPE->PHASE	PHASE
10	PIPE->VIRTUAL_F	VIRTUAL_F

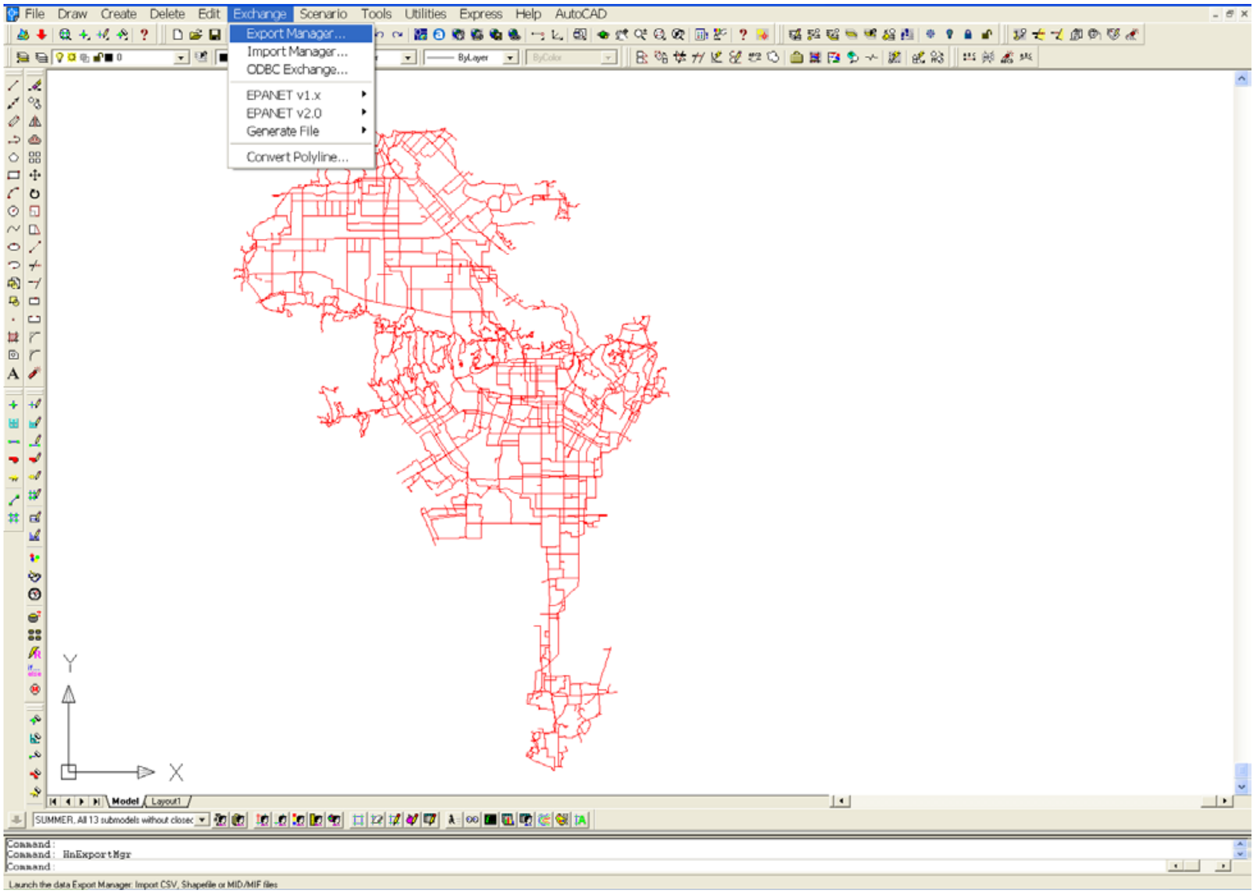
(d) Step 4

Figure B.3. Exporting Pipe Data from H2ONET to GIS (Continued)

B.3.3 Exporting Node-type Component Data to GIS

The procedures to export node-type component data from H2ONET to GIS are illustrated in this section using the junction data as an example. To export the data from H2ONET to GIS,

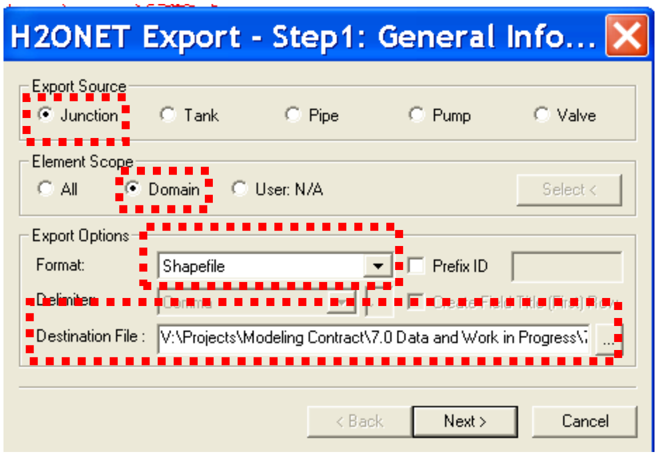
- go to the H2ONET drop-down menu **Exchange | Export Manager…**and click on it, as shown in Figure B.4



```
Command:
Command:  HnExportMgr
Command:
```

Launch the data Export Manager: Import CSV, Shapefile or MID/MIF files

(a) Step 1



Export Source: ● Junction ○ Tank ○ Pipe ○ Pump ○ Valve

Element Scope: ○ All ● Domain ○ User: N/A

Export Options

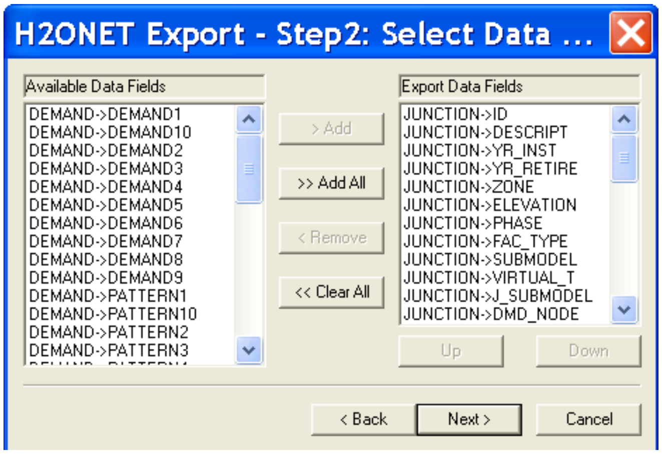
Format: Shapefile ☐ Prefix ID

Delimiter: Comma ☐ Create Field Title (First) Row

Destination File : V:\Projects\Modeling Contract\7.0 Data and Work in Progress\

(b) Step 2

Figure B.4. Exporting Junction Data from H2ONET to GIS



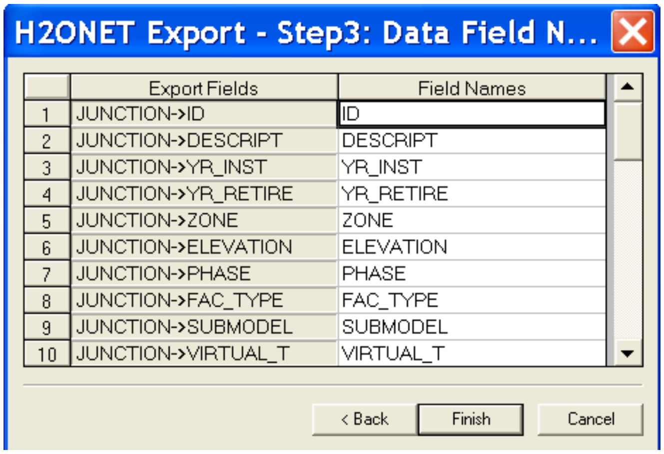
Available Data Fields

DEMAND->DEMAND1
DEMAND->DEMAND10
DEMAND->DEMAND2
DEMAND->DEMAND3
DEMAND->DEMAND4
DEMAND->DEMAND5
DEMAND->DEMAND6
DEMAND->DEMAND7
DEMAND->DEMAND8
DEMAND->DEMAND9
DEMAND->PATTERN1
DEMAND->PATTERN10
DEMAND->PATTERN2
DEMAND->PATTERN3

Export Data Fields

JUNCTION->ID
JUNCTION->DESCRIPT
JUNCTION->YR_INST
JUNCTION->YR_RETIRE
JUNCTION->ZONE
JUNCTION->ELEVATION
JUNCTION->PHASE
JUNCTION->FAC_TYPE
JUNCTION->SUBMODEL
JUNCTION->VIRTUAL_T
JUNCTION->J_SUBMODEL
JUNCTION->DMD_NODE

(c) Step 3



	Export Fields	Field Names
1	JUNCTION->ID	ID
2	JUNCTION->DESCRIPT	DESCRIPT
3	JUNCTION->YR_INST	YR_INST
4	JUNCTION->YR_RETIRE	YR_RETIRE
5	JUNCTION->ZONE	ZONE
6	JUNCTION->ELEVATION	ELEVATION
7	JUNCTION->PHASE	PHASE
8	JUNCTION->FAC_TYPE	FAC_TYPE
9	JUNCTION->SUBMODEL	SUBMODEL
10	JUNCTION->VIRTUAL_T	VIRTUAL_T

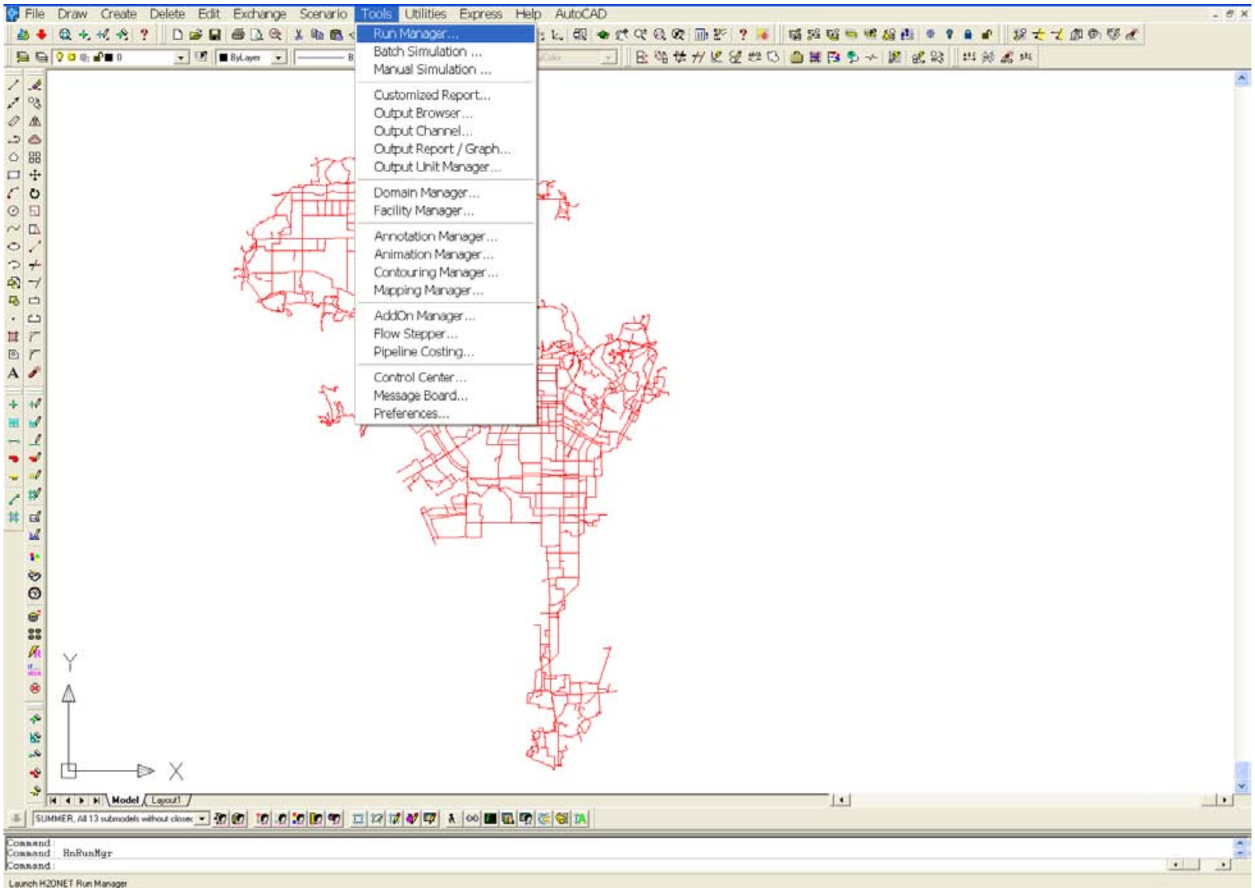
(d) Step 4

Figure B.4. Exporting Junction Data from H2ONET to GIS (Continued)

- a H2ONET Export window will open, select **Junction** in **Export Source**, **Domain** in **Element Scope**, **Shapefile** in **Format**, name your file and specify your destination to store the file.
- Click **Next** button, and another window will open
- Click **Next** button, and another window will open
- Click **Finish** button

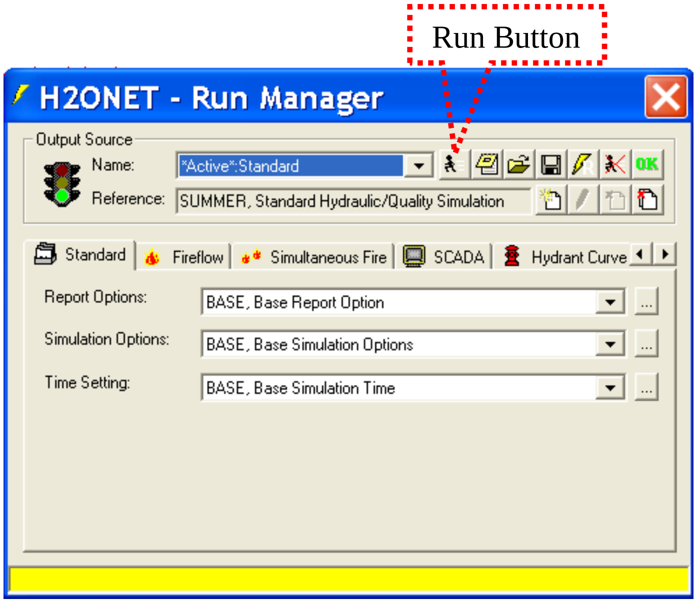
GIRAFFE accounts for the damage to distribution pipelines implicitly by adjusting the nodal demands and requires mean pressures of the undamaged, local distribution systems to facilitate such adjustment (Shi 2006 and Wang 2006). To obtain the mean pressures of the local distribution systems, the pressures at each node of the system must be first exported to GIS by the following procedures:

- Go to the H2ONET drop-down menu **Tools | Run Manager…**and click on it, as shown in Figure B.5
- A Run Manager Window will open, and click **Run** button after choosing the appropriate settings and model.
- After the simulation is finished, go to the H2ONET drop-down menu **Tools | Output Report/Graph…**and click on it.
- An Output Report Manager Window will open, and click on the **New** button
- An Output Report & Graph Window will open, select **Junction Report**, and click **OK**.
- An window will open showing the hydraulic analysis results at all nodes
- Select all the results and copy them.
- Open Microsoft Excel, paste all the node results to a new spreadsheet, and save it as ***Node_Pressure.dbf*** in a dBASE IV (**.dbf*) format, which can be directly linked to ESRI ArcGIS or Manifold System.



Command:
Command: HnRunMgr
Command:
Launch H2ONET Run Manager

(a) Step 1



Name: *Active*:Standard

Reference: SUMMER, Standard Hydraulic/Quality Simulation

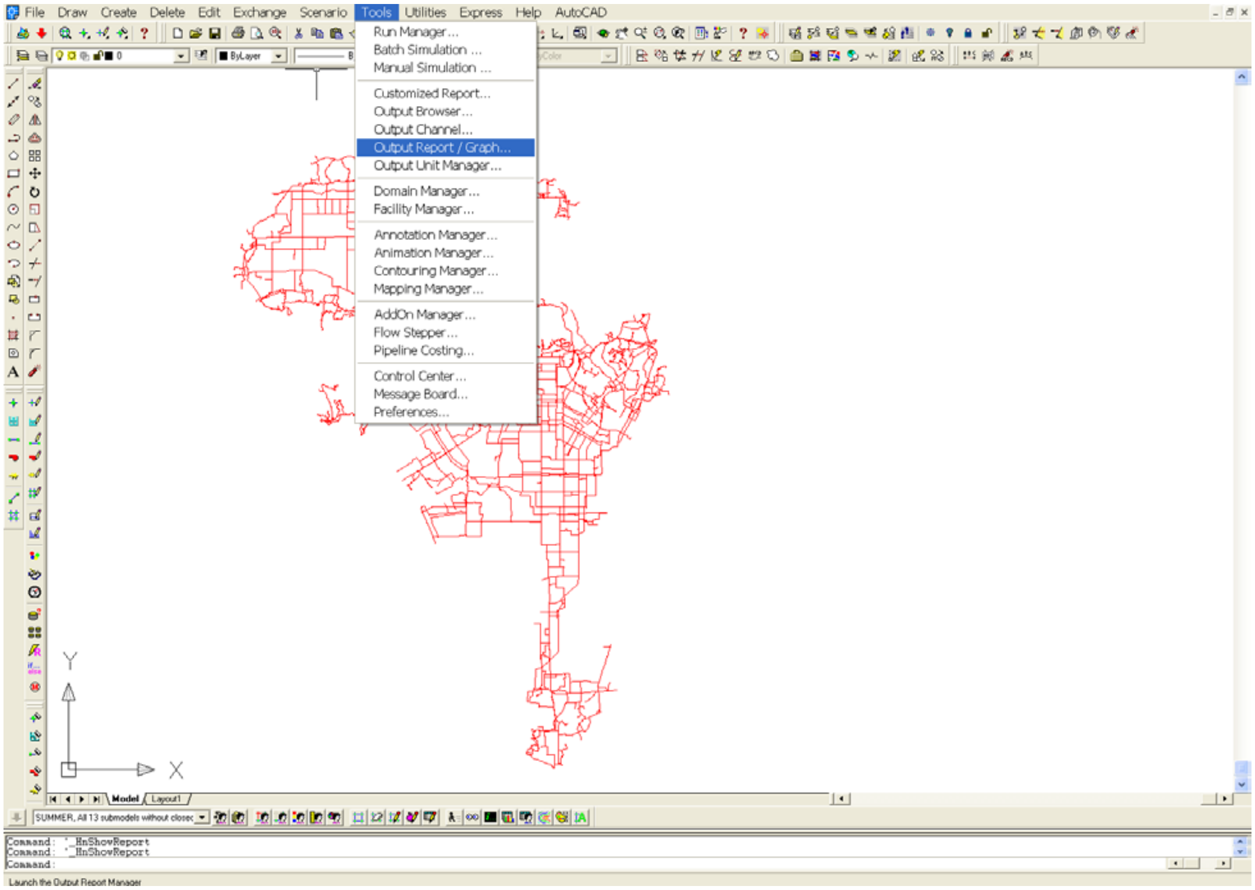
Report Options: BASE, Base Report Option

Simulation Options: BASE, Base Simulation Options

Time Setting: BASE, Base Simulation Time

(b) Step 2

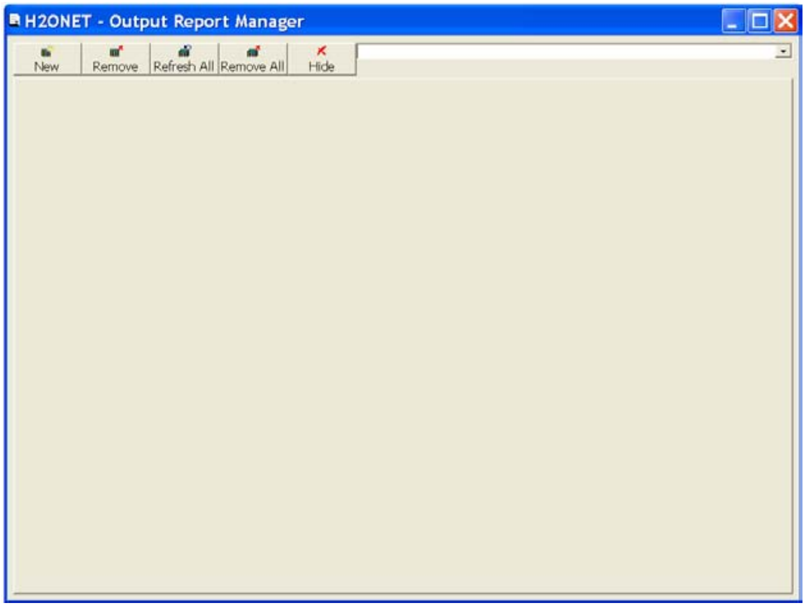
Figure B.5. Exporting Node Pressure to GIS



```
Command: '_HnShowReport
Command: '_HnShowReport
Command:
```

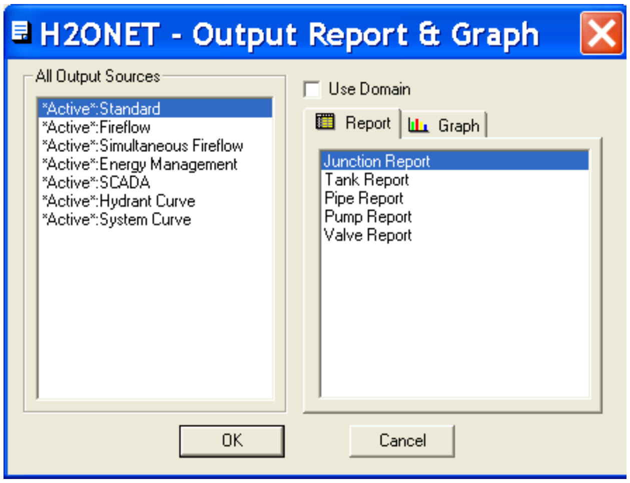
Launch the Output Report Manager

(c) Step 3

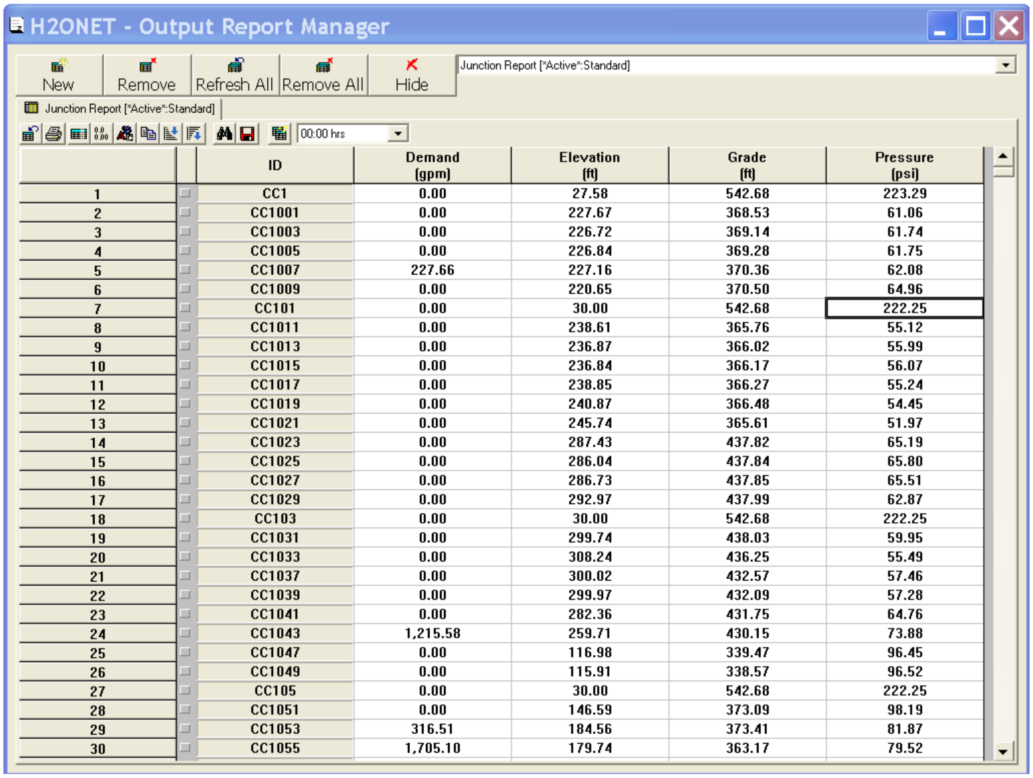


(d) Step 4

Figure B.5. Exporting Node Pressure to GIS (Continued)



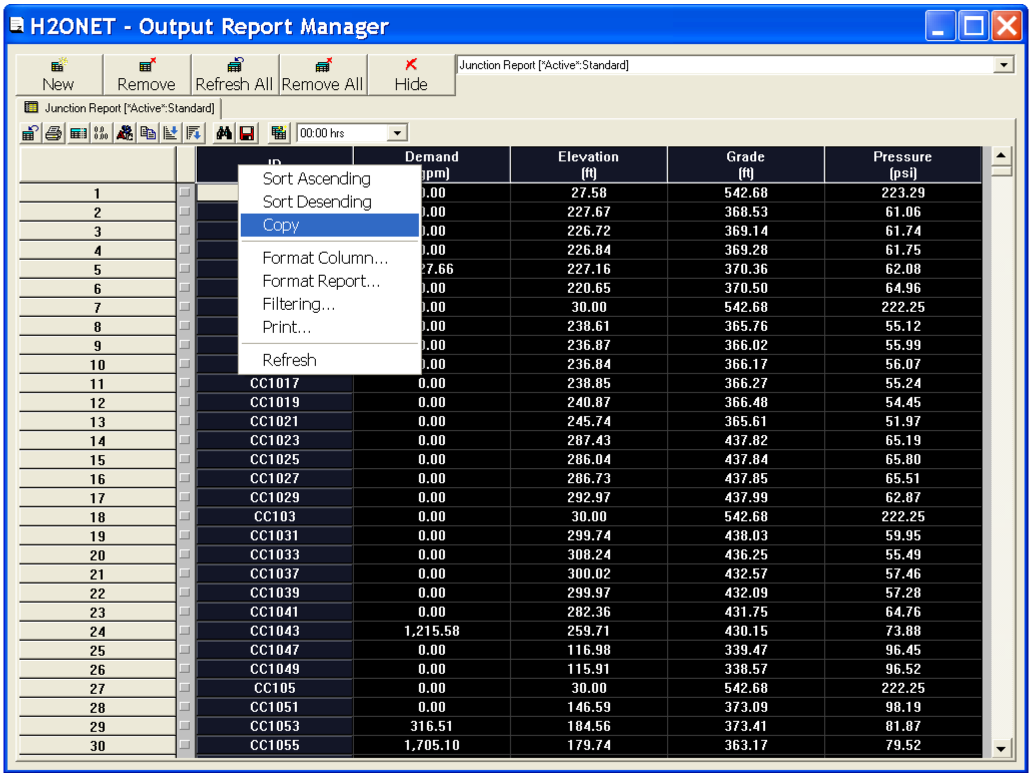
(e) Step 5



		ID	Demand (gpm)	Elevation (ft)	Grade (ft)	Pressure (psi)
1	☐	CC1	0.00	27.58	542.68	223.29
2	☐	CC1001	0.00	227.67	368.53	61.06
3	☐	CC1003	0.00	226.72	369.14	61.74
4	☐	CC1005	0.00	226.84	369.28	61.75
5	☐	CC1007	227.66	227.16	370.36	62.08
6	☐	CC1009	0.00	220.65	370.50	64.96
7	☐	CC101	0.00	30.00	542.68	222.25
8	☐	CC1011	0.00	238.61	365.76	55.12
9	☐	CC1013	0.00	236.87	366.02	55.99
10	☐	CC1015	0.00	236.84	366.17	56.07
11	☐	CC1017	0.00	238.85	366.27	55.24
12	☐	CC1019	0.00	240.87	366.48	54.45
13	☐	CC1021	0.00	245.74	365.61	51.97
14	☐	CC1023	0.00	287.43	437.82	65.19
15	☐	CC1025	0.00	286.04	437.84	65.80
16	☐	CC1027	0.00	286.73	437.85	65.51
17	☐	CC1029	0.00	292.97	437.99	62.87
18	☐	CC103	0.00	30.00	542.68	222.25
19	☐	CC1031	0.00	299.74	438.03	59.95
20	☐	CC1033	0.00	308.24	436.25	55.49
21	☐	CC1037	0.00	300.02	432.57	57.46
22	☐	CC1039	0.00	299.97	432.09	57.28
23	☐	CC1041	0.00	282.36	431.75	64.76
24	☐	CC1043	1,215.58	259.71	430.15	73.88
25	☐	CC1047	0.00	116.98	339.47	96.45
26	☐	CC1049	0.00	115.91	338.57	96.52
27	☐	CC105	0.00	30.00	542.68	222.25
28	☐	CC1051	0.00	146.59	373.09	98.19
29	☐	CC1053	316.51	184.56	373.41	81.87
30	☐	CC1055	1,705.10	179.74	363.17	79.52

(f) Step 6

Figure B.5. Exporting Node Pressure to GIS (Continued)



Junction Report [*Active*:Standard]

00:00 hrs

	ID	Demand gpm)	Elevation (ft)	Grade (ft)	Pressure (psi)
1		.00	27.58	542.68	223.29
2		.00	227.67	368.53	61.06
3		.00	226.72	369.14	61.74
4		.00	226.84	369.28	61.75
5		7.66	227.16	370.36	62.08
6		.00	220.65	370.50	64.96
7		.00	30.00	542.68	222.25
8		.00	238.61	365.76	55.12
9		.00	236.87	366.02	55.99
10		.00	236.84	366.17	56.07
11	CC1017	0.00	238.85	366.27	55.24
12	CC1019	0.00	240.87	366.48	54.45
13	CC1021	0.00	245.74	365.61	51.97
14	CC1023	0.00	287.43	437.82	65.19
15	CC1025	0.00	286.04	437.84	65.80
16	CC1027	0.00	286.73	437.85	65.51
17	CC1029	0.00	292.97	437.99	62.87
18	CC103	0.00	30.00	542.68	222.25
19	CC1031	0.00	299.74	438.03	59.95
20	CC1033	0.00	308.24	436.25	55.49
21	CC1037	0.00	300.02	432.57	57.46
22	CC1039	0.00	299.97	432.09	57.28
23	CC1041	0.00	282.36	431.75	64.76
24	CC1043	1,215.58	259.71	430.15	73.88
25	CC1047	0.00	116.98	339.47	96.45
26	CC1049	0.00	115.91	338.57	96.52
27	CC105	0.00	30.00	542.68	222.25
28	CC1051	0.00	146.59	373.09	98.19
29	CC1053	316.51	184.56	373.41	81.87
30	CC1055	1,705.10	179.74	363.17	79.52

(g) Step 7

Figure B.5. Exporting Node Pressure to GIS (Continued)

B.4 GIS SPATIAL ANALYSIS AND EXCEL SPREADSHEET CALCULATION

After the seismic hazard in the LADWP water supply system is characterized by the 59 scenario earthquakes and the system characteristics of the LADWP system are exported from H2ONET, GIS spatial analysis and Excel spreadsheet calculations are followed to generate the system damage files in GIRAFFE format. This section first describes how to calculate the mean pressures at each demand node, followed by interpolation of strong ground motion data and site condition correction. Then it demonstrates the procedures to assign strong ground motion demands to both link-type and node-type components of water system. This section uses the Scenario 175 Verdugo earthquake as an illustration, and the same procedures apply to each of the 59 scenario earthquakes.

B.4.1. Importing LADWP Water Supply System in GIS

To import the LADWP water supply system into a GIS, launch ESRI ArcGIS or Manifold System 7.x and add the pipe (***epa_pipes*** in this example) and junction data (*epa_junctions* in this example) in ArcMap or in your Manifold project, as shown in Figure B.6(a) (ArcGIS) and B.6(b) (Manifold System). After importing both shapefiles, assign their projection to be State Plane – California 5, North American Datum (NAD) of 1983, with units of feet. To do this in Manifold, right click on each file and select **Assign Projection**. In the pop-up window, go to **National Grids | State Plane (NAD83, feet) | State Plane – California 5**, and make sure that the center latitude/longitude, offset, scale, false easting/northing, and units match what is shown in Figure B.6(c). To project the shapefiles in ArcGIS, open ArcToolbox and go to **Data Management Tools | Projections | Project Wizard (shapefiles, geodatabases)**. Follow the instructions in the Projection Wizard and in the **Spatial Reference Properties** window click the **Select** button to select a predefined coordinate system. In the **Browse for Coordinate System** window, go to **Projected Coordinate Systems | State Plane | NAD83 (Feet) | NAD 1983 StatePlane California V FIPS 0405 (Feet).prj** and click the Add button.

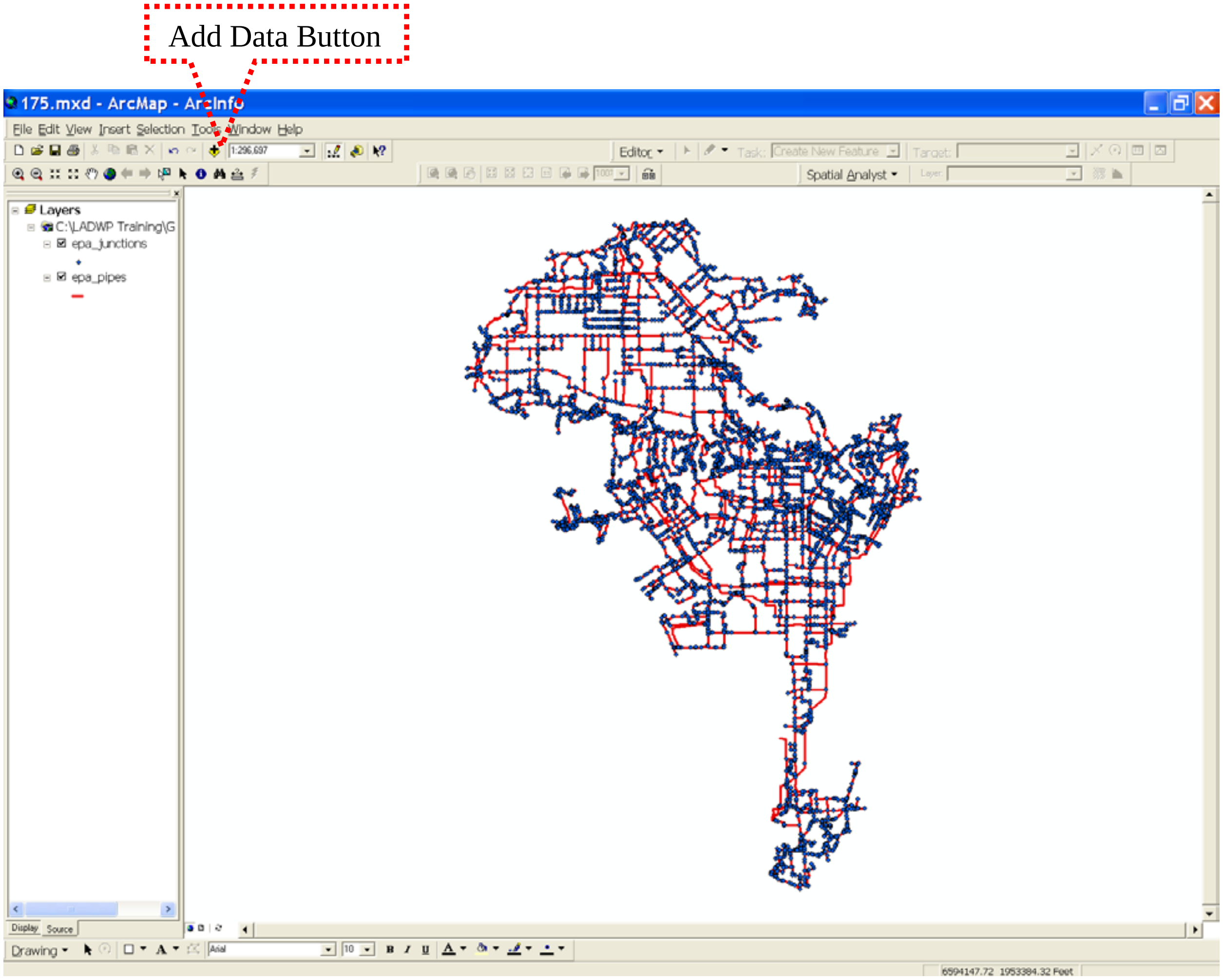

Add Data Button

Figure B.6(a). Importing Pipe and Junction Data in ESRI's ArcGIS

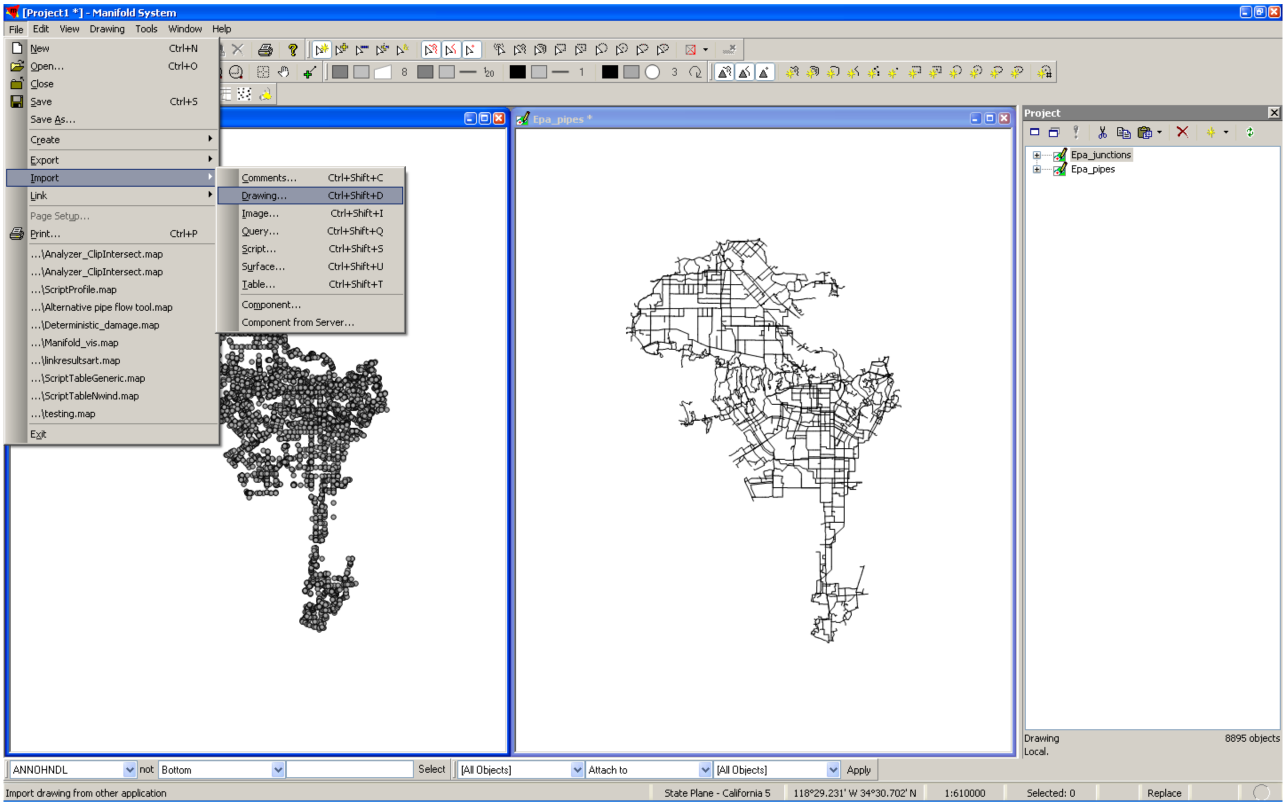
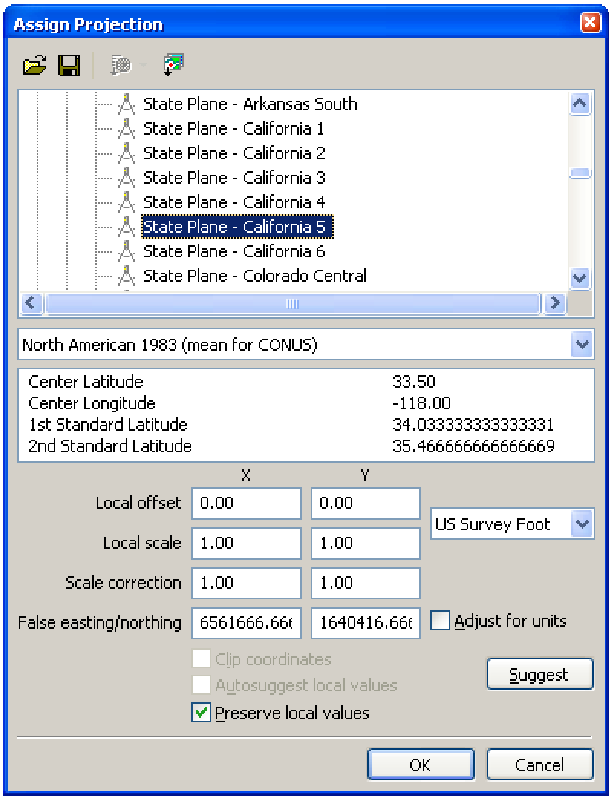


Figure B.6(b). Importing Pipe and Junction Data in Manifold System GIS.



North American 1983 (mean for CONUS)

Center Latitude	33.50
Center Longitude	-118.00
1st Standard Latitude	34.0333333333333331
2nd Standard Latitude	35.4666666666666669

	X	Y
Local offset	0.00	0.00
Local scale	1.00	1.00
Scale correction	1.00	1.00
False easting/northing	6561666.66(	1640416.66(

US Survey Foot

☐ Adjust for units

☐ Clip coordinates

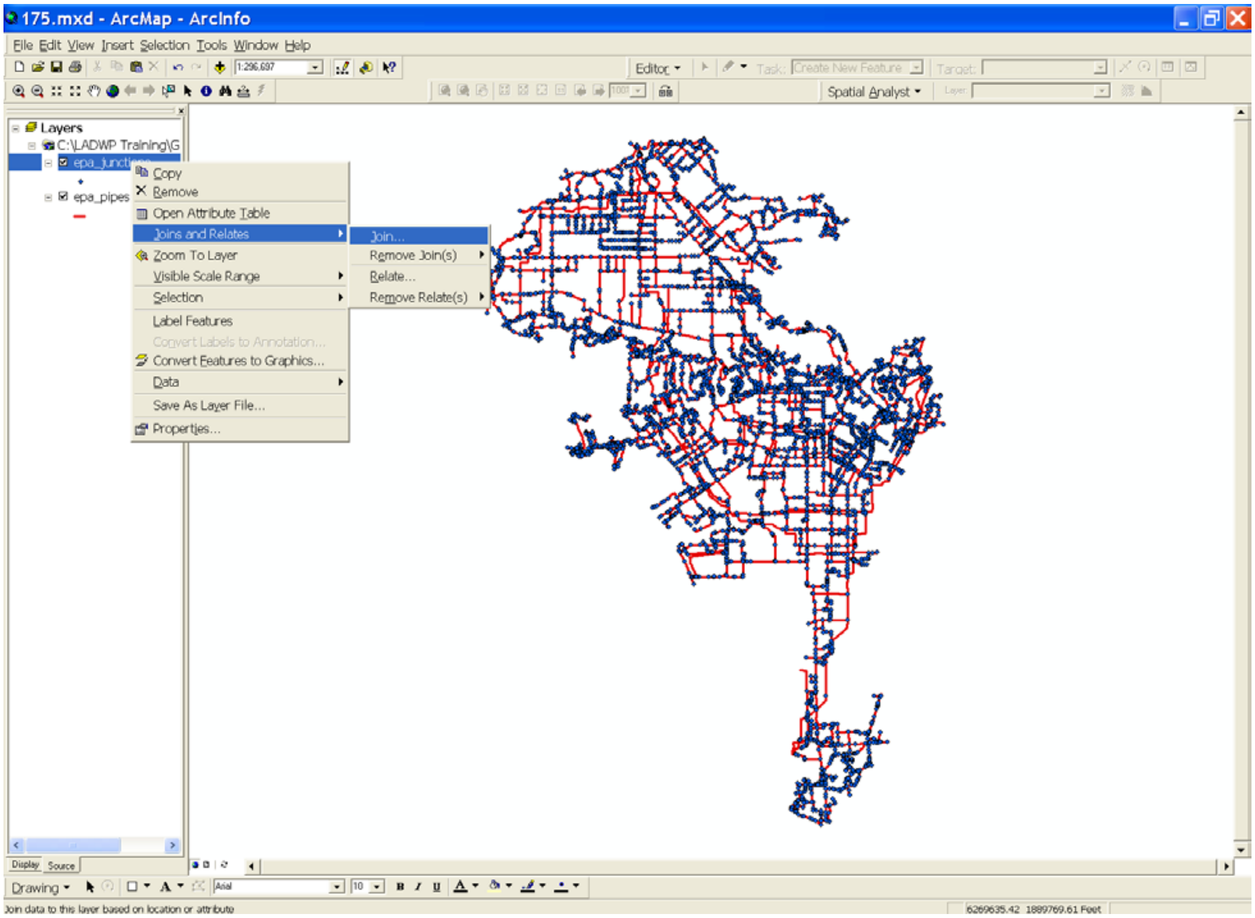
☐ Autosuggest local values

☑ Preserve local values

Figure B.6(c). Projecting Pipe and Junction Data in Manifold System GIS.

After projecting the shapefiles, calculate the mean pressures at local distribution systems:

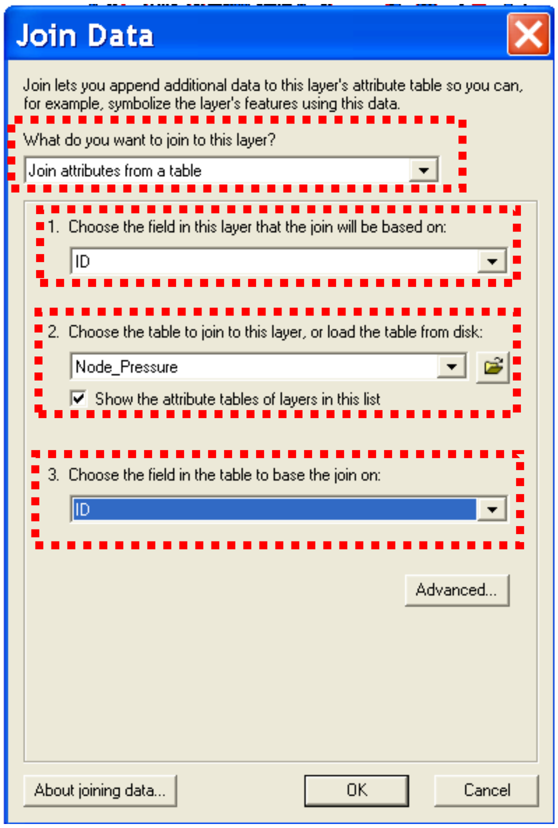
- Right-click on ***epa_junctions*** and select **Joins and Relates | Join…** from the pop-up menu, as shown in Figure B.7(a).
- A Join Data window will open. Assign the parameters as shown in Figure B.7(b) to join the node pressure data, ***Node_Pressure.dbf***, to the *epa_junctions* shapefile.
- Right-click on ***epa_junctions*** and click on **Open Attribute Table** in the pop-up menu. The attribute table of ***epa_junctions*** will open.
- Find the attribute column named **epa_junctions.Zone**, and right-click the header of the column.
- Click on **Summarize…** in the pop-up menu.
- A window will open. Assign the parameters as shown in Figure B. 7(e) to generate a file named ***MeanPressure.dbf*** containing the mean pressures for each local pressure zone
- Right-click on ***epa_junctions*** and go to the pop-up menu **Joins and Relates | Join…**, as shown in Figure B. 7(a).
- The Join Data window will open. Assign the parameters as shown in Figure B.7(f) to join ***MeanPressure.dbf*** to *epa_junctions*.



Join data to this layer based on location or attribute

(a) Step 1

Figure B.7. Calculating Mean Pressure for Each Local Pressure Zone



Join lets you append additional data to this layer's attribute table so you can, for example, symbolize the layer's features using this data.

What do you want to join to this layer?

Join attributes from a table

1. Choose the field in this layer that the join will be based on:

ID

2. Choose the table to join to this layer, or load the table from disk:

Node_Pressure

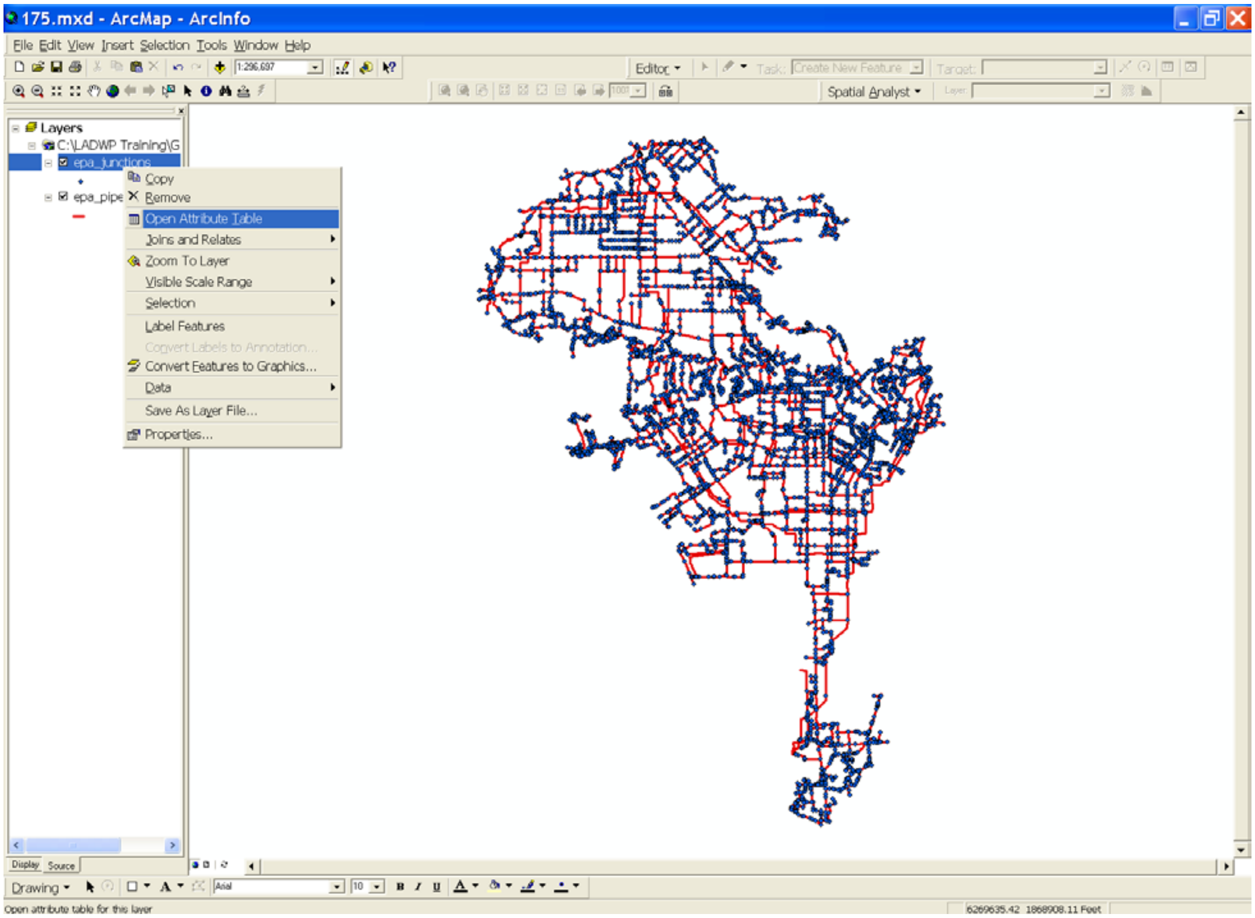
☑ Show the attribute tables of layers in this list

3. Choose the field in the table to base the join on:

ID

(b) Step 2

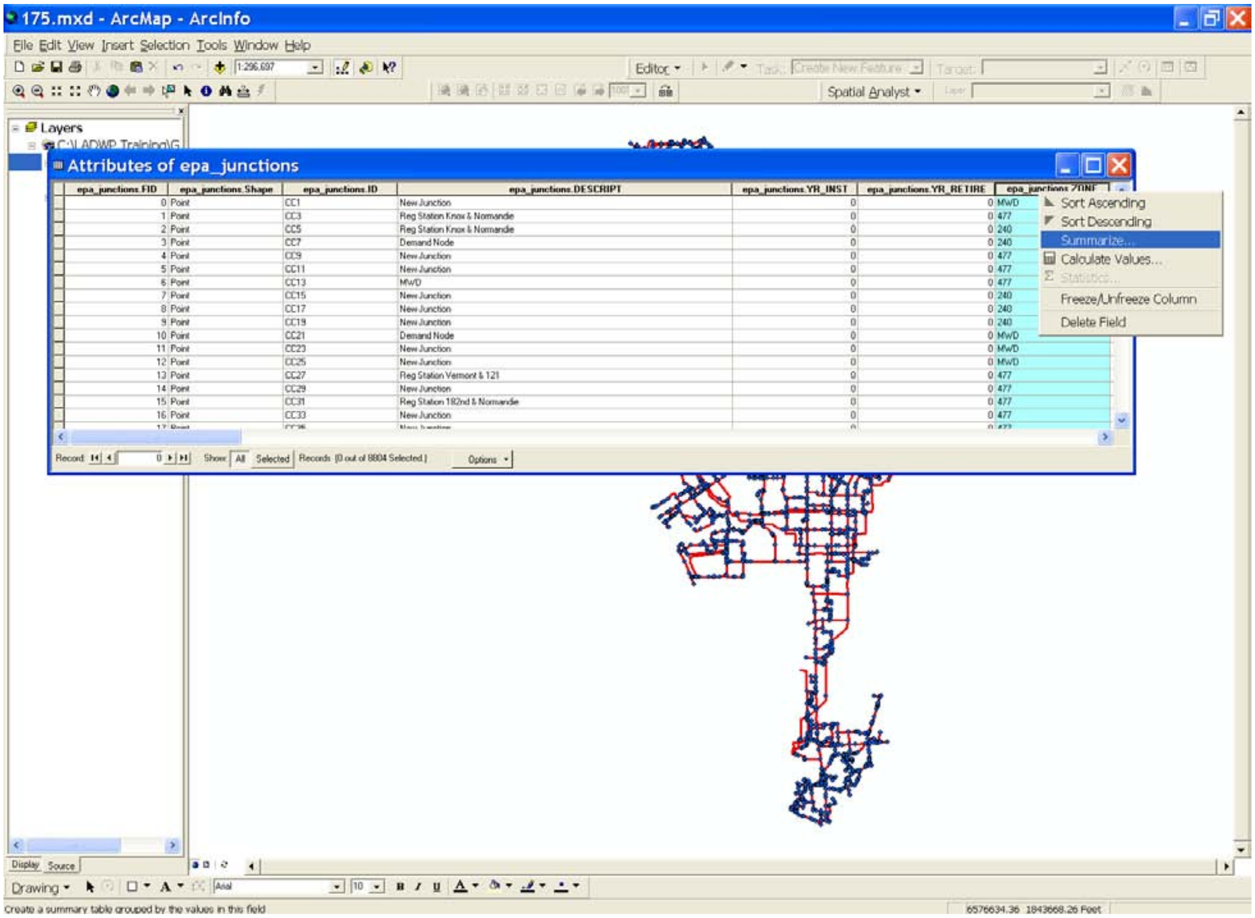
Figure B.7. Calculating Mean Pressure for Each Local Pressure Zone (Continued)



Open attribute table for this layer

(c) Step 3

Figure B.7. Calculating Mean Pressure for Each Local Pressure Zone (Continued)



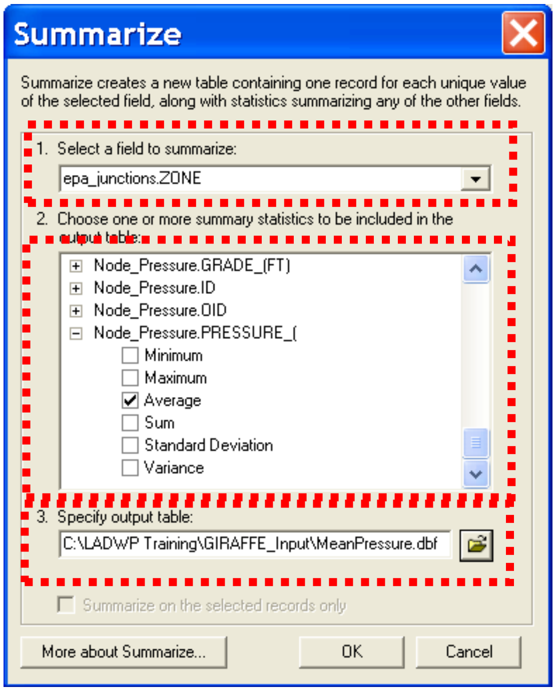
epa_junctions.FID	epa_junctions.Shape	epa_junctions.ID	epa_junctions.DESCRIPT	epa_junctions.YR_INST	epa_junctions.YR_RETIRE	epa_junctions.ZONE
0	Point	CC1	New Junction	0	0	MWD
1	Point	CC3	Reg Station Knox & Normandie	0	0	477
2	Point	CC5	Reg Station Knox & Normandie	0	0	240
3	Point	CC7	Demand Node	0	0	240
4	Point	CC9	New Junction	0	0	477
5	Point	CC11	New Junction	0	0	477
6	Point	CC13	MWD	0	0	477
7	Point	CC15	New Junction	0	0	240
8	Point	CC17	New Junction	0	0	240
9	Point	CC19	New Junction	0	0	240
10	Point	CC21	Demand Node	0	0	MWD
11	Point	CC23	New Junction	0	0	MWD
12	Point	CC25	New Junction	0	0	MWD
13	Point	CC27	Reg Station Vermont & 121	0	0	477
14	Point	CC29	New Junction	0	0	477
15	Point	CC31	Reg Station 182nd & Normandie	0	0	477
16	Point	CC33	New Junction	0	0	477

Records (0 out of 8804 Selected.)

Create a summary table grouped by the values in this field

(d) Step 4

Figure B.7. Calculating Mean Pressure for Each Local Pressure Zone (Continued)



Summarize

Summarize creates a new table containing one record for each unique value of the selected field, along with statistics summarizing any of the other fields.

1. Select a field to summarize:

epa_junctions.ZONE

2. Choose one or more summary statistics to be included in the output table:

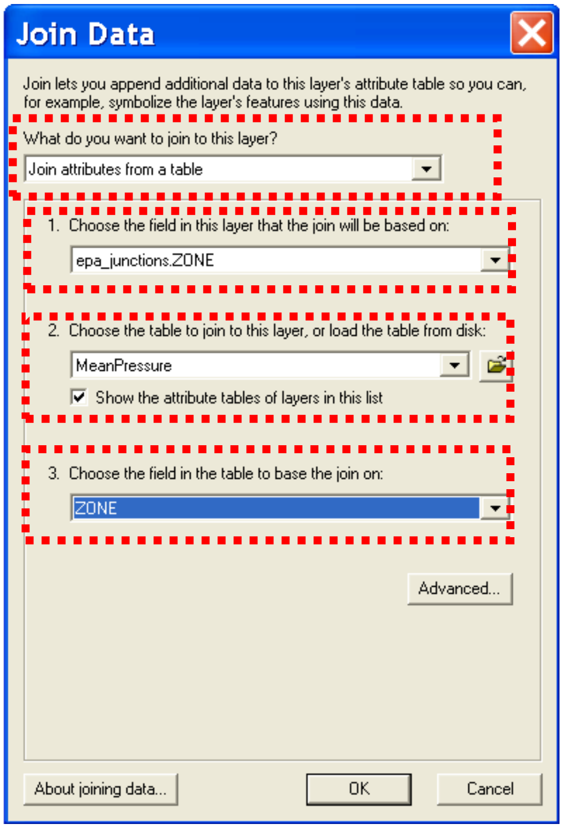
- Node_Pressure.GRADE_(FT)
- Node_Pressure.ID
- Node_Pressure.OID
- Node_Pressure.PRESSURE_(
  - ☐ Minimum
  - ☐ Maximum
  - ☑ Average
  - ☐ Sum
  - ☐ Standard Deviation
  - ☐ Variance

3. Specify output table:

C:\LADWP Training\GIRAFFE_Input\MeanPressure.dbf

☐ Summarize on the selected records only

(e) Step 5



Join Data

Join lets you append additional data to this layer's attribute table so you can, for example, symbolize the layer's features using this data.

What do you want to join to this layer?

Join attributes from a table

1. Choose the field in this layer that the join will be based on:

epa_junctions.ZONE

2. Choose the table to join to this layer, or load the table from disk:

MeanPressure

☑ Show the attribute tables of layers in this list

3. Choose the field in the table to base the join on:

ZONE

(f) Step 6

Figure B.7. Calculating Mean Pressure for Each Local Pressure Zone (Continued)

GIRAFFE considers demand nodes in the LADWP trunk line system as an approximation of local distribution systems and adjusts the nodal demands to simulate the local distribution pipeline damage indirectly. Therefore, only the information regarding the demand nodes is required in GIRAFFE simulations. To obtain the GIS data containing the demand nodes only:

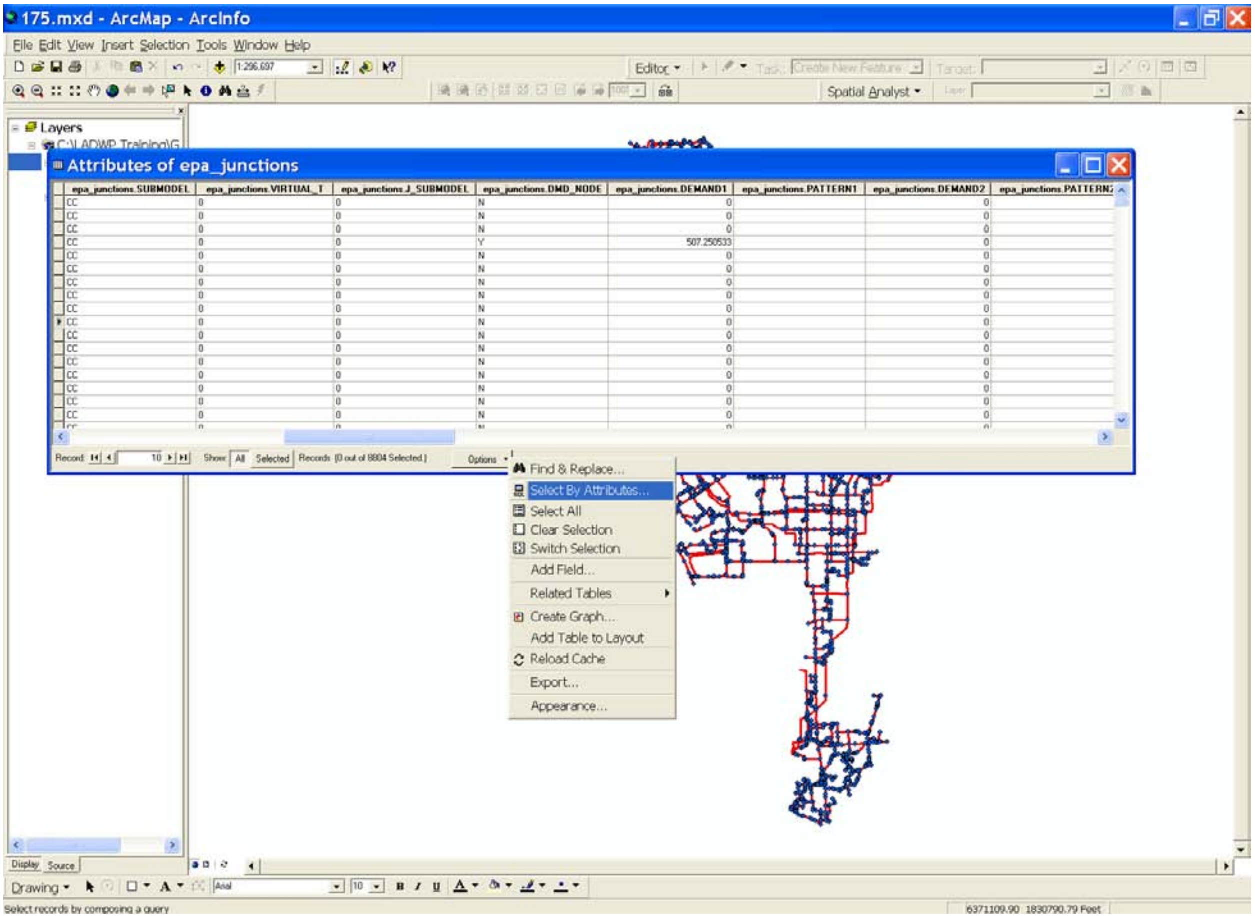
- open the attribute table of ***epa_junctions***, as shown in Figure B. 8(a).
- Click on the **Option** button at the bottom of the attribute table.
- Click on **Select by Attributes…** in the pop-up menu.
- In the Select by Attributes window, key in the syntax as shown in Figure B. 8(b), and click **Apply** button.
- Right-click on ***epa_junctions*** and go to the pop-up menu **Data | Export Data…**, as shown in Figure B. 8(c)
- An Export Data window will open. Name the data **DemandNode**, as shown in Figure B. 8(d)

B.4.2. Strong Ground Motion Data Interpolation

As described in Section B.2, strong ground motion data are generated at 572 points for each of the 59 scenario earthquakes. The data are provided in a **.txt* format and cannot be directly used by ESRI GIS. To convert the file format, open the strong ground motion data file (*e.g.* ***175.txt*** for the scenario 175 Verdugo earthquake) in Microsoft Excel, and save it in dBASE IV (**.dbf*) format (*e.g.* ***175.dbf***). To add the strong ground motion data to GIS,

- go to ArcMap drop-down menu **Tools | Add XY Data…**and click on it, as shown in Figure B.9(a)
- In the open window, assign the parameters as shown in Figure B.9(b), and click the **Edit...** button.
- A window will open. Click the **Select…** button as shown in Figure B.9(c).
- Another window will open. Go to **Geographic Coordinate Systems | North America |** ***North America Datum 1983.prj***, and click the **Add** button.

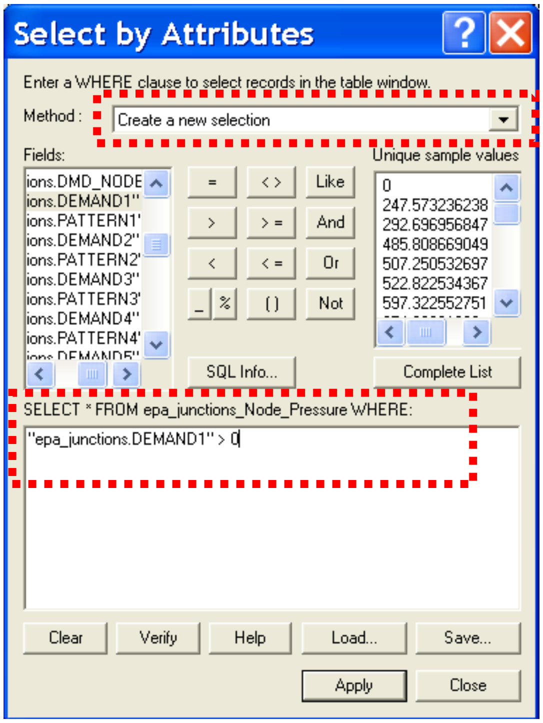
- Right-click on ***175 Events***, and go to **Data | Export Data…** in the pop-up menu, as shown in Figure B.9(g).
- A window will open. Generate strong motion data in GIS format (*.*shp*) named ***175_Data*** as shown in Figure B.9(h).



epa_junctions.SUBMODEL	epa_junctions.VIRTUAL_T	epa_junctions.J_SUBMODEL	epa_junctions.DMD_NODE	epa_junctions.DEMAND1	epa_junctions.PATTERN1	epa_junctions.DEMAND2	epa_junctions.PATTERN2
CC	0	0	N	0		0	
CC	0	0	N	0		0	
CC	0	0	N	0		0	
CC	0	0	Y	507.250533		0	
CC	0	0	N	0		0	
CC	0	0	N	0		0	
CC	0	0	N	0		0	
CC	0	0	N	0		0	
CC	0	0	N	0		0	
CC	0	0	N	0		0	
CC	0	0	N	0		0	
CC	0	0	N	0		0	
CC	0	0	N	0		0	
CC	0	0	N	0		0	
CC	0	0	N	0		0	
CC	0	0	N	0		0	
CC	0	0	N	0		0	

(a) Step 1

Figure B.8. Generating GIS Data for Demand Nodes



Enter a WHERE clause to select records in the table window.

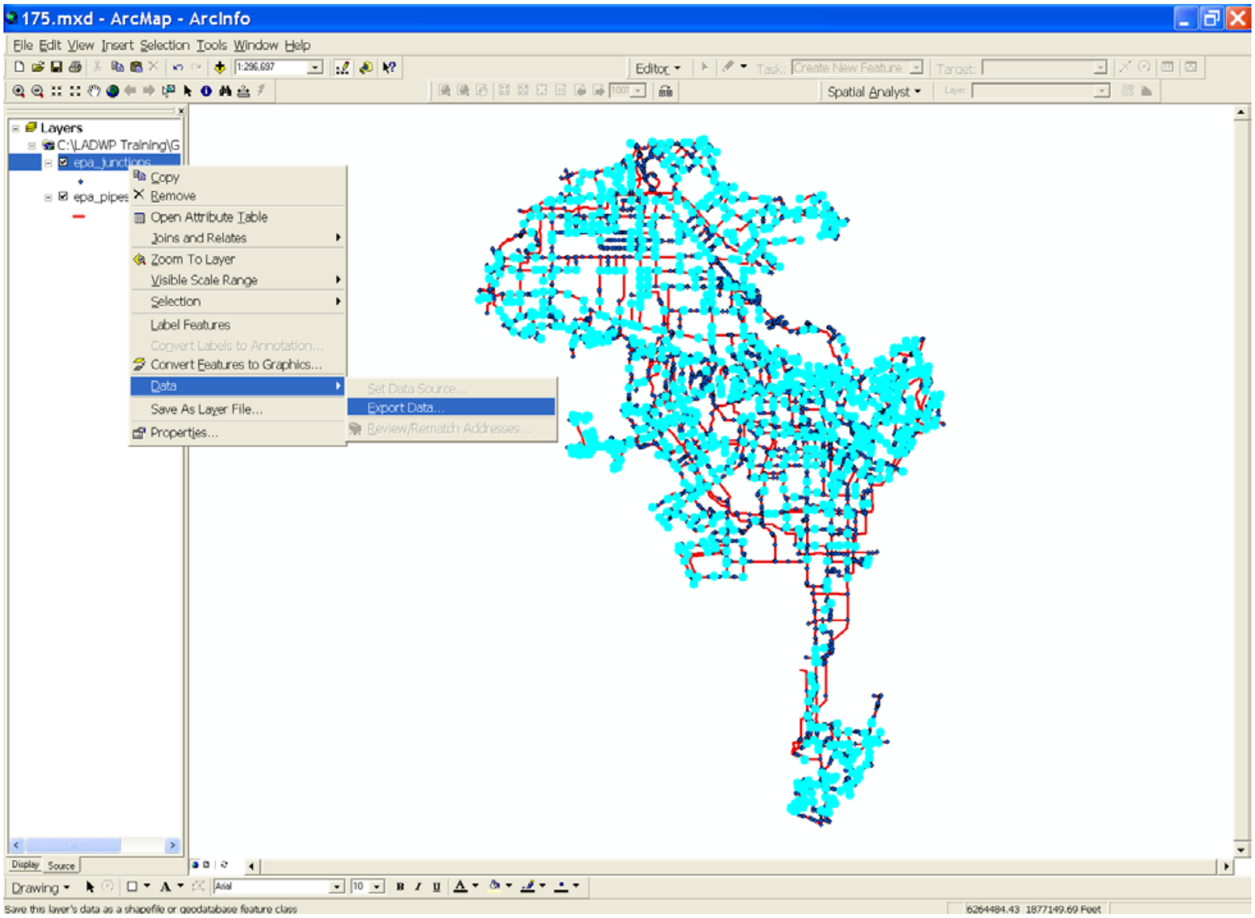
Method : Create a new selection

SELECT * FROM epa_junctions_Node_Pressure WHERE:

"epa_junctions.DEMAND1" > 0

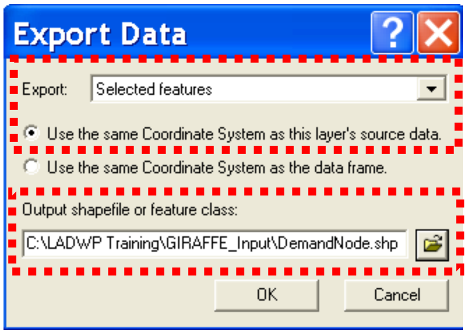
(b) Step 2

Figure B.8. Generating GIS Data for Demand Nodes (Continued)



Save this layer's data as a shapefile or geodatabase feature class

(c) Step 3



Export: Selected features

● Use the same Coordinate System as this layer's source data.

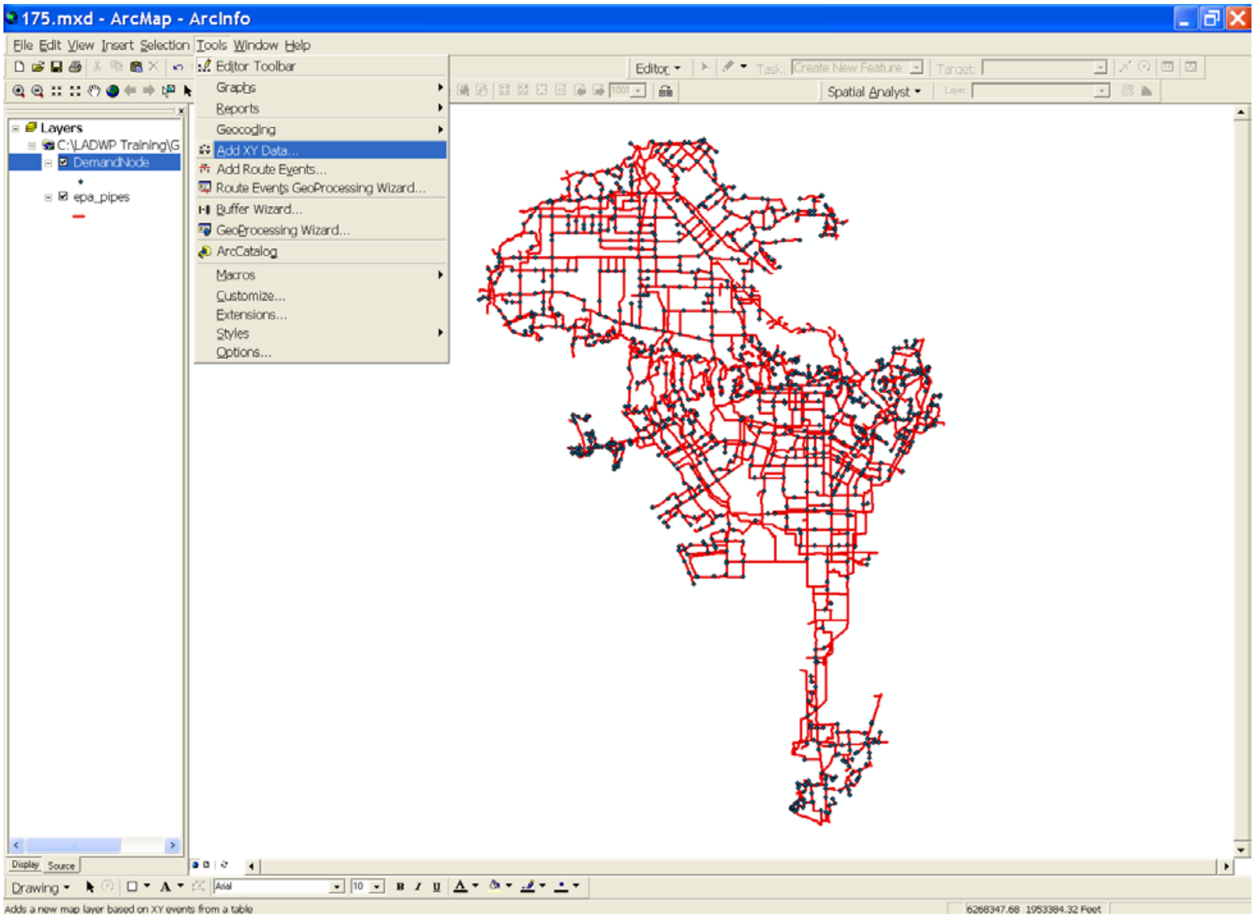
○ Use the same Coordinate System as the data frame.

Output shapefile or feature class:

C:\LADWP Training\GIRAFFE_Input\DemandNode.shp

(d) Step 4

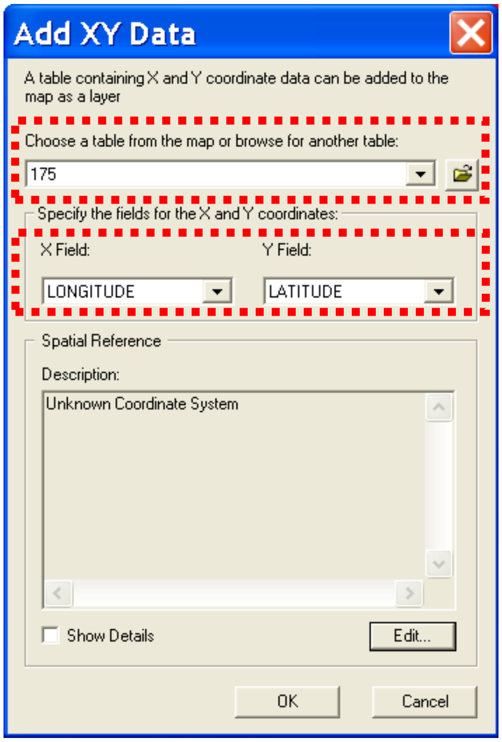
Figure B.8. Generating GIS Data for Demand Nodes (Continued)



Adds a new map layer based on XY events from a table

(a) Step 1

Figure B.9. Importing Strong Ground Motion Data in GIS



A table containing X and Y coordinate data can be added to the map as a layer

Choose a table from the map or browse for another table: 175

Specify the fields for the X and Y coordinates:

X Field: LONGITUDE

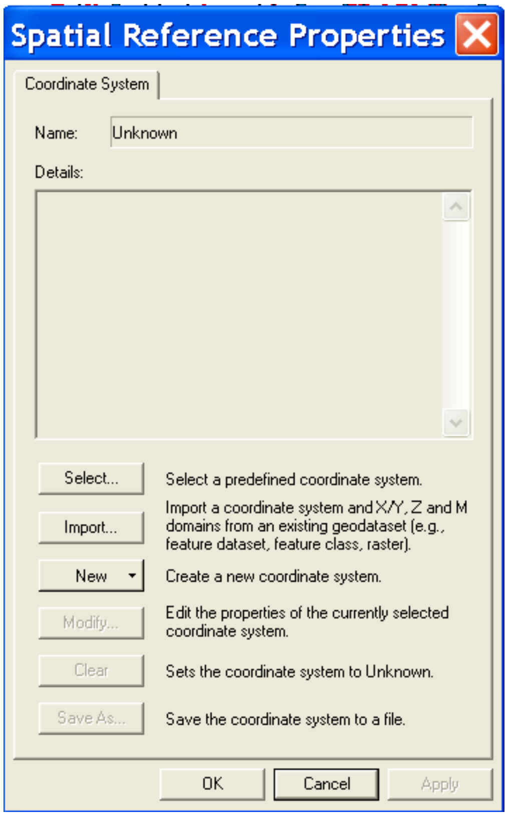
Y Field: LATITUDE

Spatial Reference

Description: Unknown Coordinate System

☐ Show Details

(b) Step 2



Name: Unknown

Details:

Select... Select a predefined coordinate system.

Import... Import a coordinate system and X/Y, Z and M domains from an existing geodataset (e.g., feature dataset, feature class, raster).

New Create a new coordinate system.

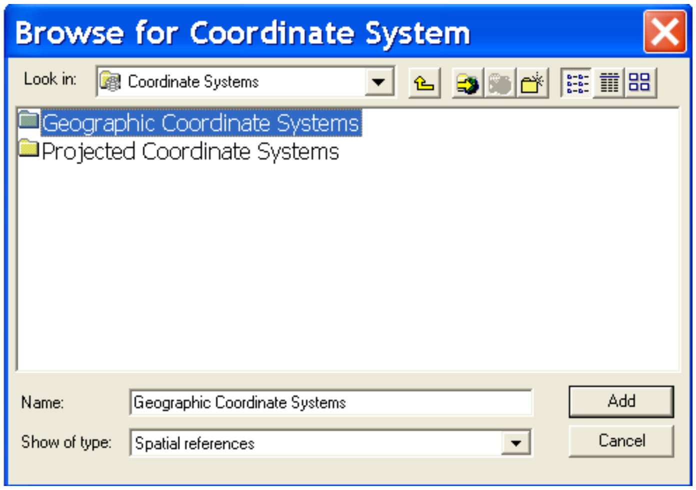
Modify... Edit the properties of the currently selected coordinate system.

Clear Sets the coordinate system to Unknown.

Save As... Save the coordinate system to a file.

(c) Step 3

Figure B.9. Importing Strong Ground Motion Data in GIS (Continued)



Look in: Coordinate Systems

Name: Geographic Coordinate Systems

Show of type: Spatial references

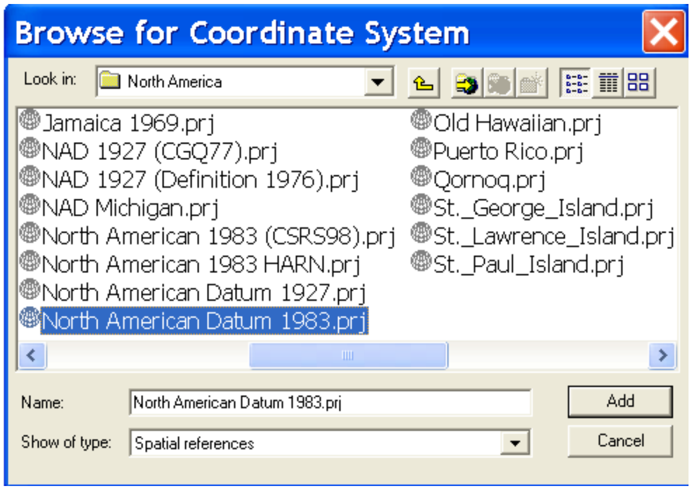
(d) Step 4

Look in: Geographic Coordinate Systems

Name: North America

Show of type: Spatial references

(e) Step 5



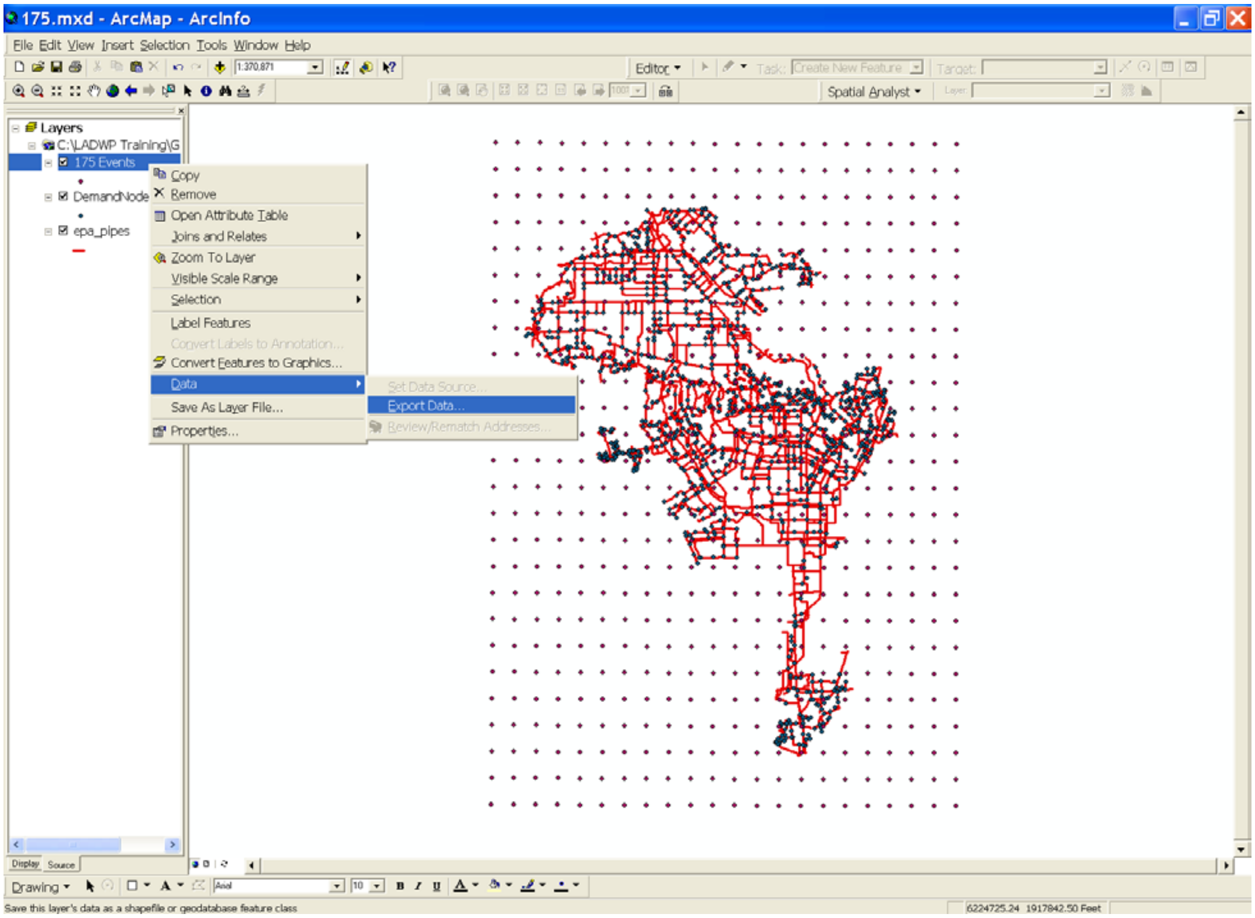
Look in: North America

Name: North American Datum 1983.prj

Show of type: Spatial references

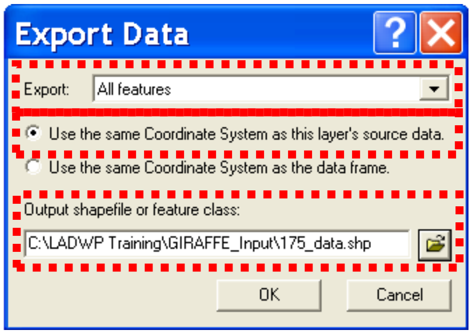
(f) Step 6

Figure B.9. Importing Strong Ground Motion Data in GIS (Continued)



Save this layer's data as a shapefile or geodatabase feature class

(g) Step 7



Export: All features

● Use the same Coordinate System as this layer's source data.

○ Use the same Coordinate System as the data frame.

Output shapefile or feature class: C:\LADWP Training\GIRAFFE_Input\175_data.shp

(h) Step 8

Figure B.9. Importing Strong Ground Motion Data in GIS (Continued)

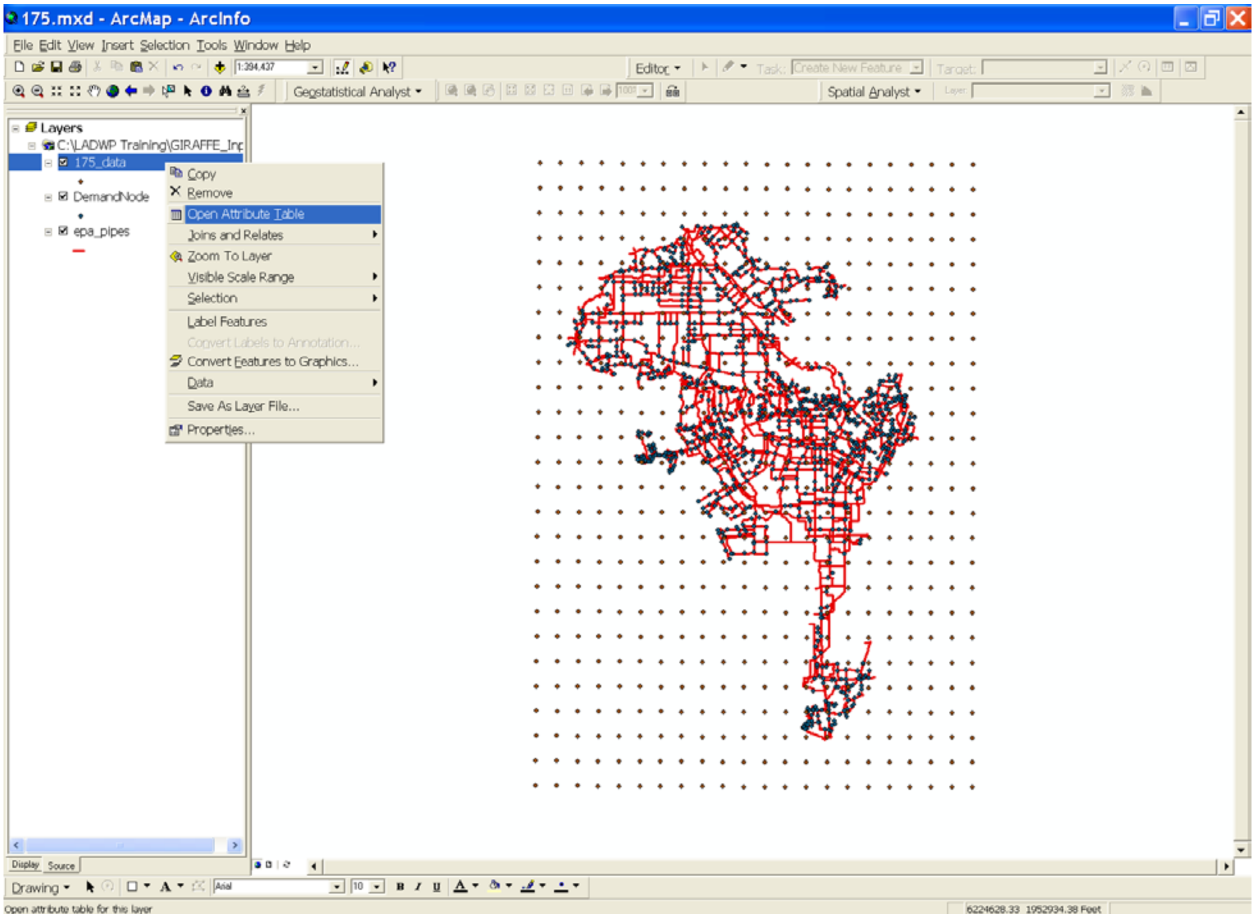
As described in Section B.2, the mean, mean + σ, and mean - σ value of the ground motion are provided, as well as an estimate of $\sigma_{\text{inter-event}}$. In the seismic performance evaluation of the LADWP water supply system, the mean + $\sigma_{\text{inter-event}}$ PGV are used (Wang 2006). To calculate the mean + $\sigma_{\text{inter-event}}$ PGV,

- open attribute table of ***175_data***, as shown in Figure B.10(a).
- Click the **Option** button at the bottom of the attribute table and select **Add Field…** in the pop-up menu.
- Create a new attribute column named **SM_PGV** with the parameters specified in Figure B.10(c).
- Right-click the header of the **SM_PGV** column and select **Calculate Values…** in the pop-up menu, as shown in Figure B.10(d).
- Ignore the warning message by clicking the **Yes** button.
- Key in the syntax in the Field Calculator window and click **OK**, as shown in Figure B.10(e).

The PGV contours based on the mean + $\sigma_{\text{inter-event}}$ value are then generated in GIS using the Geostatistical Analyst module by the following procedures:

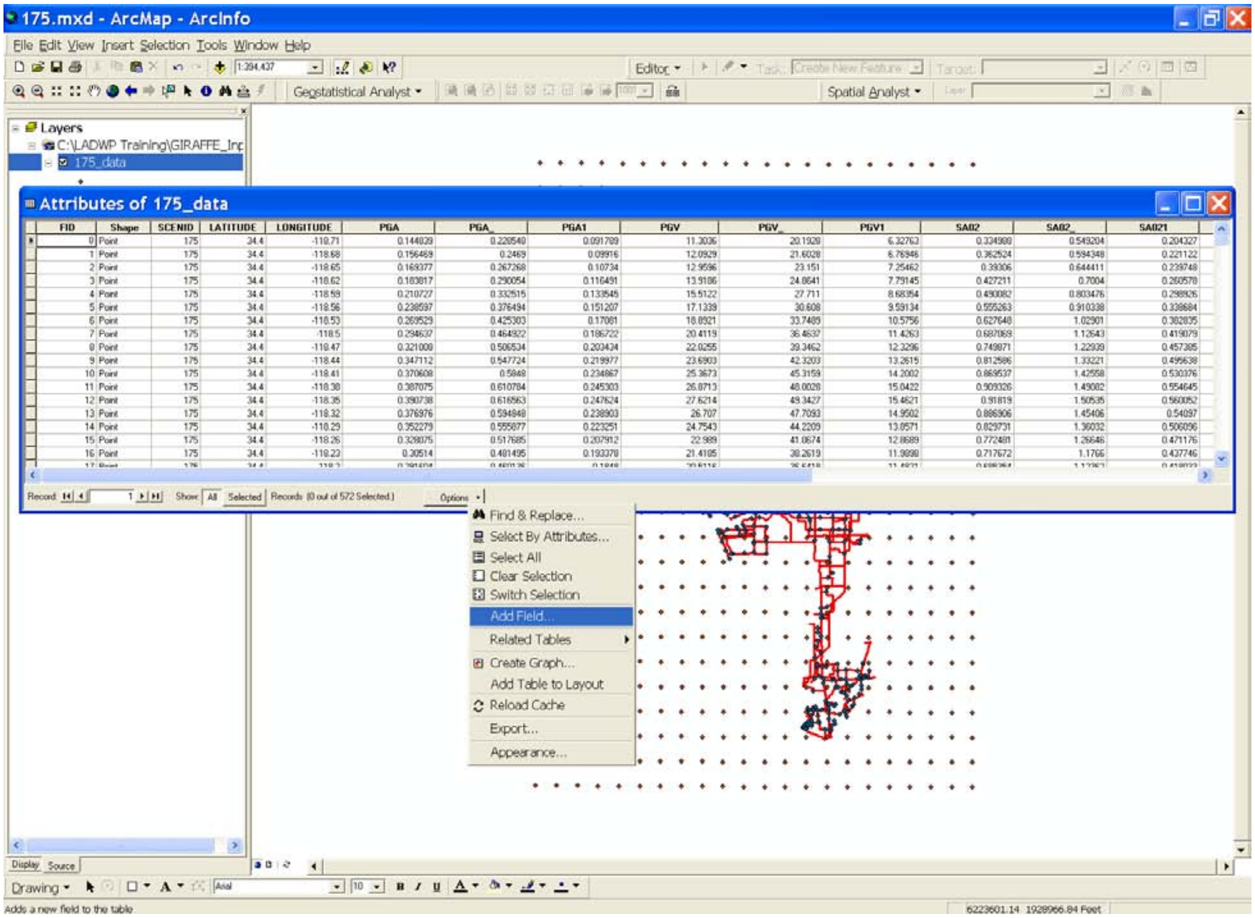
- go to **Geostatistical Analyst | Geostatistical Wizard…**, as shown in Figure B.11(a).
- The Geostatistical Wizard window will open. Assign the parameters as shown in Figure B.11(b), and click **Finish** button.
- A color contour surface will be generated as shown in Figure B.11(c).
- Right-click the contour surface, and select **Properties…** in the pop-up menu, as shown in Figure B.11(d).
- A layer properties window will open. Check **Filled contours**, click the **Symbology** tab, and then click the **Classify…** button, as shown in Figure B.11(e).
- A classification window will open, as shown in Figure B.11(f).

- Change the parameters in the classification window as shown in Figure B.11(g), and click **OK**.
- The color contour surface changes the intervals to 5 cm/sec, as shown in Figure B.11(h).
- Right-click the contour surface and go to **Data** | **Export to Vector…** in the pop-up menu, as shown in Figure B.11(i).
- A window will open. Assign the parameters to generate a GIS file name ***SM_PGV_B***, as shown in Figure B.11(j).
- Add *SM_PGV_B* to the ArcMap, as shown in Figure B.11(k).



(a) Step 1

Figure B.10. Calculating Mean + $\sigma_{\text{inter-event}}$ PGV



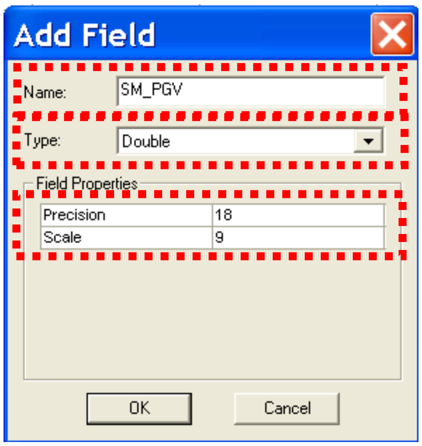
FID	Shape	SCENID	LATITUDE	LONGITUDE	PGA	PGA_	PGA1	PGV	PGV_	PGV1	SA02	SA02_	SA021
0	Point	175	34.4	-118.71	0.144829	0.220540	0.091789	11.3036	20.1920	6.32763	0.334900	0.549204	0.204327
1	Point	175	34.4	-118.68	0.156469	0.2469	0.09916	12.0929	21.6028	6.76946	0.362524	0.594348	0.221122
2	Point	175	34.4	-118.65	0.169377	0.267268	0.10734	12.9596	23.151	7.25462	0.39306	0.644411	0.239748
3	Point	175	34.4	-118.62	0.183817	0.290054	0.116491	13.9186	24.8641	7.79145	0.427211	0.7004	0.260578
4	Point	175	34.4	-118.59	0.210727	0.332515	0.133545	15.5122	27.711	8.68354	0.490082	0.803476	0.298926
5	Point	175	34.4	-118.56	0.238597	0.376494	0.151207	17.1339	30.608	9.59134	0.555263	0.910338	0.338684
6	Point	175	34.4	-118.53	0.269529	0.425303	0.17081	18.8921	33.7489	10.5756	0.627648	1.02901	0.382835
7	Point	175	34.4	-118.5	0.294637	0.464922	0.186722	20.4119	36.4637	11.4263	0.687069	1.12643	0.419079
8	Point	175	34.4	-118.47	0.321008	0.506534	0.203434	22.0255	39.3462	12.3296	0.749871	1.22939	0.457385
9	Point	175	34.4	-118.44	0.347112	0.547724	0.219977	23.6903	42.3203	13.2615	0.812586	1.33221	0.495638
10	Point	175	34.4	-118.41	0.370608	0.5848	0.234867	25.3673	45.3159	14.2002	0.869537	1.42558	0.530376
11	Point	175	34.4	-118.38	0.387075	0.610784	0.245303	26.8713	48.0028	15.0422	0.909326	1.49082	0.554645
12	Point	175	34.4	-118.35	0.390738	0.616563	0.247624	27.6214	49.3427	15.4621	0.91819	1.50535	0.560052
13	Point	175	34.4	-118.32	0.376976	0.594848	0.238903	26.707	47.7093	14.9502	0.886906	1.45406	0.54097
14	Point	175	34.4	-118.29	0.352279	0.555877	0.223251	24.7543	44.2209	13.8571	0.829731	1.36032	0.506096
15	Point	175	34.4	-118.26	0.328075	0.517685	0.207912	22.989	41.0674	12.8689	0.772481	1.26646	0.471176
16	Point	175	34.4	-118.22	0.30514	0.481495	0.193378	21.4105	38.2619	11.9898	0.717672	1.1766	0.437746

Record: 1 Show: All Selected Records (0 out of 572 Selected.) Options

Adds a new field to the table

6223601.14 1928966.84 Feet

(b) Step 2



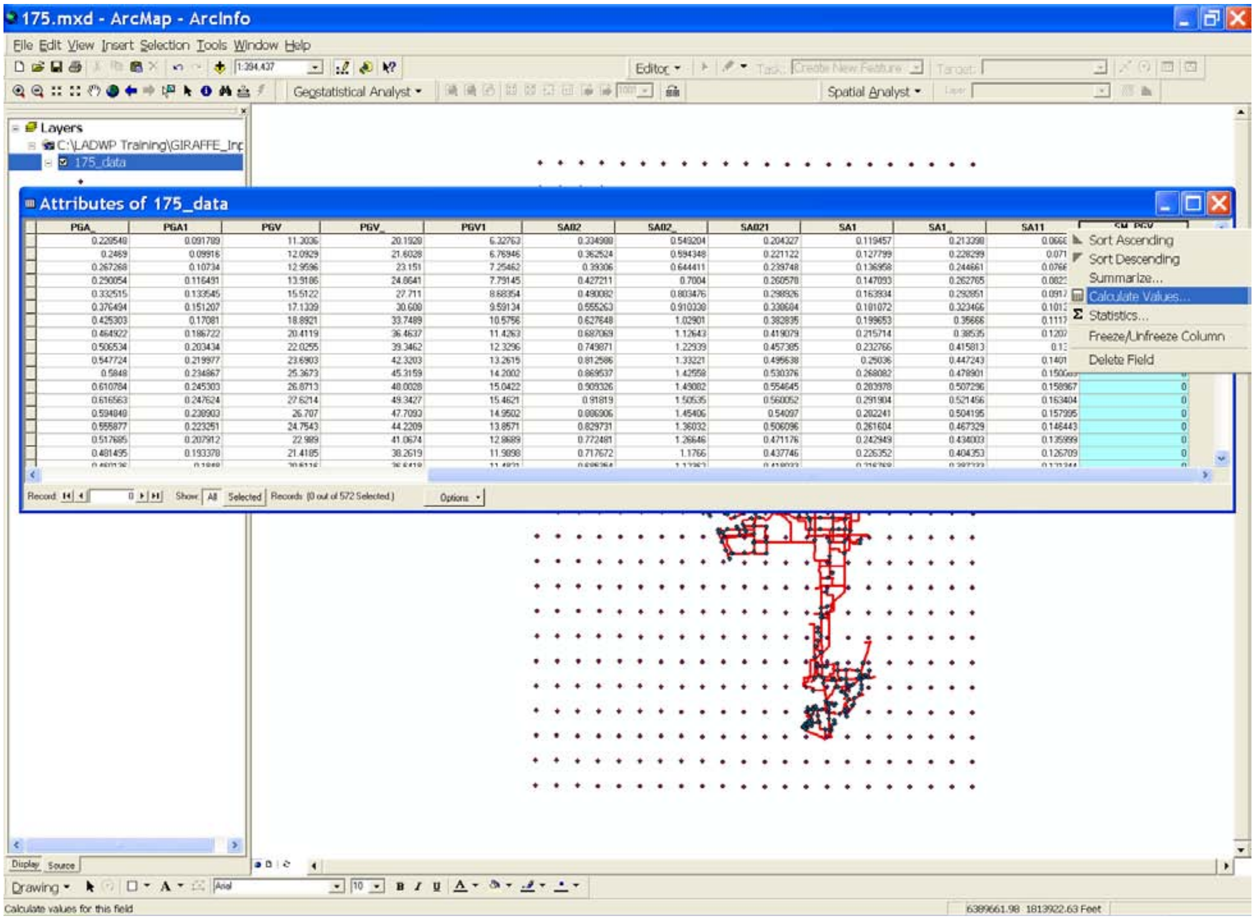
Name: SM_PGV

Type: Double

Precision	18
Scale	9

(c) Step 3

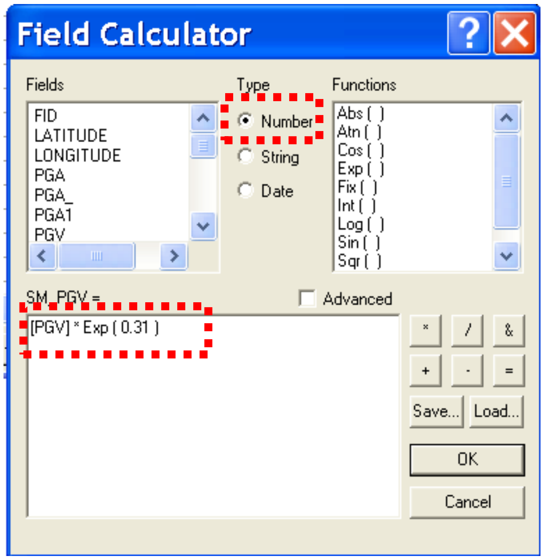
Figure B.10. Calculating Mean + $\sigma_{\text{inter-event}}$ PGV (Continued)



PGA_	PGA1	PGV	PGV_	PGV1	SA02	SA02_	SA021	SA1	SA1_	SA11	SM_PGV
0.228548	0.091789	11.3036	20.1928	6.32763	0.334988	0.549204	0.204327	0.119457	0.213398	0.066	
0.2469	0.09916	12.0929	21.6028	6.76946	0.362524	0.594348	0.221122	0.127799	0.228299	0.071	
0.267268	0.10734	12.9596	23.151	7.25462	0.39306	0.644411	0.239748	0.136958	0.244661	0.076	
0.290054	0.116491	13.9186	24.8641	7.79145	0.427211	0.7004	0.260578	0.147093	0.262765	0.082	
0.332515	0.133545	15.5122	27.711	8.68354	0.490082	0.803476	0.298926	0.163934	0.292951	0.0917	
0.376494	0.151207	17.1339	30.608	9.59134	0.555263	0.910338	0.338684	0.181072	0.323466	0.101	
0.425303	0.17081	18.8921	33.7489	10.5756	0.627648	1.02901	0.382835	0.199653	0.35666	0.1117	
0.464922	0.186722	20.4119	36.4637	11.4263	0.687069	1.12643	0.419079	0.215714	0.38535	0.120	
0.506534	0.203434	22.0255	39.3462	12.3296	0.749871	1.22939	0.457385	0.232766	0.415813	0.1	
0.547724	0.219977	23.6903	42.3203	13.2615	0.812586	1.33221	0.495638	0.25036	0.447243	0.1401	
0.5848	0.234867	25.3673	45.3159	14.2002	0.869537	1.42558	0.530376	0.268082	0.478901	0.150	
0.610784	0.245303	26.8713	48.0028	15.0422	0.909326	1.49082	0.554645	0.283978	0.507296	0.158967	0
0.616563	0.247624	27.6214	49.3427	15.4621	0.91819	1.50535	0.560052	0.291904	0.521456	0.163404	0
0.594848	0.238903	26.707	47.7093	14.9502	0.886906	1.45406	0.54097	0.282241	0.504195	0.157995	0
0.555877	0.223251	24.7543	44.2209	13.8571	0.829731	1.36032	0.506096	0.261604	0.467329	0.146443	0
0.517685	0.207912	22.989	41.0674	12.8689	0.772481	1.26646	0.471176	0.242949	0.434003	0.135999	0
0.481495	0.193378	21.4185	38.2619	11.9898	0.717672	1.1766	0.437746	0.226352	0.404353	0.126709	0

Record 0 — Records (0 out of 572 Selected)

(d) Step 4



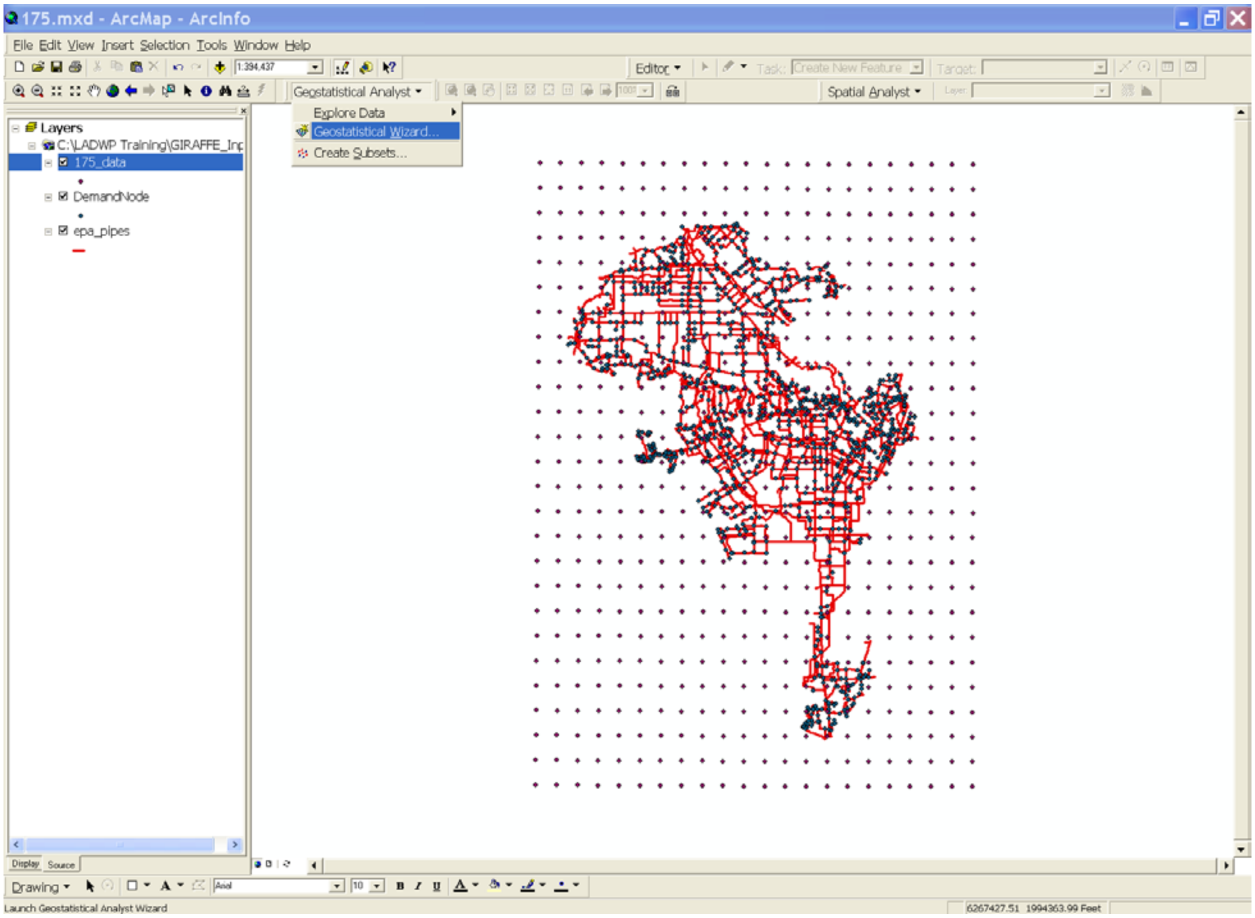
Type: ● Number ○ String ○ Date

SM_PGV =

[PGV] * Exp (0.31)

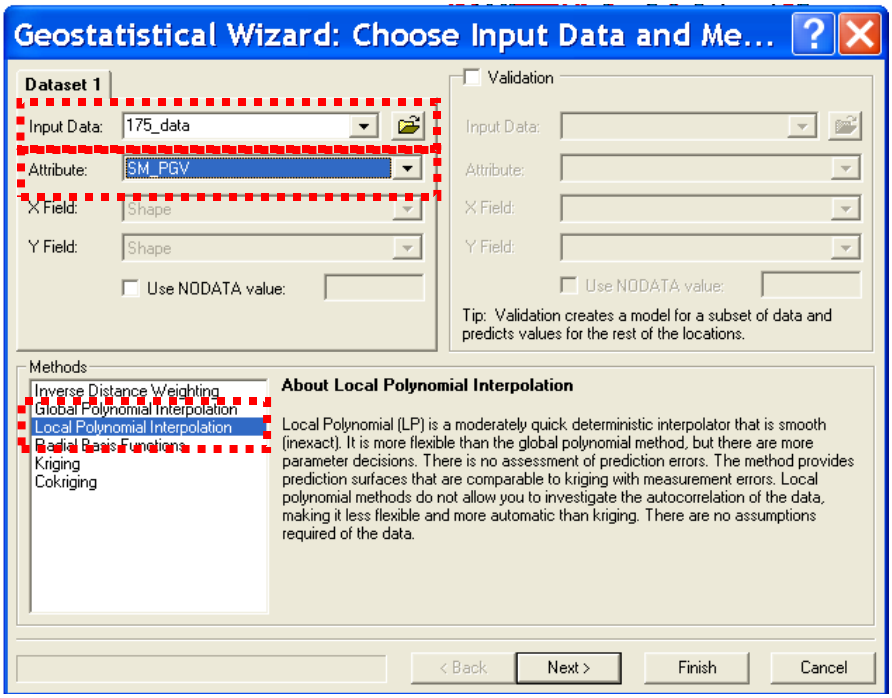
(e) Step 5

Figure B.10. Calculating Mean + $\sigma_{\text{inter-event}}$ PGV (Continued)



(a) Step 1

Figure B.11. Generating Contour Surfaces for PGV at Rock Sites



Geostatistical Wizard: Choose Input Data and Me...

Input Data: 175_data

Attribute: SM_PGV

X Field: Shape

Y Field: Shape

☐ Use NODATA value:

☐ Validation

☐ Use NODATA value:

Tip: Validation creates a model for a subset of data and predicts values for the rest of the locations.

Methods

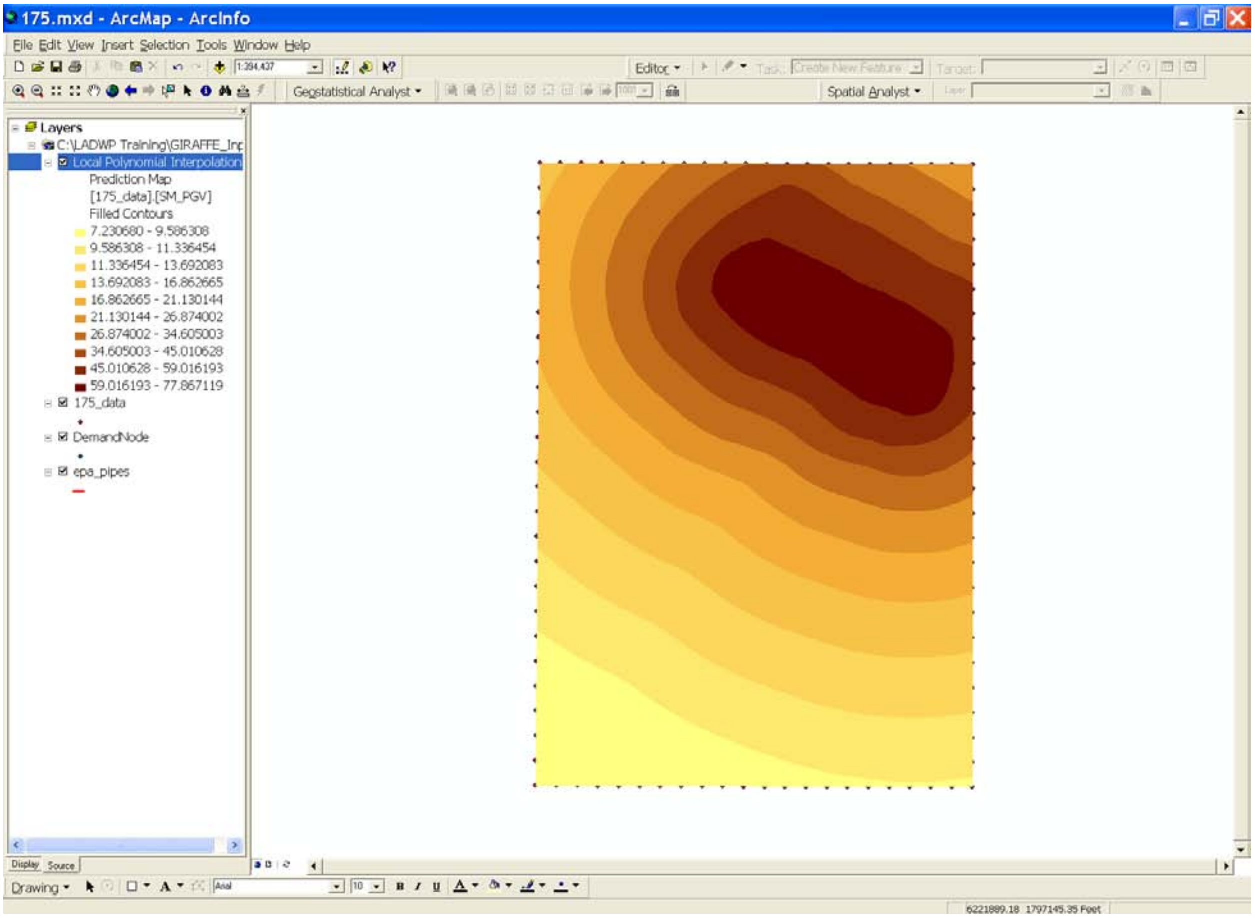
- Inverse Distance Weighting
- Global Polynomial Interpolation
- Local Polynomial Interpolation
- Radial Basis Functions
- Kriging
- Cokriging

About Local Polynomial Interpolation

Local Polynomial (LP) is a moderately quick deterministic interpolator that is smooth (inexact). It is more flexible than the global polynomial method, but there are more parameter decisions. There is no assessment of prediction errors. The method provides prediction surfaces that are comparable to kriging with measurement errors. Local polynomial methods do not allow you to investigate the autocorrelation of the data, making it less flexible and more automatic than kriging. There are no assumptions required of the data.

(b) Step 2

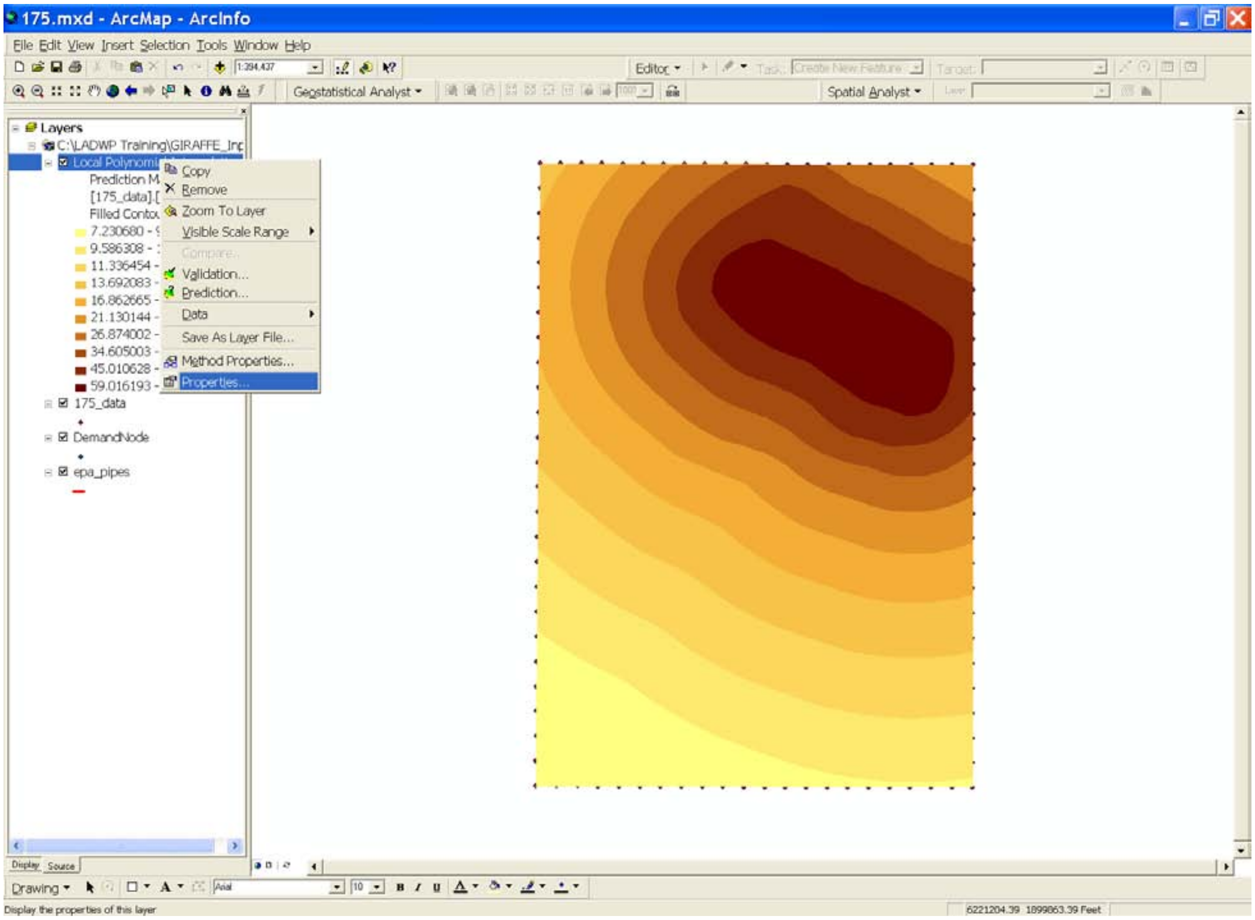
Figure B.11. Generating Contour Surfaces for PGV at Rock Sites (Continued)



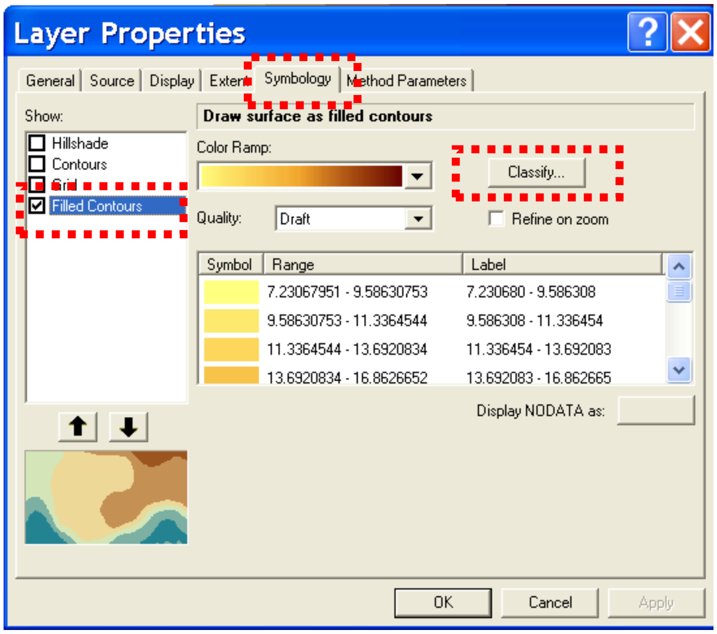
- Layers
  - C:\LADWP Training\GIRAFFE_Inp
    - ☑ Local Polynomial Interpolation
      - Prediction Map
      - [175_data].[SM_PGV]
      - Filled Contours
      - 7.230680 - 9.586308
      - 9.586308 - 11.336454
      - 11.336454 - 13.692083
      - 13.692083 - 16.862665
      - 16.862665 - 21.130144
      - 21.130144 - 26.874002
      - 26.874002 - 34.605003
      - 34.605003 - 45.010628
      - 45.010628 - 59.016193
      - 59.016193 - 77.867119
    - ☑ 175_data
    - ☑ DemandNode
    - ☑ epa_pipes

(c) Step 3

Figure B.11. Generating Contour Surfaces for PGV at Rock Sites (Continued)



(d) Step 4



Draw surface as filled contours

Show:

☐ Hillshade
☐ Contours
☐ Grid
☑ Filled Contours

Color Ramp:

Quality: Draft

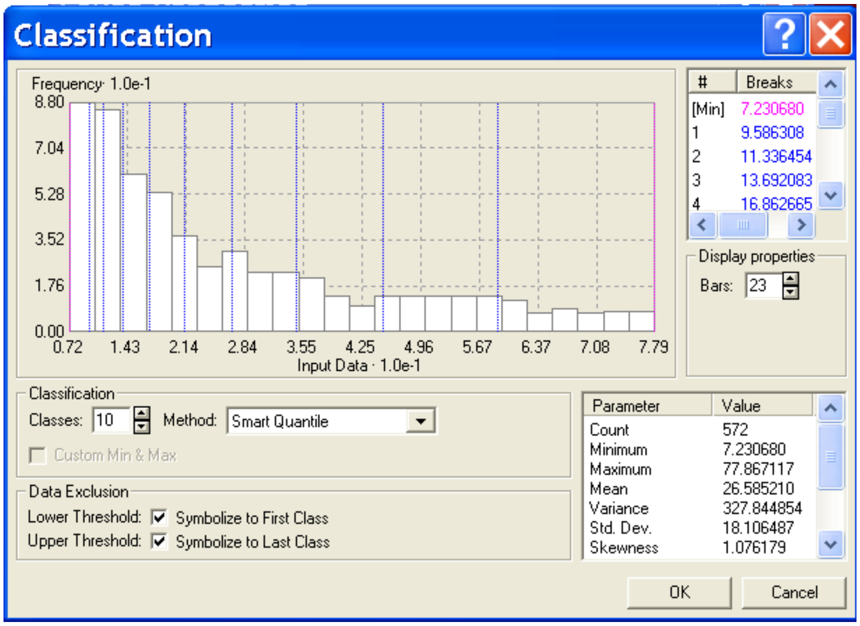
☐ Refine on zoom

Symbol	Range	Label
▨	7.23067951 - 9.58630753	7.230680 - 9.586308
▨	9.58630753 - 11.3364544	9.586308 - 11.336454
▨	11.3364544 - 13.6920834	11.336454 - 13.692083
▨	13.6920834 - 16.8626652	13.692083 - 16.862665

Display NODATA as:

(e) Step 5

Figure B.11. Generating Contour Surfaces for PGV at Rock Sites (Continued)



#	Breaks
[Min]	7.230680
1	9.586308
2	11.336454
3	13.692083
4	16.862665

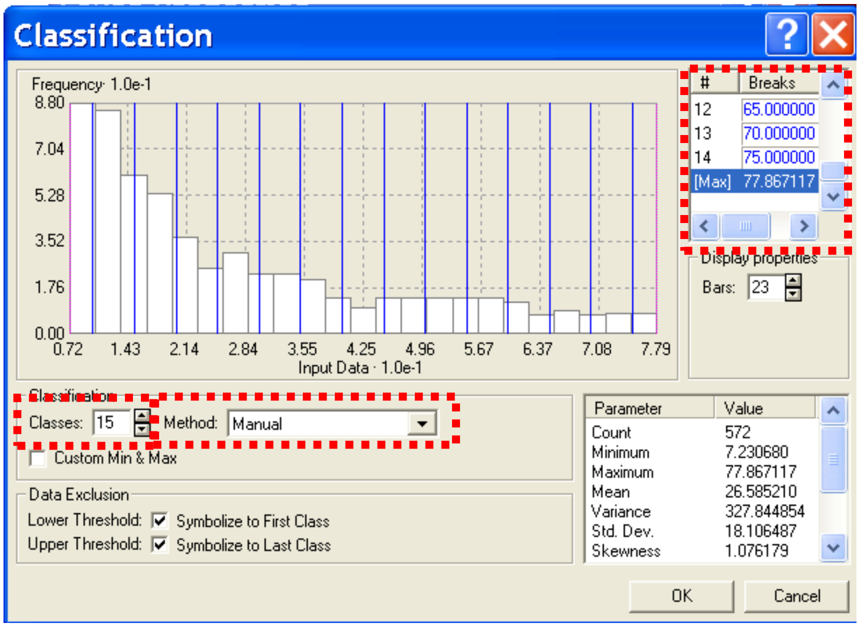
Display properties
Bars: 23

Classification
Classes: 10 Method: Smart Quantile
☐ Custom Min & Max

Data Exclusion
Lower Threshold: ☑ Symbolize to First Class
Upper Threshold: ☑ Symbolize to Last Class

Parameter	Value
Count	572
Minimum	7.230680
Maximum	77.867117
Mean	26.585210
Variance	327.844854
Std. Dev.	18.106487
Skewness	1.076179

(f) Step 6



#	Breaks
12	65.000000
13	70.000000
14	75.000000
[Max]	77.867117

Display properties
Bars: 23

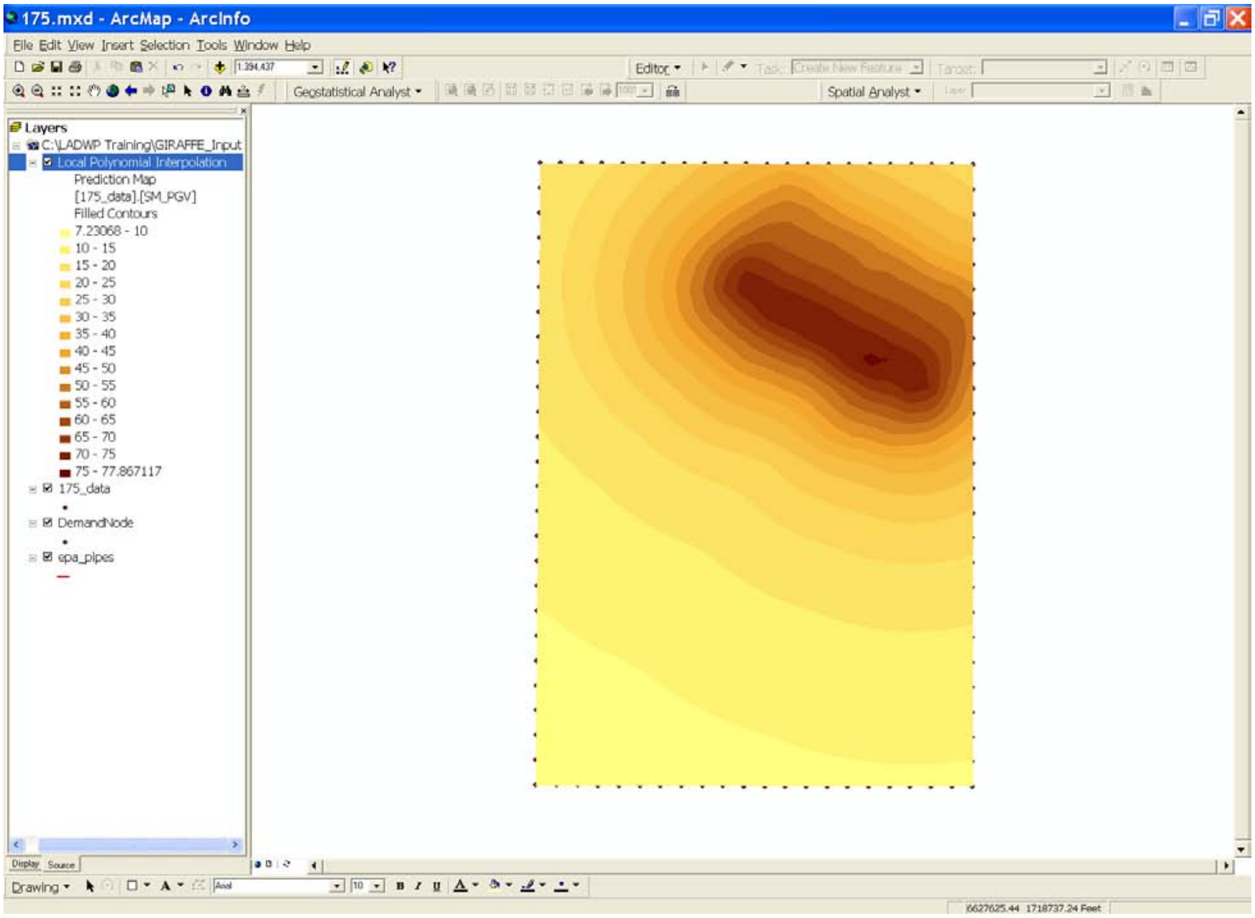
Classification
Classes: 15 Method: Manual
☐ Custom Min & Max

Data Exclusion
Lower Threshold: ☑ Symbolize to First Class
Upper Threshold: ☑ Symbolize to Last Class

Parameter	Value
Count	572
Minimum	7.230680
Maximum	77.867117
Mean	26.585210
Variance	327.844854
Std. Dev.	18.106487
Skewness	1.076179

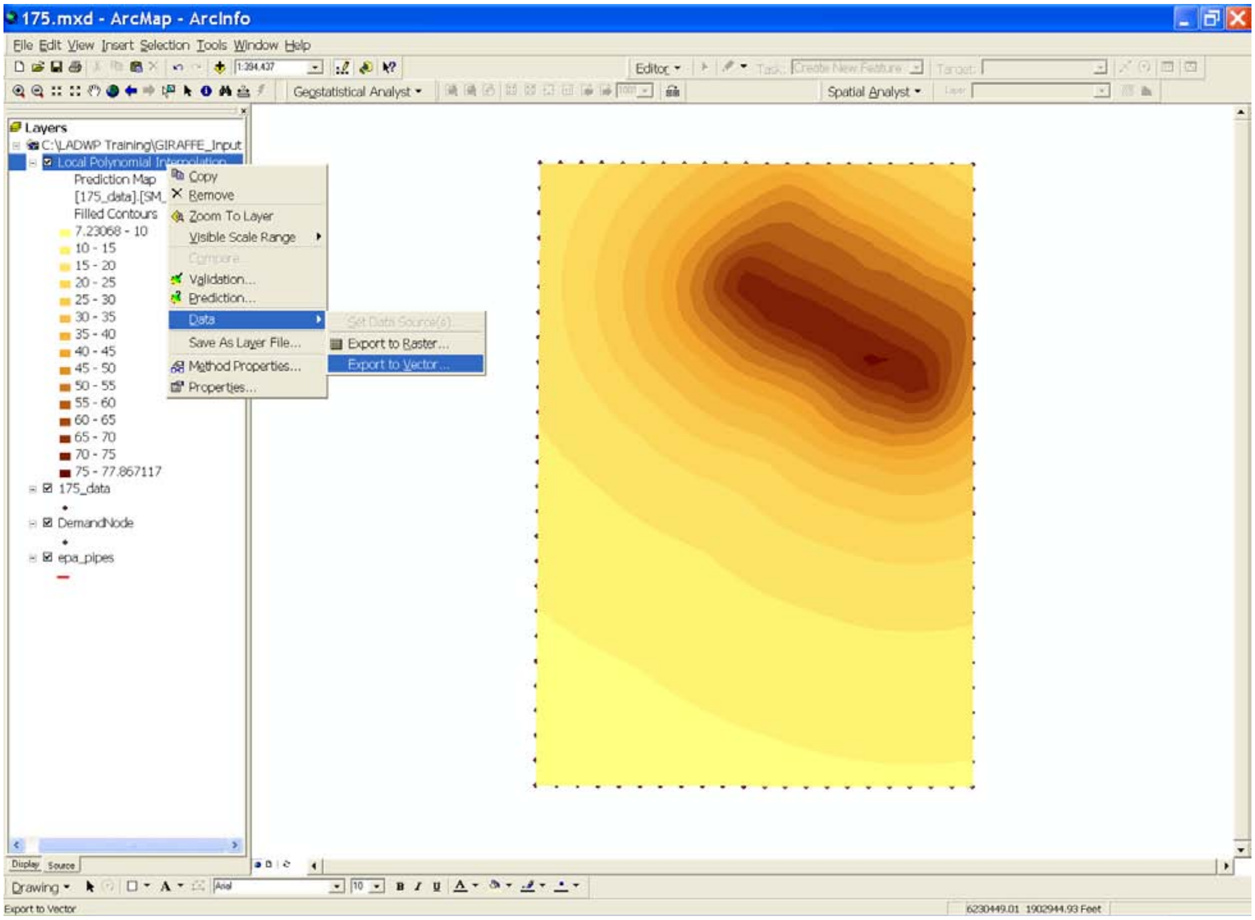
(g) Step 7

Figure B.11. Generating Contour Surfaces for PGV at Rock Sites (Continued)

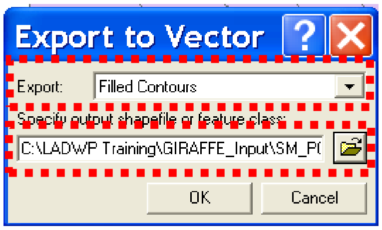


(h) Step 8

Figure B.11. Generating Contour Surfaces for PGV at Rock Sites (Continued)



(i) Step 9



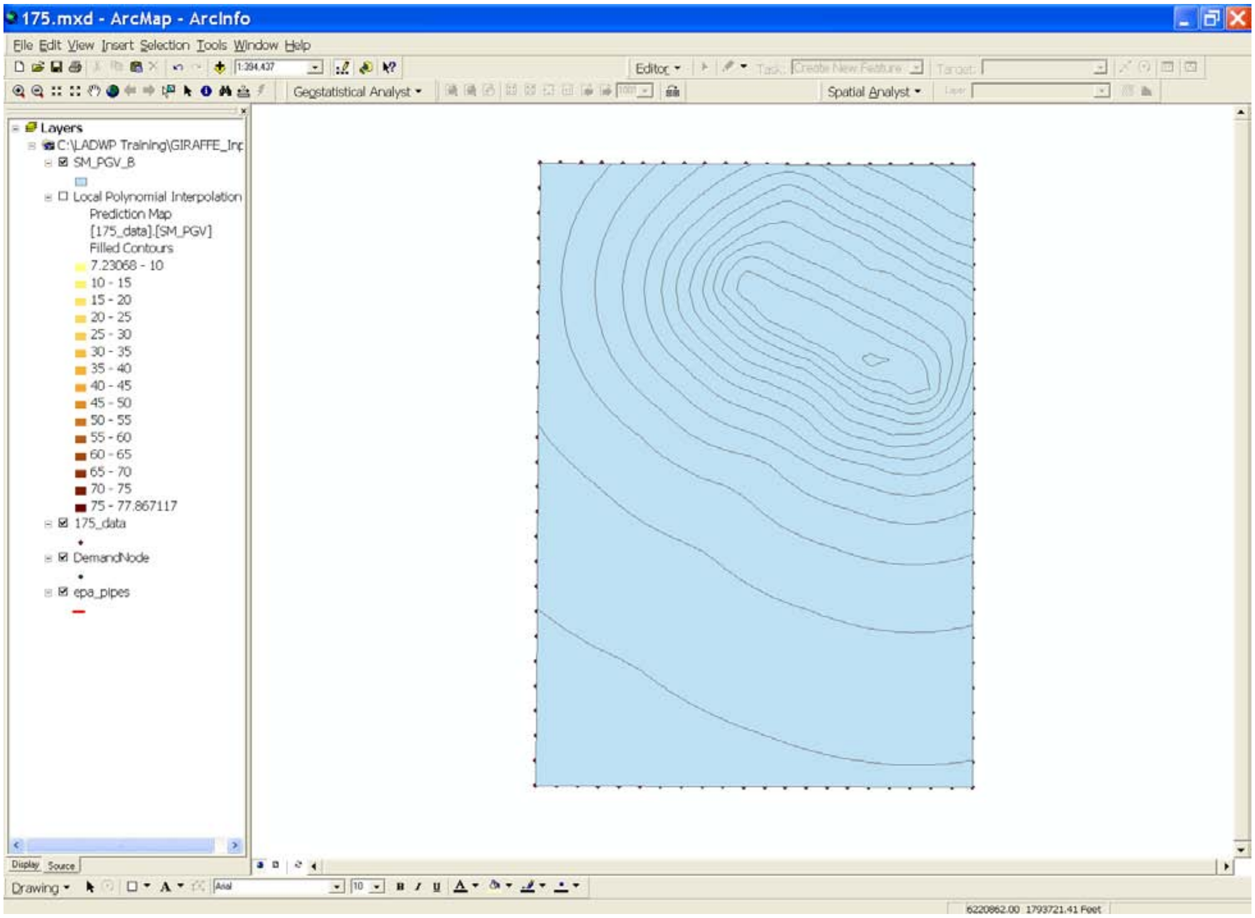
Export: Filled Contours

Specify output shapefile or feature class:

C:\LADWP Training\GIRAFFE_Input\SM_P(

(j) Step 10

Figure B.11. Generating Contour Surfaces for PGV at Rock Sites (Continued)



(k) Step 11

Figure B.11. Generating Contour Surfaces for PGV at Rock Sites (Continued)

The strong ground motion data described above are generated for the rock site conditions, i.e., NEHRP B or BC category site conditions (FEMA, 2003). However, the site conditions in the LADWP water system service areas do not necessarily fall into the NEHRP B or BC site categories. The NEHRP site conditions are divided into 6 categories, from A to F, representing the site conditions from hard rock to soft soils, to soils requiring site specific evaluation. Intermediate categories, such as BC, CD, and DE, can also be assigned to accommodate the site conditions that fall close to the category boundary.

Wills et al. (2000) developed a site-condition map for California based on geologic units and the average shear wave velocity in the upper 30-m subsurface layer. The GIS data for the site conditions used in this study are provided by California Geological Survey, and the effects of site amplification are accounted using the NEHRP-HAZUS approach (Wang 2006). The PGV for category site conditions (other than B and B/C) can be calculated by

$$V_{pi} = F_{PGVi} V_{pB} \tag{B.2}$$

where V_{pi} is the PGV for category site condition i (i.e., site conditions corresponding to A, C, D, or E), V_{pB} is the PGV for site category B, and F_{PGVi} is the correction factor for site condition i, given by Table B.3.

The site condition data are added to ArcMap, as shown in Figure B.12(a). To make the correction for site conditions, the following procedures are utilized:

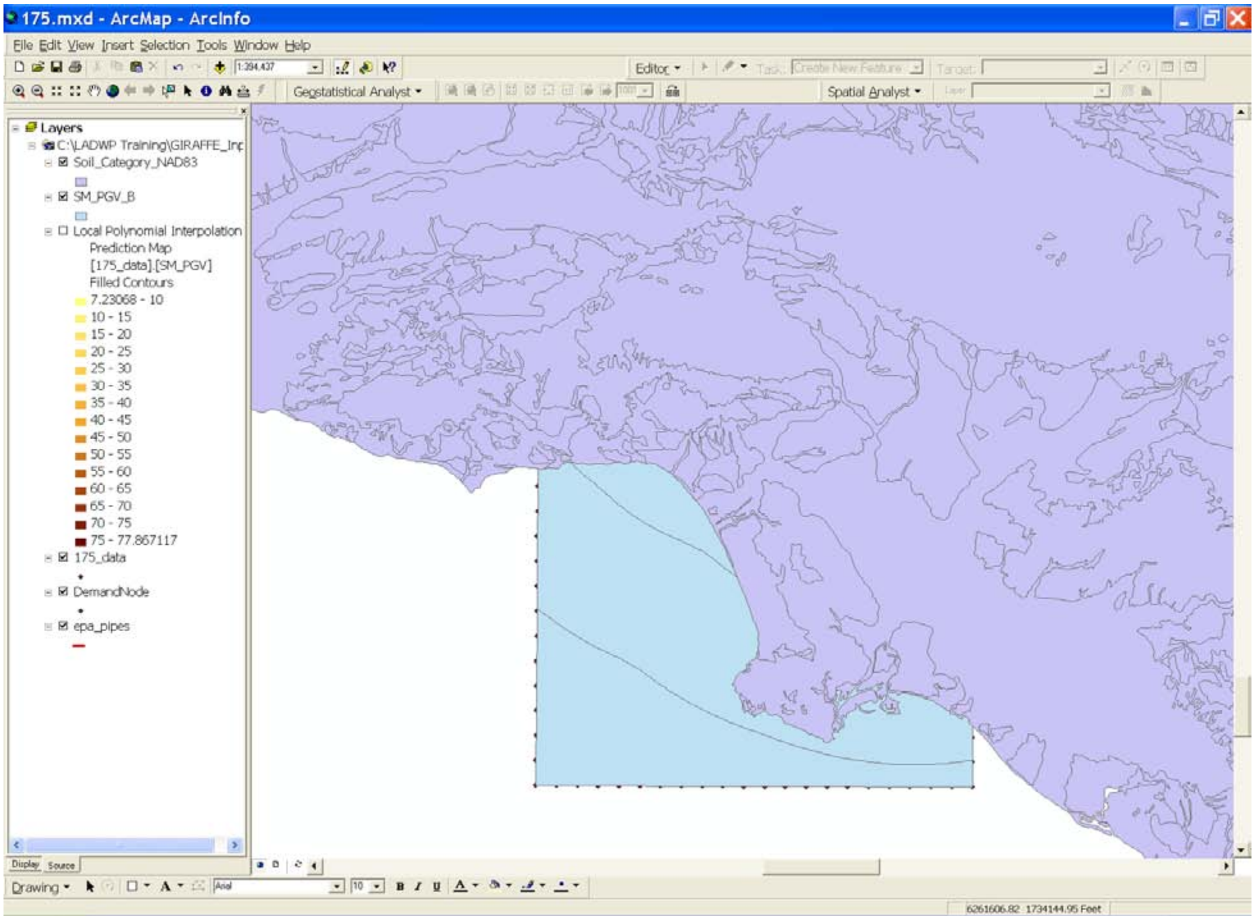
- Go to the drop-down menu **Tools | GeoProcessing Wizard…**, as shown in Figure B.12(b)
- In the GeoProcessing window check **Intersect two layers**, and click the **Next** button, as shown in Figure B.12(c).
- A window will open. Specify the parameters as shown in Figure B.12(d) to generate a new GIS file named ***SM_PGV_Soils***, and click the **Finish** button
- Add ***SM_PGV_Soils*** to ArcMap, as shown in Figure B.12(e).
- Open the attribute table of ***SM_PGV_Soils*** and click the **Option** button at the bottom of the attribute table window. Go to **Add Field…** in the pop-up menu, as shown in Figure B.12(f).
- Create an attribute column named **PGV**, and specify the parameters as shown in Figure B.12(g).
- Right-click on the header of **PGV** column with and go to **Calculate Values…** in the pop-up menu, as shown in Figure B.12(h).
- A field calculator window will open. Key in the syntax as shown in Figure B.12(i), and click **OK**.
- Click the **Option** button at the bottom of the attribute table window, and go to **Add Field…** in the pop-up menu, as shown in Figure B.12(j).

- Create an attribute column named **PGV_Soils**, and specify the parameters as shown in Figure B.12(k).
- Click the **Option** button at the bottom of the attribute table window, and go to **Select by Attributes…** in the pop-up menu, as shown in Figure B.12(l).
- A window will open. Key in the syntax to select site condition **CD** as shown in Figure B.12(m), and click the **Apply** button.
- Right-click on the header of **PGV_Soils** column and go to **Calculate Values…** in the pop-up menu, as shown in Figure B.12(n).
- A field calculator window will open. Key in the syntax to make correction for site condition **CD** as shown in Figure B.12(o), and click **OK** button.
- Repeat the last four steps for correction of other site conditions listed in Table B.3.

Table B.3. Site Condition Correction Factor F_{PGV} for PGV

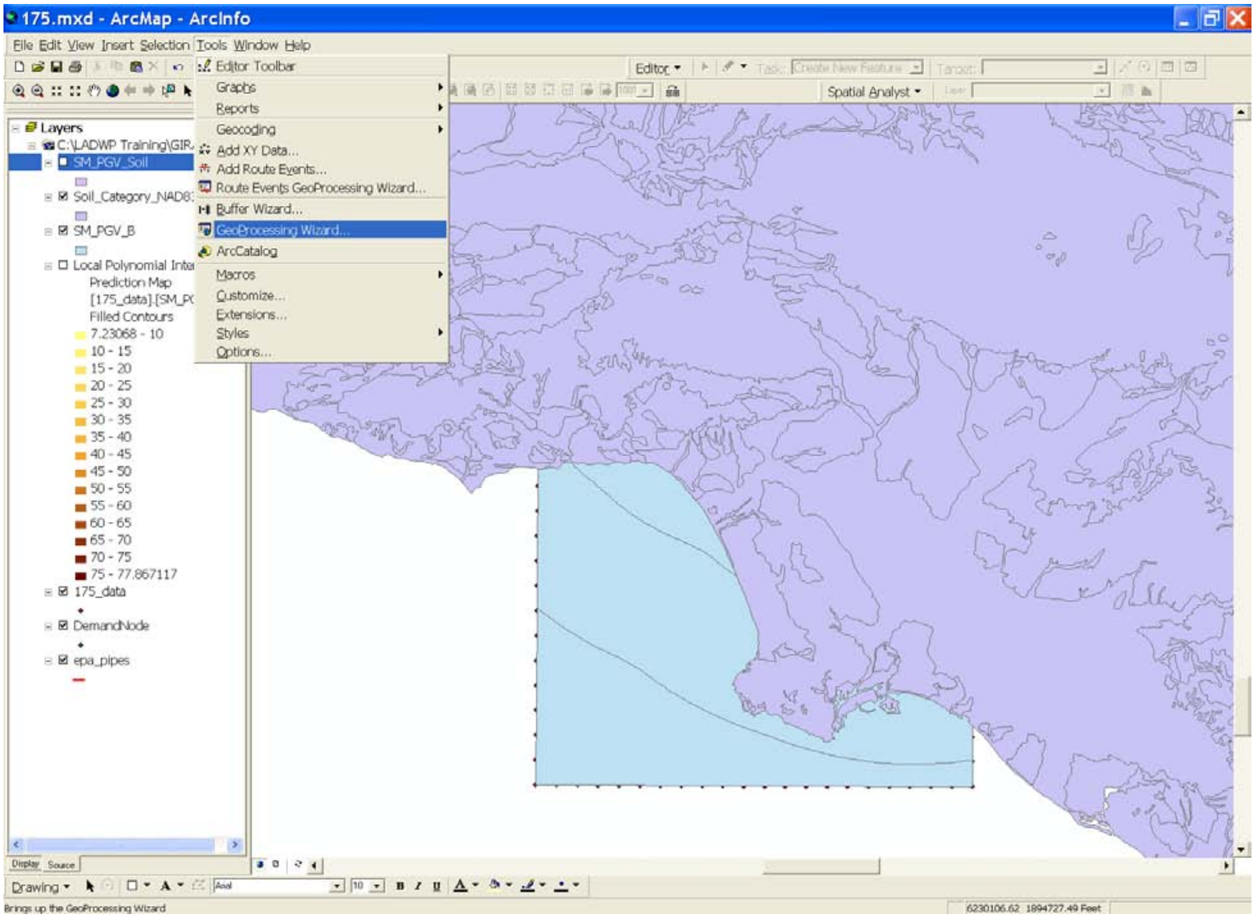
Site Class	**PGV ≤ 14 cm/sec**	**14 cm/sec < PGV ≤ 23.67 cm/sec**	**23.67 cm/sec < PGV ≤ 33.13 cm/sec**	**33.13 cm/sec < PGV ≤ 42.5 cm/sec**	**PGV > 42.5 cm/sec**
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	---[a]	---[a]	---[a]	---[a]	---[a]
AB	0.9	0.9	0.9	0.9	0.9
BC	1.0	1.0	1.0	1.0	1.0
CD	2.05	1.8	1.65	1.5	1.4
DE	2.95	2.6	2.3	2.0	1.95

Note: a: Site-specific geotechnical investigation and dynamic site response analyses should be performed.
b: Use straight line interpolation for intermediate values of PGV.



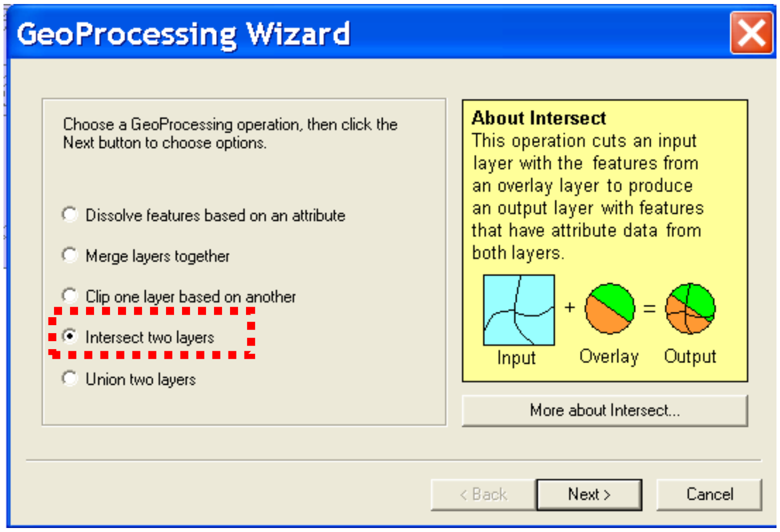
(a) Step 1

Figure B.12. Site Condition Correction



Brings up the GeoProcessing Wizard

(b) Step 2



Choose a GeoProcessing operation, then click the Next button to choose options.

○ Dissolve features based on an attribute

○ Merge layers together

○ Clip one layer based on another

● Intersect two layers

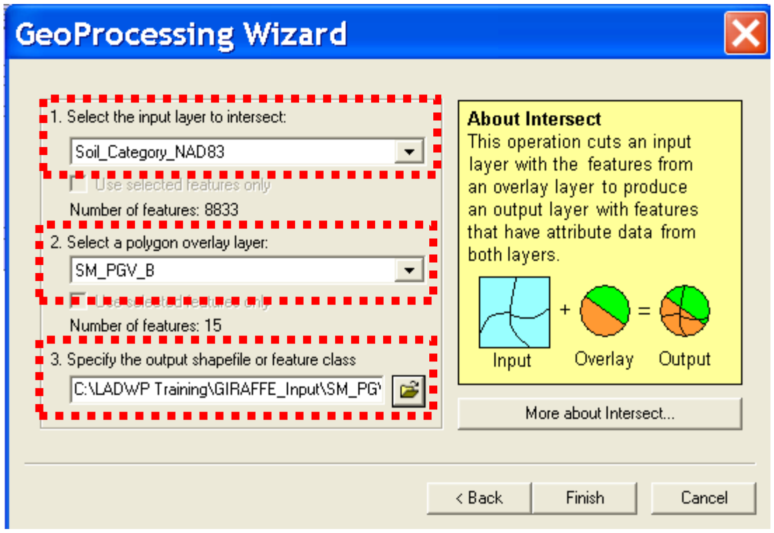
○ Union two layers

About Intersect

This operation cuts an input layer with the features from an overlay layer to produce an output layer with features that have attribute data from both layers.

(c) Step 3

Figure B.12. Site Condition Correction (Continued)



GeoProcessing Wizard

1. Select the input layer to intersect: Soil_Category_NAD83

☐ Use selected features only

Number of features: 8833

2. Select a polygon overlay layer: SM_PGV_B

☐ Use selected features only

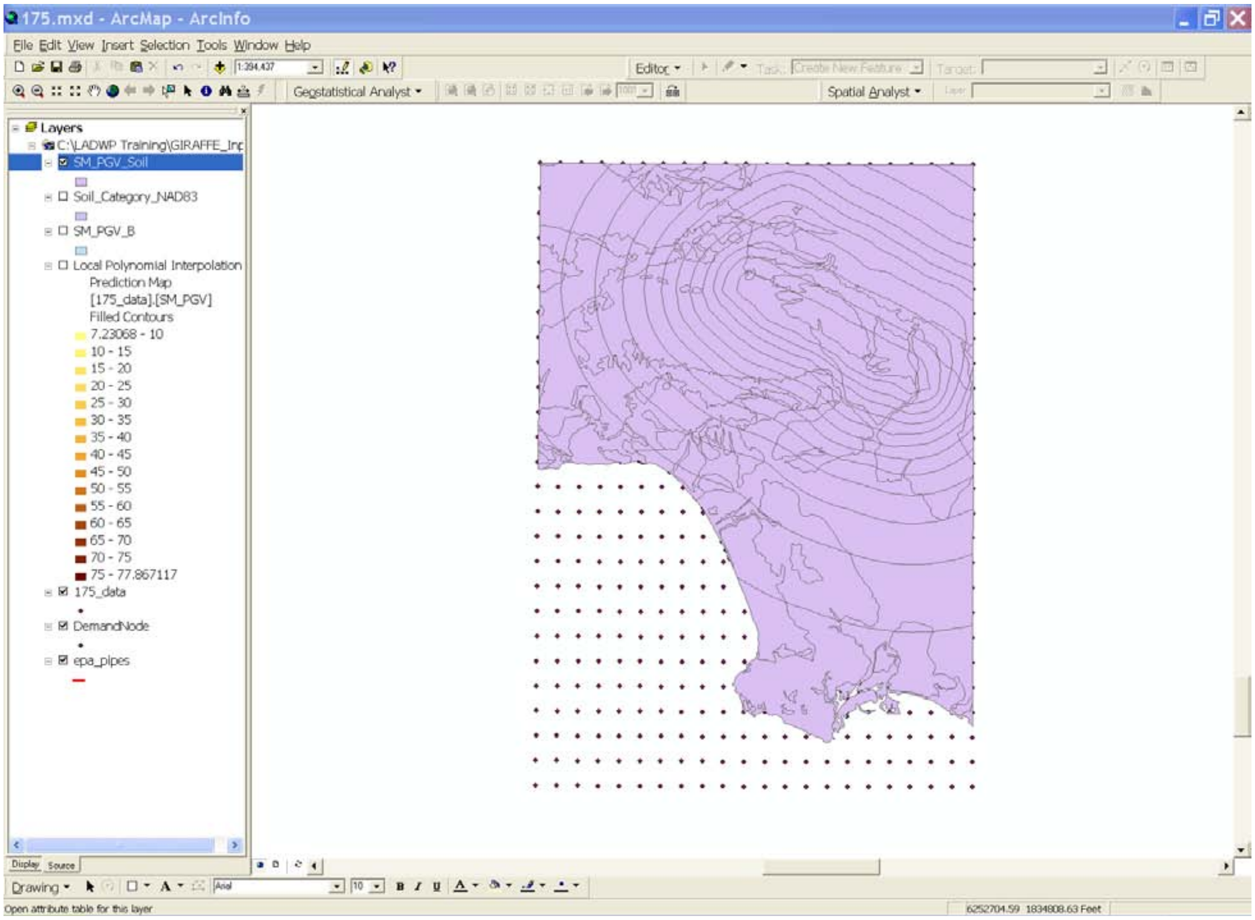
Number of features: 15

3. Specify the output shapefile or feature class: C:\LADWP Training\GIRAFFE_Input\SM_PG\

About Intersect

This operation cuts an input layer with the features from an overlay layer to produce an output layer with features that have attribute data from both layers.

(d) Step 4

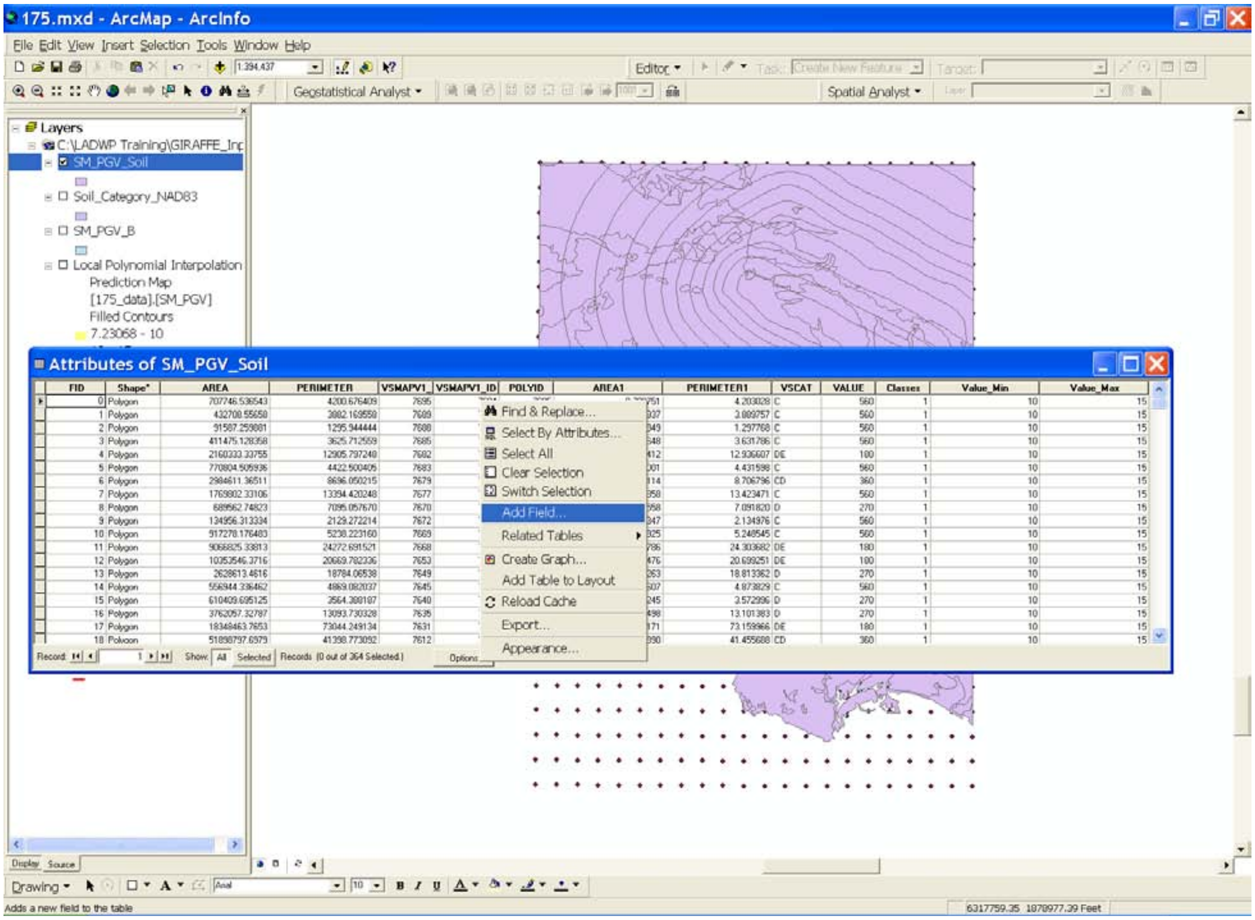


175.mxd - ArcMap - ArcInfo

Layers
- C:\LADWP Training\GIRAFFE_Inp
  - ☑ SM_PGV_Soil
  - ☐ Soil_Category_NAD83
  - ☐ SM_PGV_B
  - ☐ Local Polynomial Interpolation Prediction Map [175_data].[SM_PGV] Filled Contours
    - 7.23068 - 10
    - 10 - 15
    - 15 - 20
    - 20 - 25
    - 25 - 30
    - 30 - 35
    - 35 - 40
    - 40 - 45
    - 45 - 50
    - 50 - 55
    - 55 - 60
    - 60 - 65
    - 65 - 70
    - 70 - 75
    - 75 - 77.867117
  - ☑ 175_data
  - ☑ DemandNode
  - ☑ epa_pipes

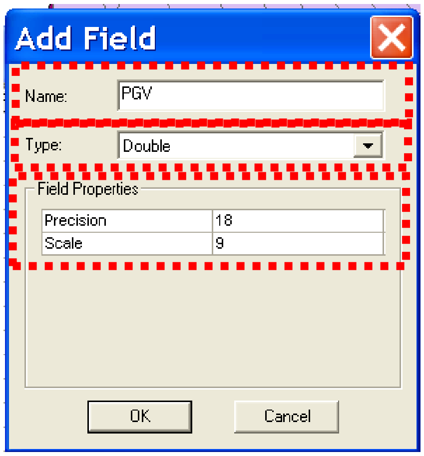
(e) Step 5

Figure B.12. Site Condition Correction (Continued)



FID	Shape*	AREA	PERIMETER	VSMAPV1_	PERIMETER1	VSCAT	VALUE	Classes	Value_Min	Value_Max
0	Polygon	707746.536543	4200.676409	7695	4.203028	C	560	1	10	15
1	Polygon	432708.55658	3882.169558	7689	3.889757	C	560	1	10	15
2	Polygon	91587.259881	1295.944444	7688	1.297768	C	560	1	10	15
3	Polygon	411475.128358	3625.712559	7685	3.631786	C	560	1	10	15
4	Polygon	2160333.33755	12905.797240	7682	12.936607	DE	100	1	10	15
5	Polygon	770804.505936	4422.500405	7683	4.431598	C	560	1	10	15
6	Polygon	2984611.36511	8696.050215	7679	8.706796	CD	360	1	10	15
7	Polygon	1769802.33106	13394.420248	7677	13.423471	C	560	1	10	15
8	Polygon	689562.74823	7095.057670	7670	7.091820	D	270	1	10	15
9	Polygon	134956.313334	2129.272214	7672	2.134976	C	560	1	10	15
10	Polygon	917278.176483	5238.223160	7669	5.248545	C	560	1	10	15
11	Polygon	9066825.33813	24272.691521	7668	24.303682	DE	180	1	10	15
12	Polygon	10353546.3716	20669.782336	7653	20.699251	DE	100	1	10	15
13	Polygon	2628613.4616	18784.06538	7649	18.813362	D	270	1	10	15
14	Polygon	556944.336462	4869.082037	7645	4.873829	C	560	1	10	15
15	Polygon	610409.695125	3564.388107	7640	3.572996	D	270	1	10	15
16	Polygon	3762057.32787	13093.730328	7635	13.101383	D	270	1	10	15
17	Polygon	18348463.7653	73044.249134	7631	73.159966	DE	180	1	10	15
18	Polygon	51898797.6979	41398.773092	7612	41.455688	CD	360	1	10	15

(f) Step 6



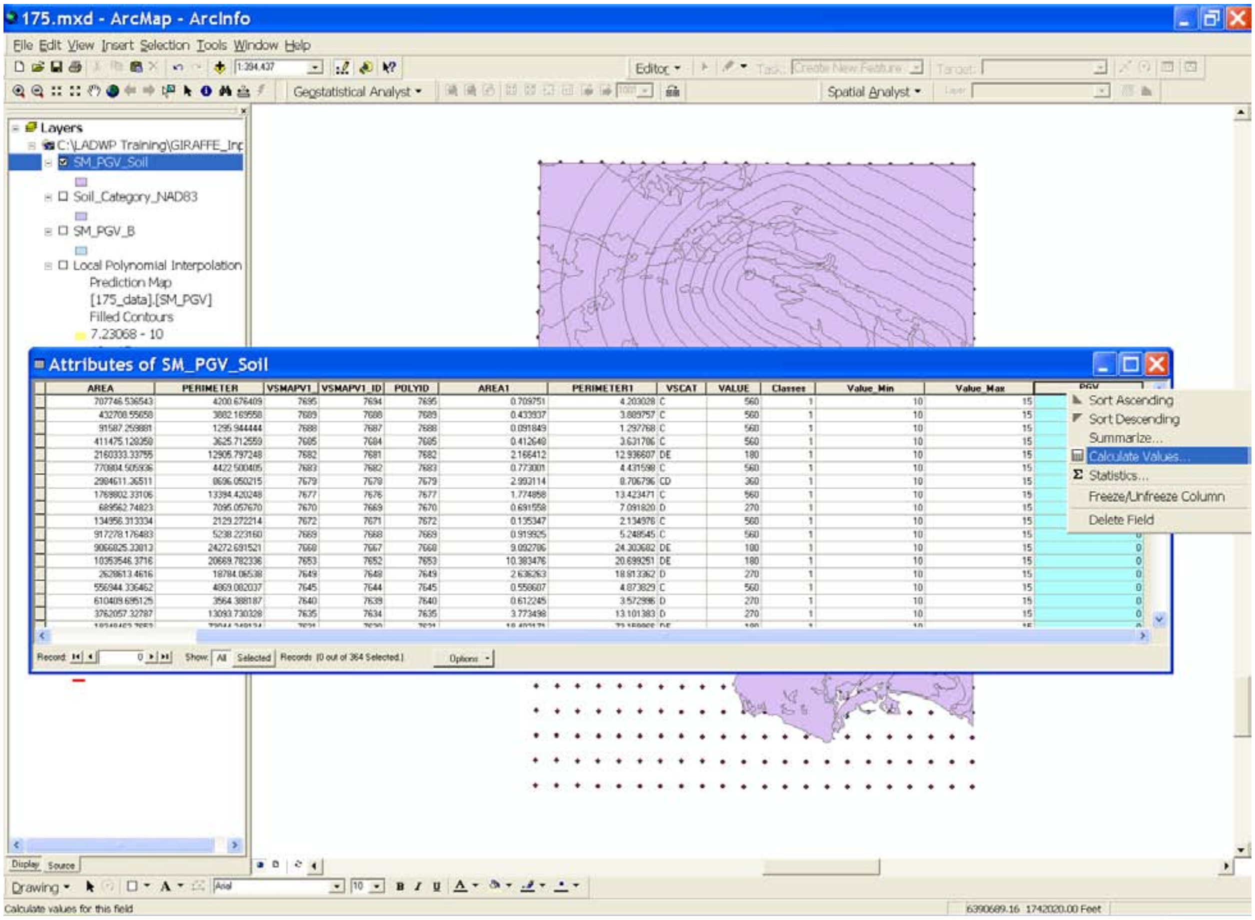
Name: PGV

Type: Double

Precision	18
Scale	9

(g) Step 7

Figure B.12. Site Condition Correction (Continued)



Attributes of SM_PGV_Soil

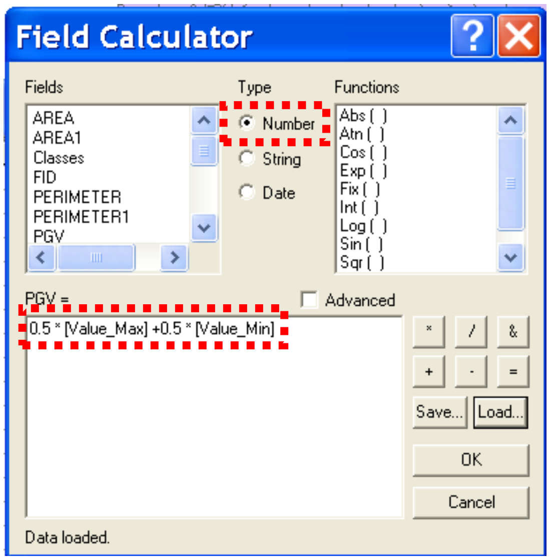
AREA	PERIMETER	VSMAPV1	VSMAPV1_ID	POLYID	AREA1	PERIMETER1	VSCAT	VALUE	Classes	Value_Min	Value_Max	PGV
707746.536543	4200.676409	7695	7694	7695	0.709751	4.203028	C	560	1	10	15	
432708.55658	3882.169558	7689	7688	7689	0.433937	3.889757	C	560	1	10	15	
91587.259881	1295.944444	7688	7687	7688	0.091849	1.297768	C	560	1	10	15	
411475.128058	3625.712559	7685	7684	7685	0.412648	3.631706	C	560	1	10	15	
2160333.33755	12905.797248	7682	7681	7682	2.166412	12.936607	DE	180	1	10	15	
770804.505936	4422.500405	7683	7682	7683	0.773001	4.431598	C	560	1	10	15	
2984611.26511	8696.050215	7679	7678	7679	2.993114	8.706796	CD	360	1	10	15	
1769802.33106	13394.420248	7677	7676	7677	1.774858	13.423471	C	560	1	10	15	
689562.74823	7095.057670	7670	7669	7670	0.691558	7.091820	D	270	1	10	15	
134956.313334	2129.272214	7672	7671	7672	0.135347	2.134976	C	560	1	10	15	
917278.176483	5238.223160	7669	7668	7669	0.919925	5.248545	C	560	1	10	15	0
9066825.33813	24272.691521	7668	7667	7668	9.092786	24.303682	DE	180	1	10	15	0
10353546.3716	20669.782336	7653	7652	7653	10.383476	20.699251	DE	180	1	10	15	0
2628613.4616	18784.06538	7649	7648	7649	2.636263	18.813362	D	270	1	10	15	0
556944.336462	4869.082037	7645	7644	7645	0.558607	4.873829	C	560	1	10	15	0
610409.695125	3564.388187	7640	7639	7640	0.612245	3.572996	D	270	1	10	15	0
3762057.32787	13093.730328	7635	7634	7635	3.773498	13.101383	D	270	1	10	15	0

Record: 0 Show: All Selected Records (0 out of 364 Selected.) Options

Calculate values for this field

6390689.16 1742020.00 Feet

(h) Step 8



Type

● Number

○ String

○ Date

☐ Advanced

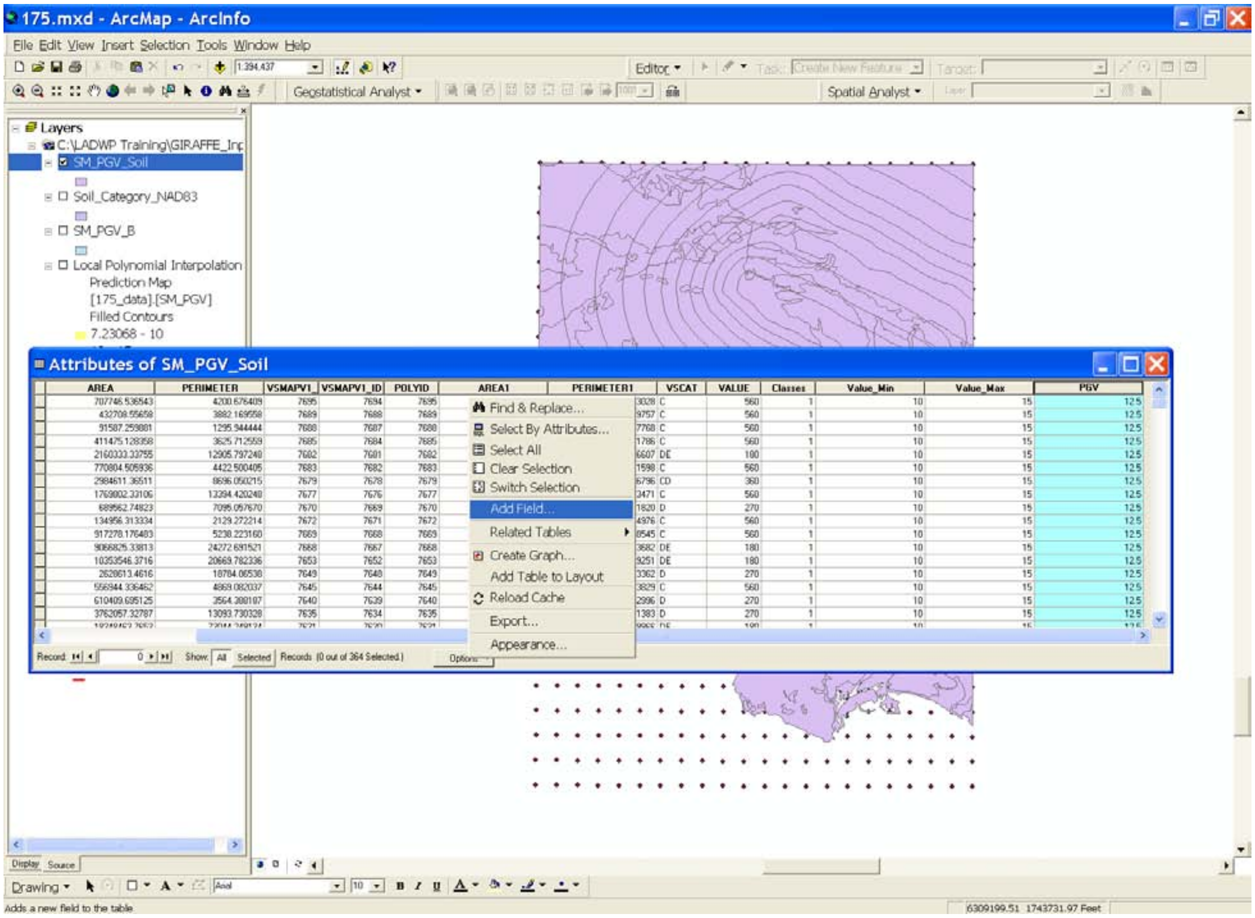
PGV =

0.5 * [Value_Max] +0.5 * [Value_Min]

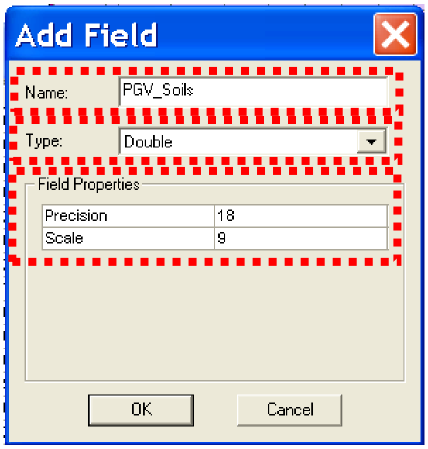
Data loaded.

(i) Step 9

Figure B.12. Site Condition Correction (Continued)



(j) Step 10



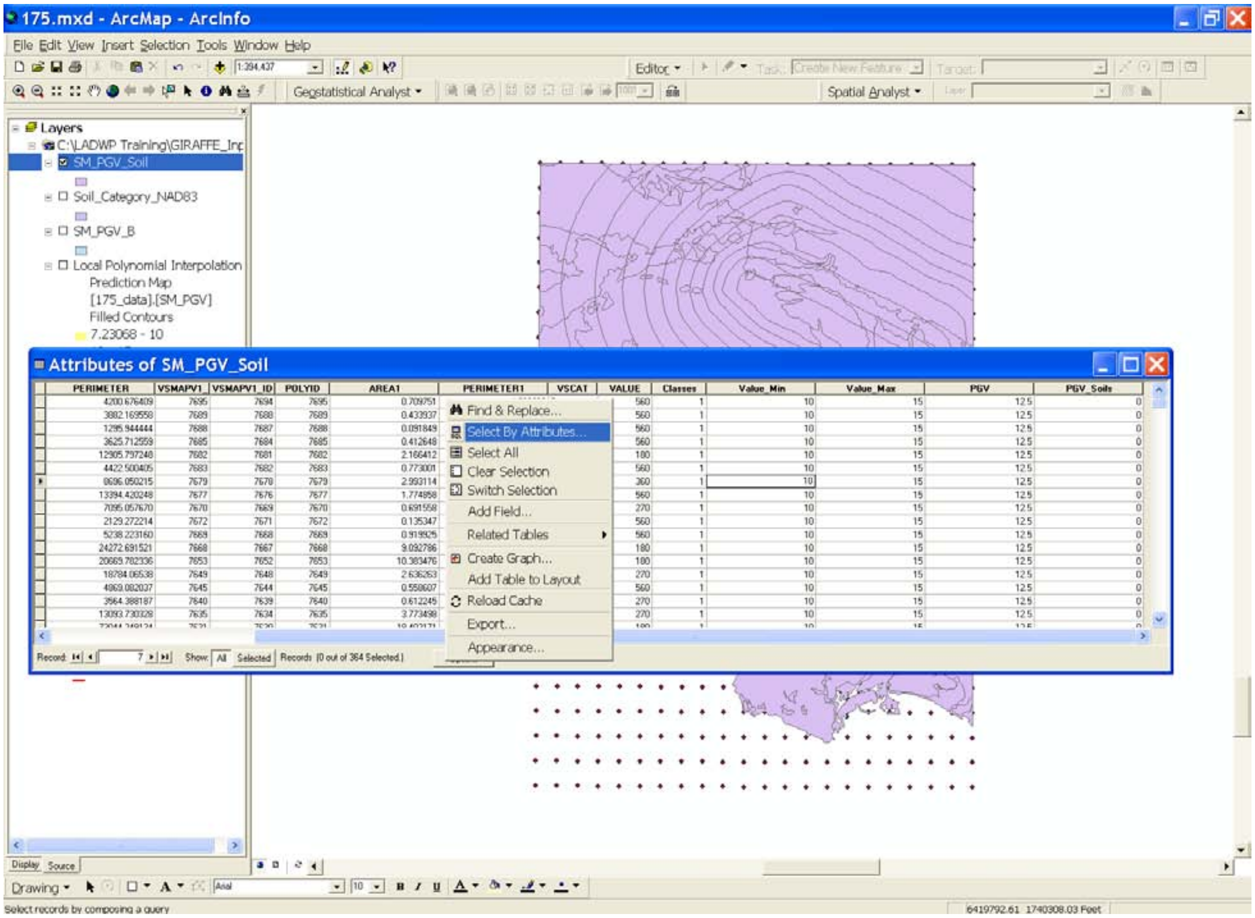
Name: PGV_Soils

Type: Double

Precision	18
Scale	9

(k) Step 11

Figure B.12. Site Condition Correction (Continued)



Attributes of SM_PGV_Soil

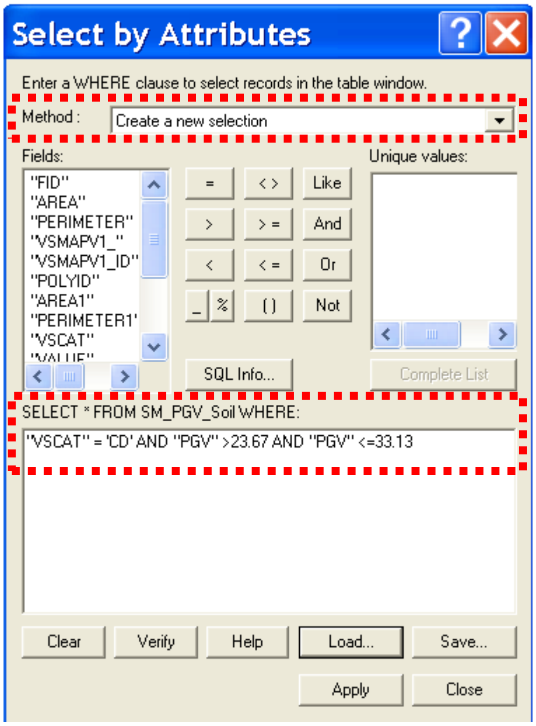
PERIMETER	VSMAPV1_	VSMAPV1_ID	POLYID	AREA1	PERIMETER1	VSCAT	VALUE	Classes	Value_Min	Value_Max	PGV	PGV_Soils
4200.676409	7695	7694	7695	0.709751			560	1	10	15	12.5	0
3882.169558	7689	7688	7689	0.433937			560	1	10	15	12.5	0
1295.944444	7688	7687	7688	0.091849			560	1	10	15	12.5	0
3625.712559	7685	7684	7685	0.412648			560	1	10	15	12.5	0
12905.797248	7682	7681	7682	2.166412			180	1	10	15	12.5	0
4422.500405	7683	7682	7683	0.773001			560	1	10	15	12.5	0
8696.050215	7679	7678	7679	2.993114			360	1	10	15	12.5	0
13394.420248	7677	7676	7677	1.774858			560	1	10	15	12.5	0
7095.057670	7670	7669	7670	0.691558			270	1	10	15	12.5	0
2129.272214	7672	7671	7672	0.135347			560	1	10	15	12.5	0
5238.223160	7669	7668	7669	0.919925			560	1	10	15	12.5	0
24272.691521	7668	7667	7668	9.092786			180	1	10	15	12.5	0
20669.782336	7653	7652	7653	10.383476			180	1	10	15	12.5	0
18784.06538	7649	7648	7649	2.636263			270	1	10	15	12.5	0
4869.082037	7645	7644	7645	0.558607			560	1	10	15	12.5	0
3964.388187	7640	7639	7640	0.612245			270	1	10	15	12.5	0
13093.730328	7635	7634	7635	3.773498			270	1	10	15	12.5	0

Record: 7 Show: All Selected Records (0 out of 364 Selected.)

Select records by composing a query

(l) Step 12

Figure B.12. Site Condition Correction (Continued)



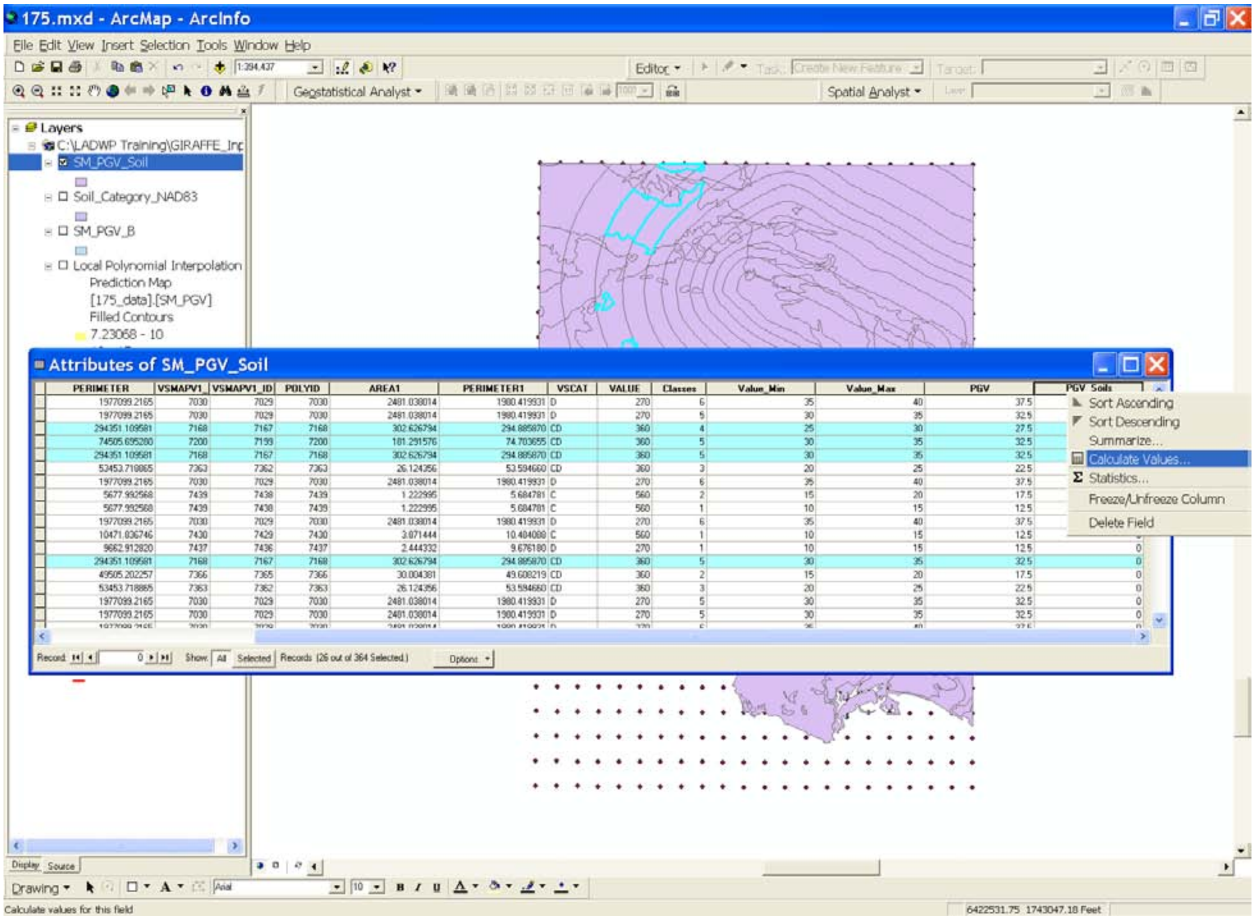
Enter a WHERE clause to select records in the table window.

Method : Create a new selection

```
SELECT * FROM SM_PGV_Soil WHERE:
"VSCAT" = 'CD' AND "PGV" >23.67 AND "PGV" <=33.13
```

(m) Step 13

Figure B.12. Site Condition Correction (Continued)

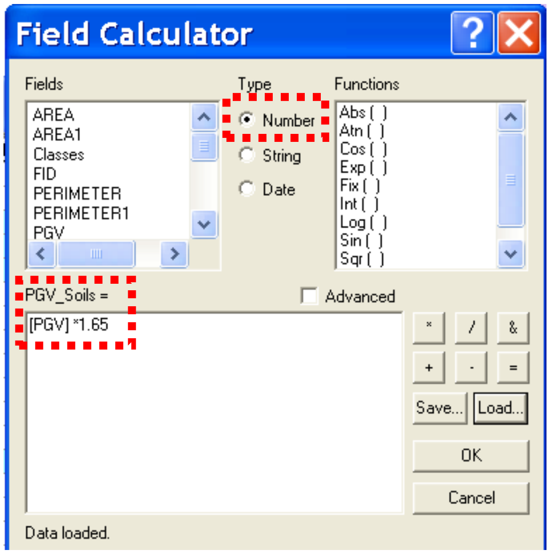


Attributes of SM_PGV_Soil

PERIMETER	VSMAPV1_	VSMAPV1_ID	POLYID	AREA1	PERIMETER1	VSCAT	VALUE	Classes	Value_Min	Value_Max	PGV	PGV_Soils
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	6	35	40	37.5	
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	5	30	35	32.5	
294351.109581	7168	7167	7168	302.626794	294.885870	CD	360	4	25	30	27.5	
74505.695200	7200	7199	7200	101.291576	74.703655	CD	360	5	30	35	32.5	
294351.109581	7168	7167	7168	302.626794	294.885870	CD	360	5	30	35	32.5	
53453.718865	7363	7362	7363	26.124356	53.594660	CD	360	3	20	25	22.5	
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	6	35	40	37.5	
5677.992568	7439	7438	7439	1.222995	5.684781	C	560	2	15	20	17.5	
5677.992568	7439	7438	7439	1.222995	5.684781	C	560	1	10	15	12.5	
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	6	35	40	37.5	
10471.836746	7430	7429	7430	3.871444	10.404088	C	560	1	10	15	12.5	0
9662.912820	7437	7436	7437	2.444332	9.676180	D	270	1	10	15	12.5	0
294351.109581	7168	7167	7168	302.626794	294.885870	CD	360	5	30	35	32.5	0
49505.202257	7366	7365	7366	30.004381	49.608219	CD	360	2	15	20	17.5	0
53453.718865	7363	7362	7363	26.124356	53.594660	CD	360	3	20	25	22.5	0
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	5	30	35	32.5	0
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	5	30	35	32.5	0

Record 0 Show: All Selected Records (26 out of 364 Selected.) Options

(n) Step 14



Type: ● Number ○ String ○ Date

☐ Advanced

PGV_Soils =

[PGV] *1.65

Data loaded.

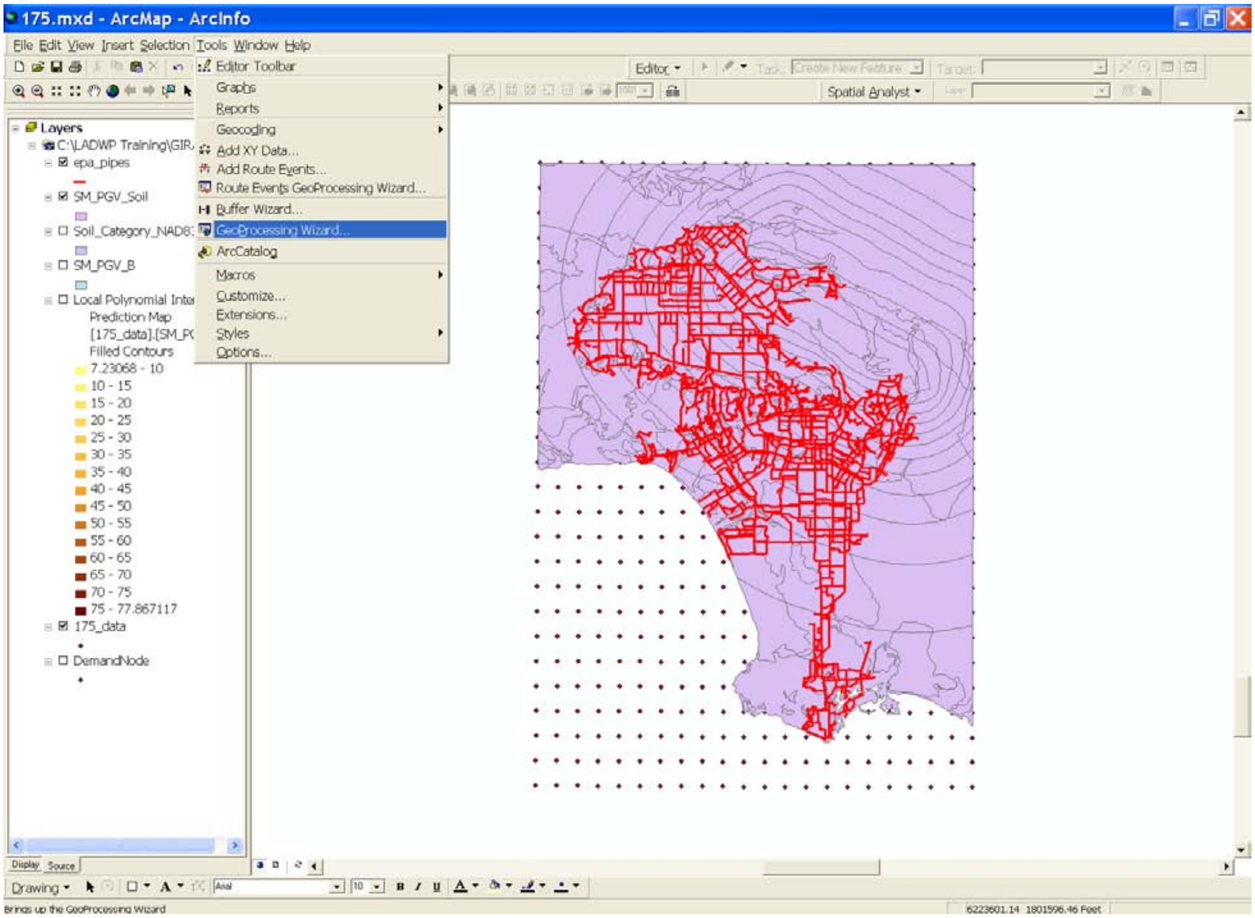
(o) Step 15

Figure B.12. Site Condition Correction (Continued)

B.4.3. Seismic Demands on Link-type Components

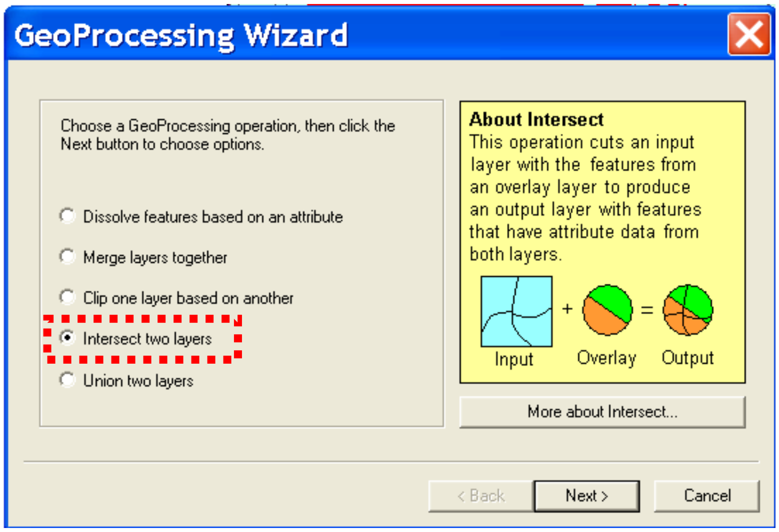
To determine the PGV that each pipeline is subjected to, the LADWP pipeline data layer is combined with the corrected PGV contour surfaces in the ArcGIS using the “Intersect” function. The “Intersect” function in ArcGIS not only combines the information from both input data layers into an output layer, but also divides the pipelines according to the PGV contour interval they fall into. Consider, for example, a pipeline that is so long that extends over three PGV contour intervals, saying 40-45, 45-50, and 50-55 cm/sec intervals. The ArcGIS “Intersect” function automatically divides the long pipeline into three new short pipelines and assigns a PGV interval of 40-45, 45-50, or 50-55 cm/sec to each of them according to their locations, respectively. A relatively small PGV interval of 5 cm/sec is utilized when developing the contour surfaces, intending to determine the PGV values to each system component with relatively high accuracy. The mean of the PGV interval (e.g., 42.5 cm/sec for 40-45 cm/sec interval) is taken as the seismic demand for the system components located within the PGV interval. The detailed procedures in ArcGIS are as follows:

- go to the drop-down menu **Tools | GeoProcessing Wizard…** and click on it, as shown in Figure B13(a).
- A window will open, check **Intersect two layers**, and click **Next** button, as shown in Figure B13(b).
- A window will open, assign the parameters as in shown in Figure B13(c) to generate a new GIS file, ***SM_PGV_Pipes***, and click **Finish** button.



Brings up the GeoProcessing Wizard

(a) Step 1



Choose a GeoProcessing operation, then click the Next button to choose options.

○ Dissolve features based on an attribute

○ Merge layers together

○ Clip one layer based on another

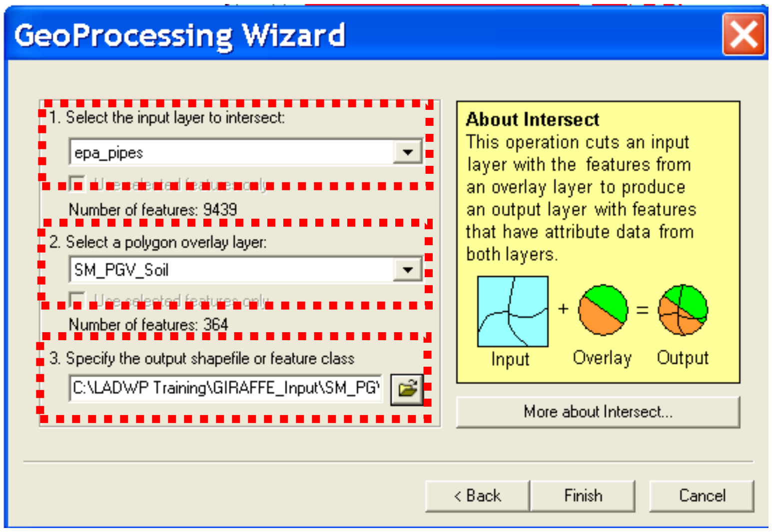
● Intersect two layers

○ Union two layers

About Intersect
This operation cuts an input layer with the features from an overlay layer to produce an output layer with features that have attribute data from both layers.

(b) Step 2

Figure B.13. Assigning PGV to Pipelines



1. Select the input layer to intersect:
epa_pipes
☐ Use selected features only
Number of features: 9439

2. Select a polygon overlay layer:
SM_PGV_Soil
☐ Use selected features only
Number of features: 364

3. Specify the output shapefile or feature class
C:\LADWP Training\GIRAFFE_Input\SM_PG

About Intersect
This operation cuts an input layer with the features from an overlay layer to produce an output layer with features that have attribute data from both layers.

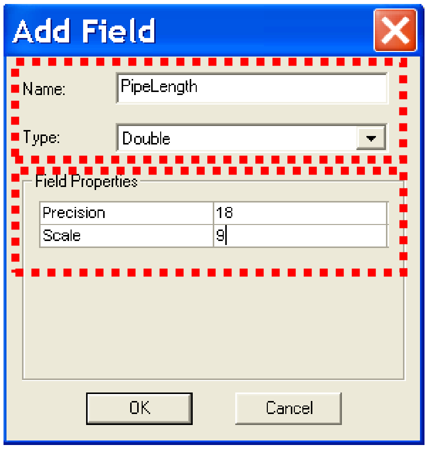
(c) Step 3

Figure B.13. Assigning PGV to Pipelines (Continued)

Because the pipes may be divided by the "Intersect" function in ArcGIS, the length for each divided pipe needs to be re-calculated. GIRAFFE can simulate damage to pipelines composed of five different materials, cast iron (CI), ductile iron (DI), riveted steel (RS), steel (STL), and concrete (CON). However, the H2ONET database contains more material types than the five specified. For example, there are several different steel pipes in the H2ONET database. Also, there are some pipes for which information about composition in the H2ONET database is lacking. Therefore, additional GIS spatial analysis is needed to adjust the data. The detailed procedures in ArcGIS are as follows:

- Open attribute table of ***SM_PGV_Pipes***, add a new attribute column **PipeLength** as shown in Figure B.14(a).
- Calculate the length of each divided pipe in the **PipeLength** column by keying in the syntax in the field calculator window, as shown in Figure B.14(b), and clicking **OK** button.
- Add a new attribute column **Material1** as shown in Figure B.14(c).
- Click **Option** button at the bottom of attribute table, and click on **Select by Attributes…** in the pop-up menu, as shown in Figure B.14(d).

- A window will open. Key in the syntax as shown in Figure B.14(e) to select cast iron (CI) pipes, and click **Apply** button.
- Right-click on the header of the **Material1** column, and select **Calculate Values…** in the pop-up menu, as shown in Figure B.14(f).
- A window will open, and key in the syntax as shown in Figure B.14(g) to classify cast iron pipes as CI.
- Repeat the last four steps to classify ductile pipes, concrete pipes, riveted steel pipes, steel pipes, and pipes without material information as DI, CON, RS, STL, and N/A, respectively. See Table B.4 for a complete description of the material reclassification scheme.



Name: PipeLength

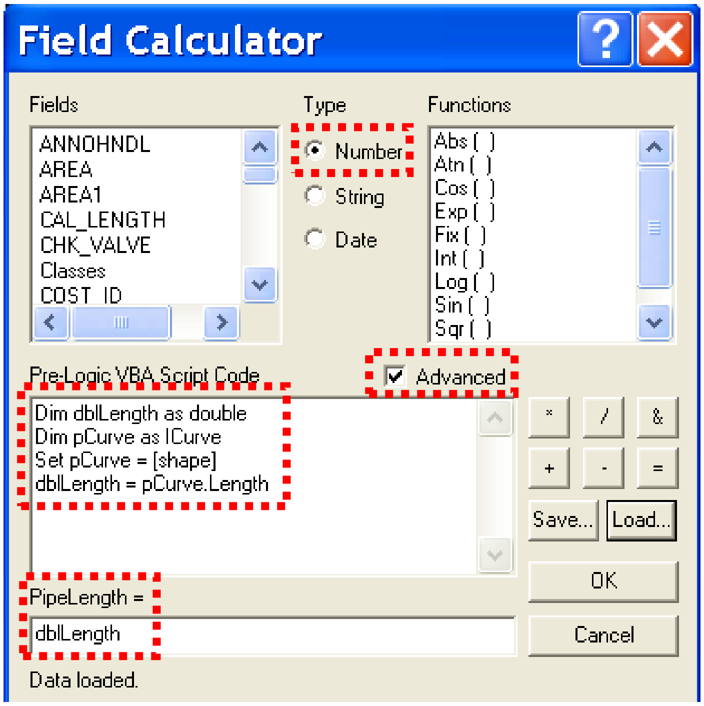
Type: Double

Field Properties

Precision	18
Scale	9

(a) Step 1

Figure B.14. Adjusting GIS Data



Type: ● Number ○ String ○ Date

☑ Advanced

Pre-Logic VBA Script Code

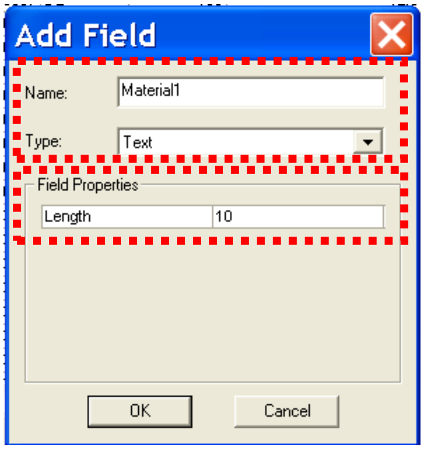
```
Dim dblLength as double
Dim pCurve as ICurve
Set pCurve = [shape]
dblLength = pCurve.Length
```

PipeLength =

```
dblLength
```

Data loaded.

(b) Step 2



Name: Material1

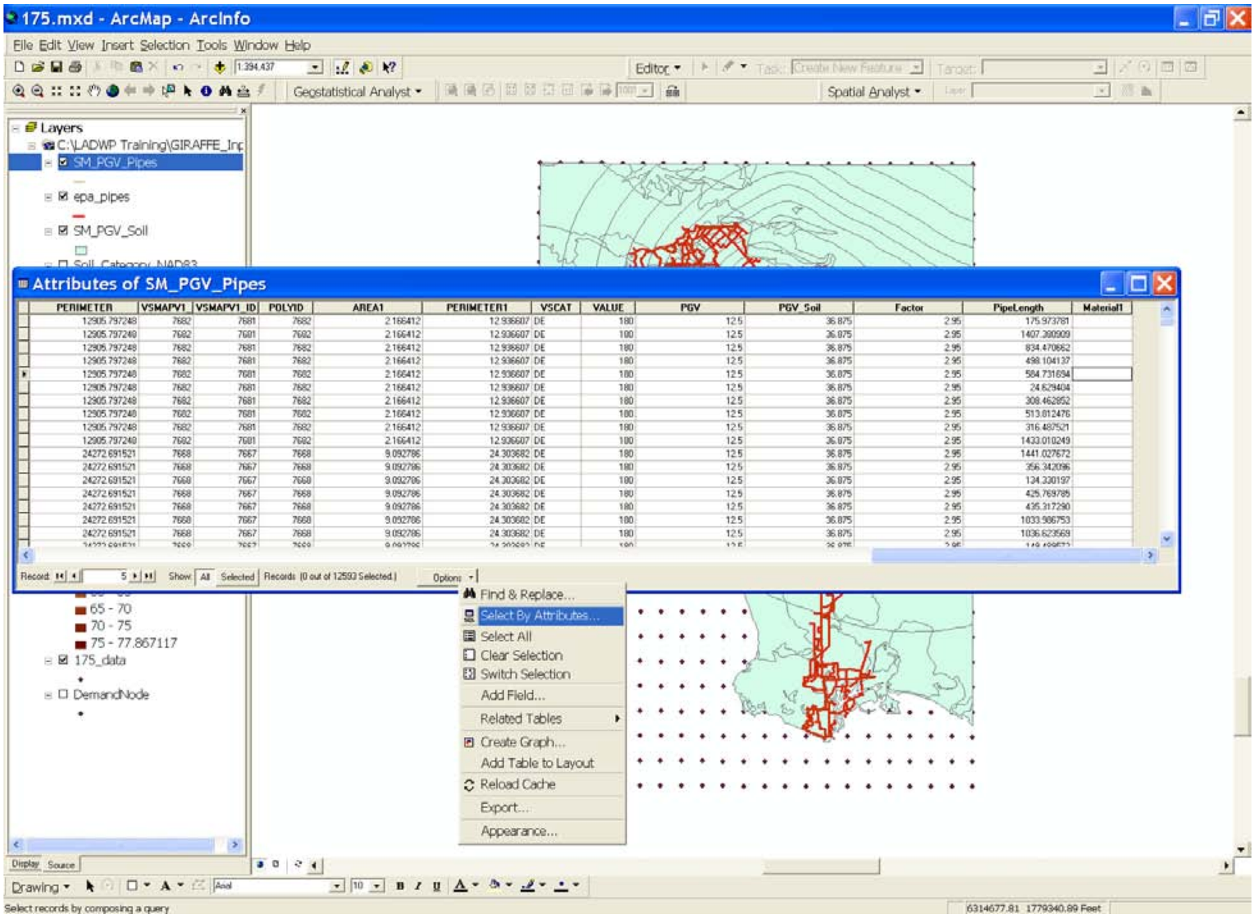
Type: Text

Field Properties

Length	10

(c) Step 3

Figure B.14. Adjusting GIS Data



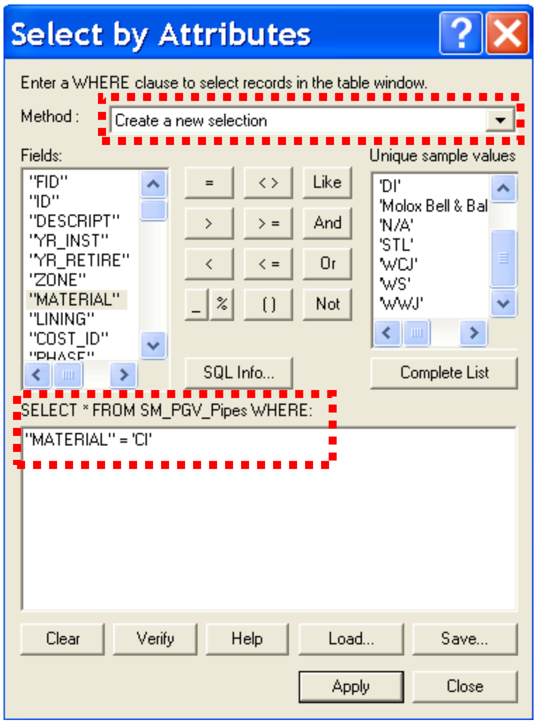
Attributes of SM_PGV_Pipes

PERIMETER	VSMAPV1	VSMAPV1_ID	POLYID	AREA1	PERIMETER1	VSCAT	VALUE	PGV	PGV_Soil	Factor	PipeLength	Material1
12905.797248	7682	7681	7682	2.166412	12.936607	DE	180	12.5	36.875	2.95	175.973781	
12905.797248	7682	7681	7682	2.166412	12.936607	DE	180	12.5	36.875	2.95	1407.380909	
12905.797248	7682	7681	7682	2.166412	12.936607	DE	180	12.5	36.875	2.95	834.470662	
12905.797248	7682	7681	7682	2.166412	12.936607	DE	180	12.5	36.875	2.95	498.104137	
12905.797248	7682	7681	7682	2.166412	12.936607	DE	180	12.5	36.875	2.95	584.731694	
12905.797248	7682	7681	7682	2.166412	12.936607	DE	180	12.5	36.875	2.95	24.629404	
12905.797248	7682	7681	7682	2.166412	12.936607	DE	180	12.5	36.875	2.95	308.462852	
12905.797248	7682	7681	7682	2.166412	12.936607	DE	180	12.5	36.875	2.95	513.812476	
12905.797248	7682	7681	7682	2.166412	12.936607	DE	180	12.5	36.875	2.95	316.487521	
12905.797248	7682	7681	7682	2.166412	12.936607	DE	180	12.5	36.875	2.95	1433.010249	
24272.691521	7668	7667	7668	9.092786	24.303682	DE	180	12.5	36.875	2.95	1441.027672	
24272.691521	7668	7667	7668	9.092786	24.303682	DE	180	12.5	36.875	2.95	356.342096	
24272.691521	7668	7667	7668	9.092786	24.303682	DE	180	12.5	36.875	2.95	134.330197	
24272.691521	7668	7667	7668	9.092786	24.303682	DE	180	12.5	36.875	2.95	425.769785	
24272.691521	7668	7667	7668	9.092786	24.303682	DE	180	12.5	36.875	2.95	435.317290	
24272.691521	7668	7667	7668	9.092786	24.303682	DE	180	12.5	36.875	2.95	1033.986753	
24272.691521	7668	7667	7668	9.092786	24.303682	DE	180	12.5	36.875	2.95	1036.623569	

Record: 5 Show: All Selected Records (0 out of 12593 Selected.)

(d) Step 4

Figure B.14. Adjusting GIS Data (Continued)


Select by Attributes

Enter a WHERE clause to select records in the table window.

Method : Create a new selection

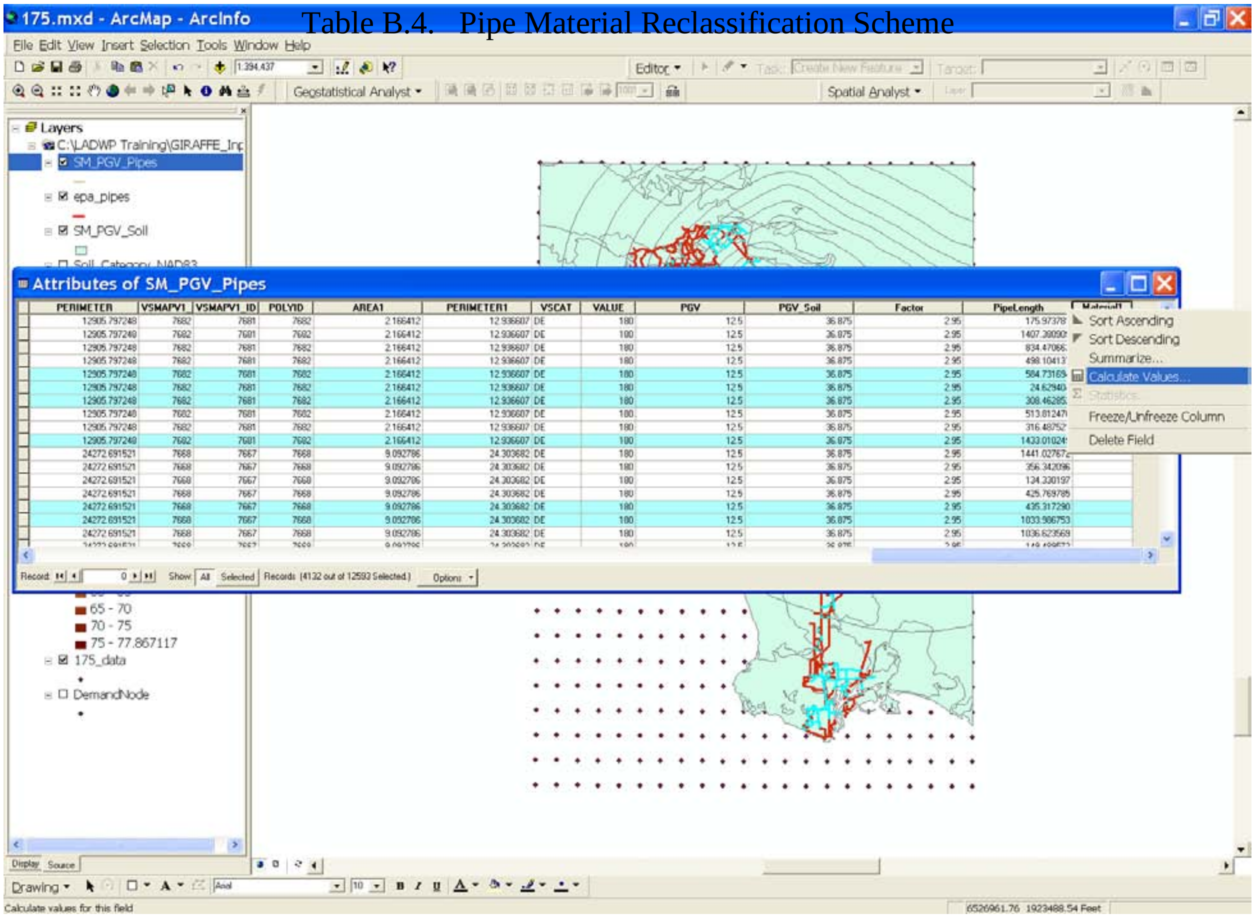
SELECT * FROM SM_PGV_Pipes WHERE:

"MATERIAL" = 'CI'

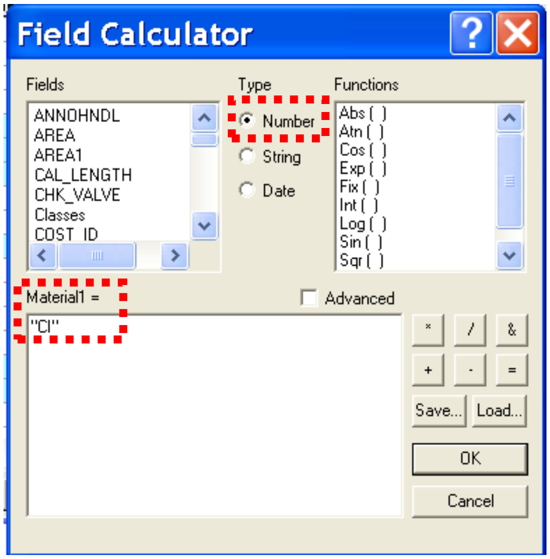
(e) Step 5

Figure B.14. Adjusting GIS Data (Continued)

Table B.4. Pipe Material Reclassification Scheme



(f) Step 6



Type: ● Number ○ String ○ Date

Material1 =

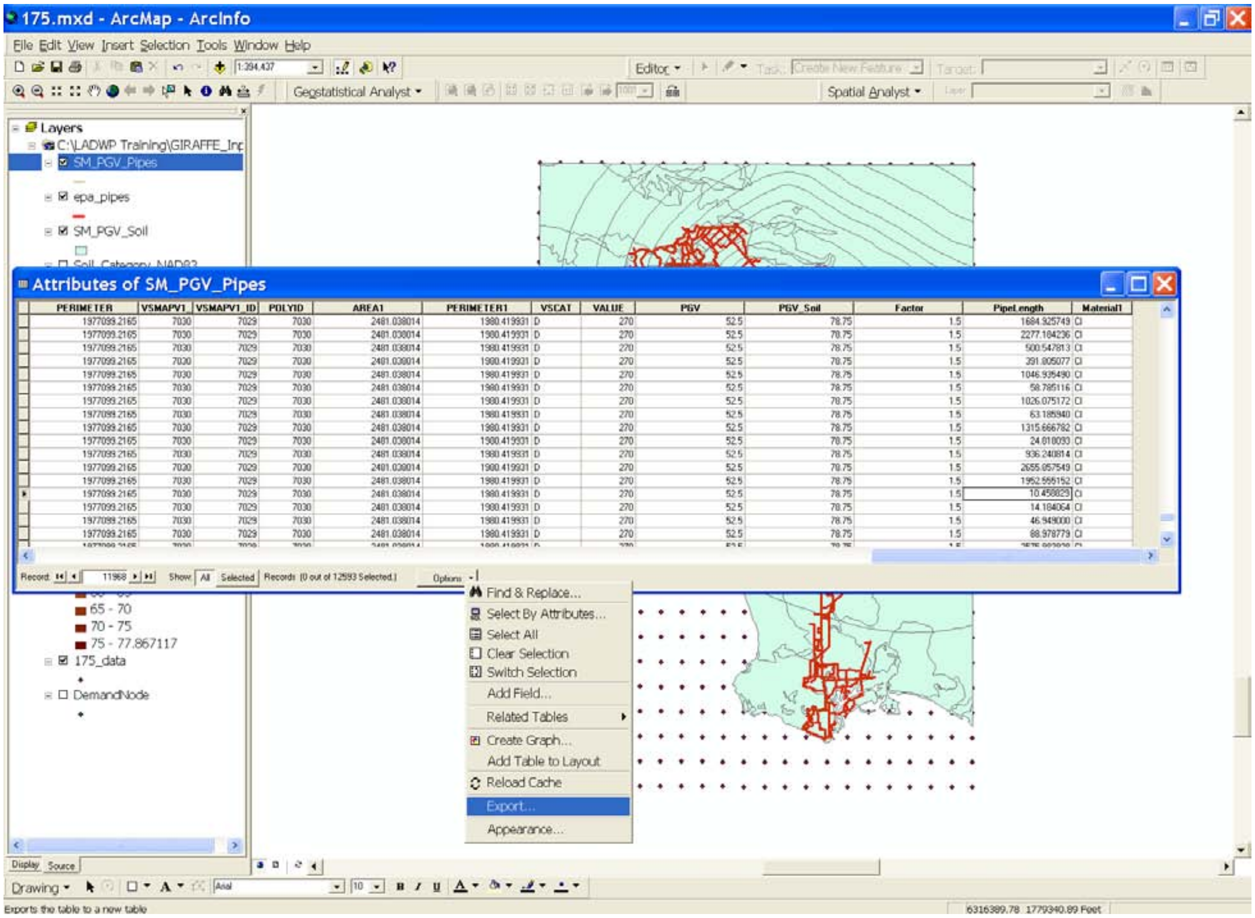
"CI"

(g) Step 7

Figure B.14. Adjusting GIS Data (Continued)

	New Classes					
	CI	**DI**	**CON**	**N/A**	**RS**	**STL**
Original Classes	CI	DI	CON	N/A	RS	STL
			COP	AC	RIV	B&S WS
						MANN
						MATH
						Molox Bell & Ball Joint
						ST
						STD
						steel
						Steel
						STL GALV
						VICT
						WCJ
						WRG
						WS
						WSJ
						WWJ

The GIS data are then exported to Microsoft Excel for spreadsheet calculation of repair rate in each pipe. To export the GIS data, click on the **Option** button at the bottom of attribute table, as shown in Figure B.15(a) and go to **Export…** in the pop-up menu. A window will open, and a spreadsheet file named ***Pipes.dbf*** in dBASE IV format is generated, as shown in Figure B.15(b). Open the ***Pipes.dbf*** in Excel, and delete all other columns except **ID**, **PGV_Soils**, **PipeLength**, and **Material1**. Then, the repair rate for each pipe can be calculated using regressions (Wang 2006). Figure B.16 shows the regressions used in this study, which are based on the performance of water supply systems in the 1994 Northridge earthquake (Jeon 2002 and Wang 2006). The repair rates for each section of pipe (after having divided the pipes using the GIS "Intersect" function) were calculated individually, using the repair rate vs. PGV regressions. These repair rate values were then integrated by a weighted average (relating the divided pipe lengths to the original pipe length) to obtain one repair rate for the original long pipe. An equal-weight average of five repair rates using the five regressions in the figures was applied to the pipelines (about 7% of total length in the LADWP system) without composition information available in the H2ONET database (*e.g*. MATERIAL1 = "N/A"). After the calculation of repair rates, the Excel spreadsheet was saved in MS-DOS text format (*.*txt*) and then renamed following the input file name convention of GIRAFFE (*.*inp*). Figure B.17 shows an illustration of the pipe damage file in GIRAFFE format. Be sure that the first line of the file matches exactly what is shown. Note that length is in units of kilometers.


175.mxd - ArcMap - ArcInfo

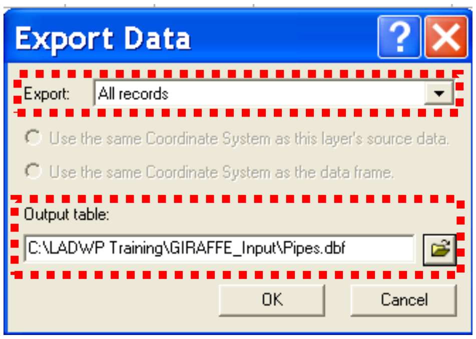
Attributes of SM_PGV_Pipes

PERIMETER	VSMAPV1_	VSMAPV1_ID	POLYID	AREA1	PERIMETER1	VSCAT	VALUE	PGV	PGV_Soil	Factor	PipeLength	Material1
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	1684.925749	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	2277.104236	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	500.547813	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	391.805077	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	1046.935490	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	58.785116	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	1026.075172	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	63.185940	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	1315.666782	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	24.010093	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	936.240814	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	2655.057549	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	1952.555152	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	10.450829	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	14.184064	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	46.949000	CI
1977099.2165	7030	7029	7030	2481.038014	1980.419931	D	270	52.5	78.75	1.5	88.978779	CI

Record: 11968 Show: All Selected Records (0 out of 12593 Selected.)

Exports the table to a new table

(a) Step 1


Export Data

Export: All records

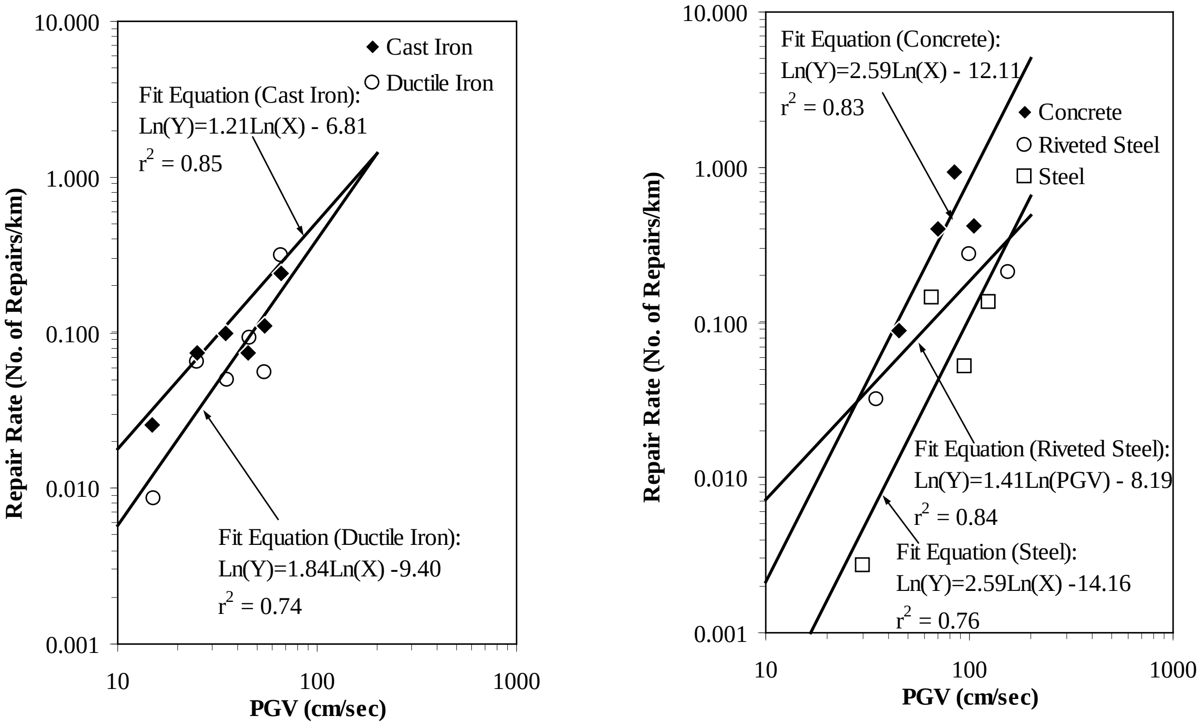
○ Use the same Coordinate System as this layer's source data.

○ Use the same Coordinate System as the data frame.

Output table: C:\LADWP Training\GIRAFFE_Input\Pipes.dbf

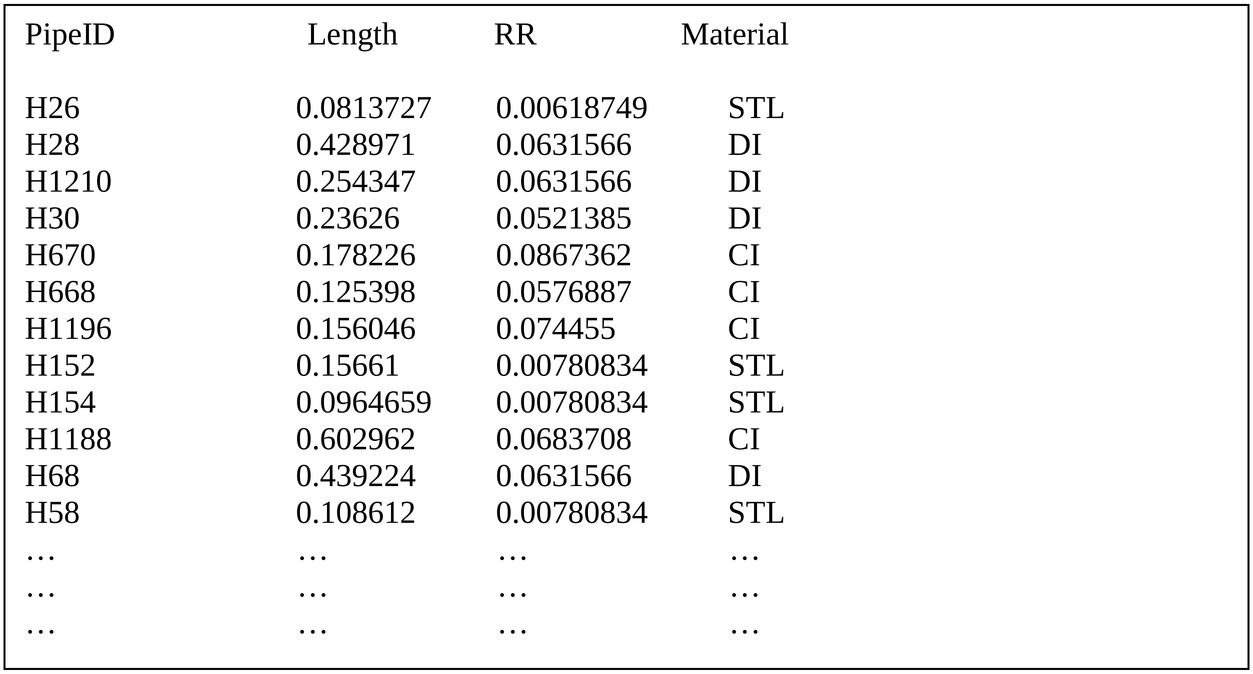
(b) Step 2

Figure B.15. Exporting Pipeline Damage GIS Data to Spreadsheet Calculation



(a) (b)

Figure B.16. Regressions of Pipeline Repair Rate vs. PGV (Wang 2006)



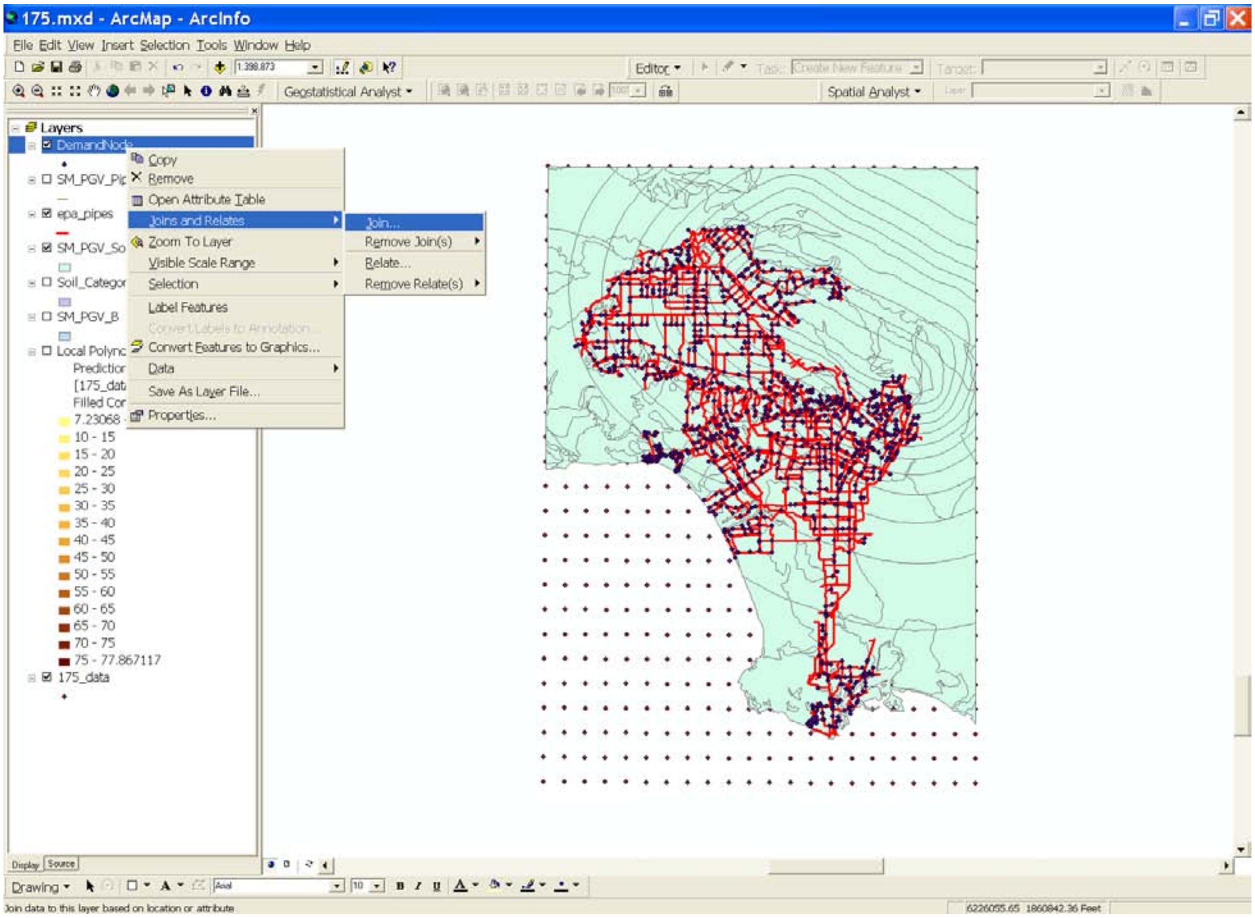
```
PipeID            Length        RR            Material

H26               0.0813727     0.00618749      STL
H28               0.428971      0.0631566       DI
H1210             0.254347      0.0631566       DI
H30               0.23626       0.0521385       DI
H670              0.178226      0.0867362       CI
H668              0.125398      0.0576887       CI
H1196             0.156046      0.074455        CI
H152              0.15661       0.00780834      STL
H154              0.0964659     0.00780834      STL
H1188             0.602962      0.0683708       CI
H68               0.439224      0.0631566       DI
H58               0.108612      0.00780834      STL
…                 …             …               …
…                 …             …               …
…                 …             …               …
```

Figure B.17. Illustration of GIRAFFE Pipeline Damage File

B.4.4. Seismic Demands on Node-type Components

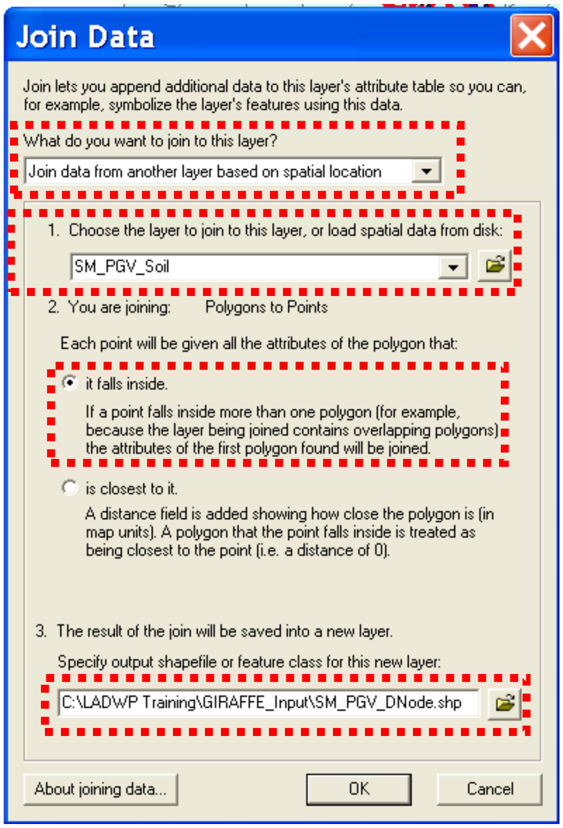
The PGVs that the demand nodes are subjected to are determined by an ArcGIS function, “Spatial Join”, which combines the information in the two input data layers (*i.e.* the demand node layer and PGV contour surface layer) into an output data layer according to their spatial positions. The detailed procedures in ArcGIS are as follows:

- right-click on ***DemandNode***, and go to **Joins and Relates | Join…** in the pop-up menu, as shown in Figure B. 18(a).
- A window will open, specify the parameters as shown in Figure B.18(b), and click **OK**.



(a) Step 1

Figure B.18. Assigning PGVs to Demand Nodes



Join lets you append additional data to this layer's attribute table so you can, for example, symbolize the layer's features using this data.

What do you want to join to this layer?

Join data from another layer based on spatial location

1. Choose the layer to join to this layer, or load spatial data from disk:

SM_PGV_Soil

2. You are joining: Polygons to Points

Each point will be given all the attributes of the polygon that:

● it falls inside.

If a point falls inside more than one polygon (for example, because the layer being joined contains overlapping polygons) the attributes of the first polygon found will be joined.

○ is closest to it.

A distance field is added showing how close the polygon is (in map units). A polygon that the point falls inside is treated as being closest to the point (i.e. a distance of 0).

3. The result of the join will be saved into a new layer.

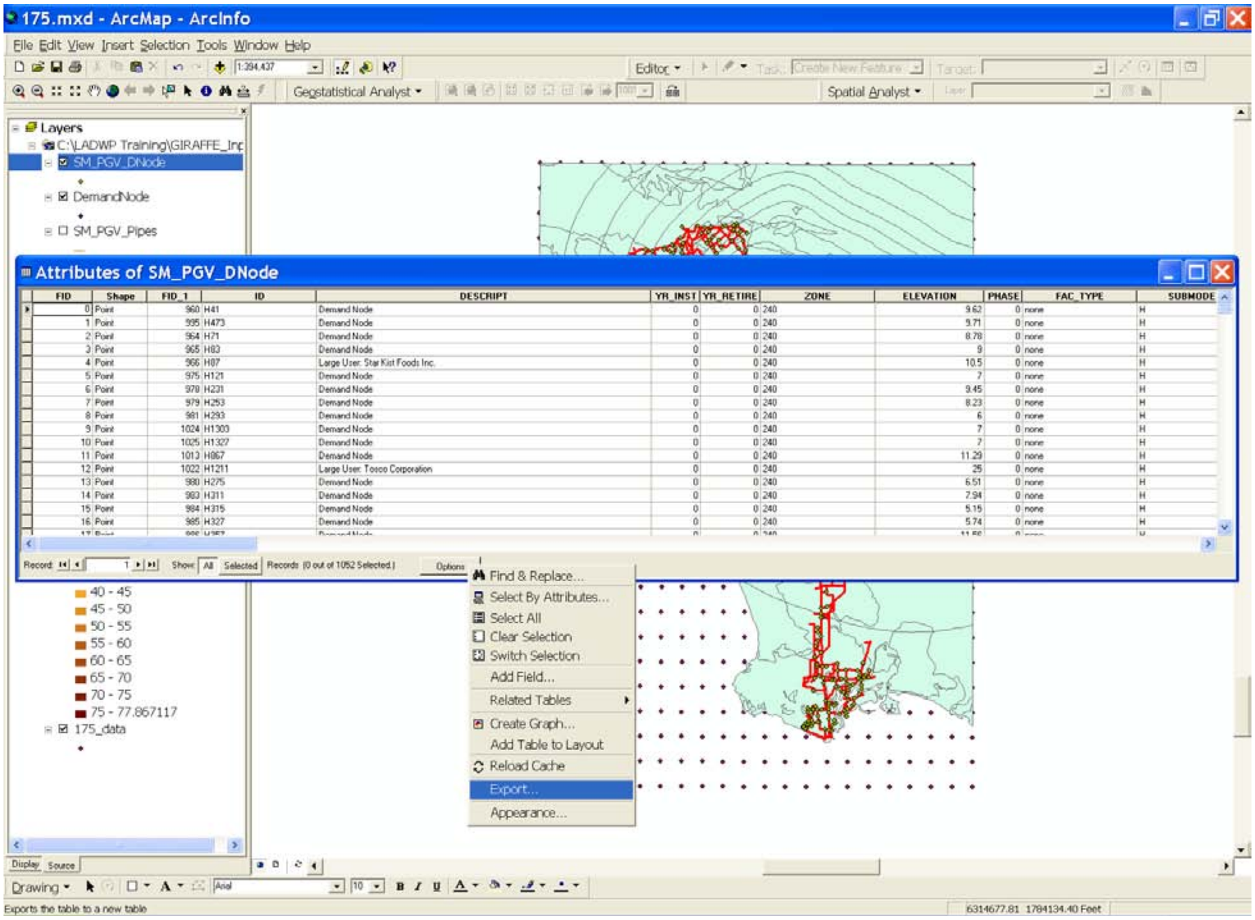
Specify output shapefile or feature class for this new layer:

C:\LADWP Training\GIRAFFE_Input\SM_PGV_DNode.shp

(b) Step 2

Figure B.18. Assigning PGVs to Demand Nodes (Continued)

The GIS data are then exported to Microsoft Excel for spreadsheet calculation of repair rate at each demand node. To export the GIS data, click on the **Option** button at the bottom of attribute table, as shown in Figure B.19(a), and go to **Export…** in the pop-up menu. A window will appear, and a spreadsheet file named ***DistributionD.dbf*** in dBASE IV format is generated, as shown in Figure B.19(b). Open the ***DistributionD.dbf*** in Excel, and delete all other columns except **ID**, **PGV_Soils**, and **Ave_Pressure**. Then, the repair rates for the local distribution pipelines are calculated using the regression for cast iron pipelines (Figure B.16) because the majority of the local distribution lines are composed of cast iron (Wang 2006). After the calculation of repair rates, the Excel spreadsheet is saved in MS-DOS text format (*.*txt*) and then renamed following the input file name convention of GIRAFFE (*.*inp*). Figure B.20 shows an illustration of local distribution pipeline damage file in GIRAFFE format. Be sure that the first line in the file matches exactly what is shown.



Attributes of SM_PGV_DNode

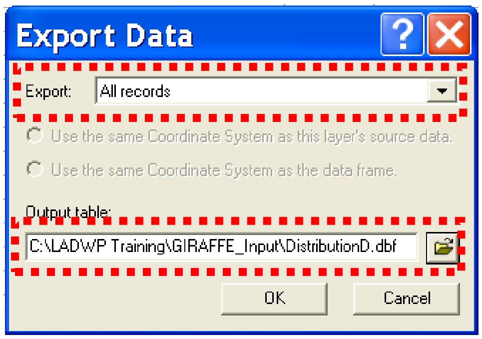
FID	Shape	FID_1	ID	DESCRIPT	YR_INST	YR_RETIRE	ZONE	ELEVATION	PHASE	FAC_TYPE	SUBMODE
0	Point	960	H41	Demand Node	0	0	240	9.62	0	none	H
1	Point	995	H473	Demand Node	0	0	240	9.71	0	none	H
2	Point	964	H71	Demand Node	0	0	240	8.78	0	none	H
3	Point	965	H83	Demand Node	0	0	240	9	0	none	H
4	Point	966	H87	Large User: Star Kist Foods Inc.	0	0	240	10.5	0	none	H
5	Point	975	H121	Demand Node	0	0	240	7	0	none	H
6	Point	978	H231	Demand Node	0	0	240	9.45	0	none	H
7	Point	979	H253	Demand Node	0	0	240	8.23	0	none	H
8	Point	981	H293	Demand Node	0	0	240	6	0	none	H
9	Point	1024	H1303	Demand Node	0	0	240	7	0	none	H
10	Point	1025	H1327	Demand Node	0	0	240	7	0	none	H
11	Point	1013	H867	Demand Node	0	0	240	11.29	0	none	H
12	Point	1022	H1211	Large User: Tosco Corporation	0	0	240	25	0	none	H
13	Point	980	H275	Demand Node	0	0	240	6.51	0	none	H
14	Point	983	H311	Demand Node	0	0	240	7.94	0	none	H
15	Point	984	H315	Demand Node	0	0	240	5.15	0	none	H
16	Point	985	H327	Demand Node	0	0	240	5.74	0	none	H

Record: 1 Show: All Selected Records (0 out of 1052 Selected.)

Exports the table to a new table

6314677.81 1784134.40 Feet

(a) Step 1



Export: All records

○ Use the same Coordinate System as this layer's source data.

○ Use the same Coordinate System as the data frame.

Output table:

C:\LADWP Training\GIRAFFE_Input\DistributionD.dbf

(b) Step 2

Figure B.19. Exporting Demand Node GIS Data to Spreadsheet Calculation

ID	G_RR	Ave_PRESSURE
H41	0.086736	84.1035
H473	0.086736	84.1035
H71	0.086736	84.1035
H83	0.086736	84.1035
H87	0.086736	84.1035
H121	0.086736	84.1035
H231	0.086736	84.1035
H253	0.086736	84.1035
H293	0.086736	84.1035
H1303	0.086736	84.1035
H1327	0.086736	84.1035
H867	0.067573	84.1035
H1211	0.067573	84.1035
…	…	…
…	…	…
…	…	…

Figure B.20. Illustration of GIRAFFE Local Distribution Pipeline Damage File

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APPENDIX C
GIRAFFE INPUT PREPARATION AND OUTPUT VISUALIZATION USING MANIFOLD GIS

C.1 INTRODUCTION

This appendix provides a demonstration of how to prepare system damage input files for GIRAFFE simulations using Manifold GIS, and how to use Manifold to create a cartographic representation of GIRAFFE results. The system damage products of this appendix are identical to those generated in Appendix B; therefore, the user may choose which method to use when generating the system damage input files. The method presented in this Appendix is much more efficient than the method used in Appendix B, though the user has less control over the results using this method. This appendix focuses on preparing system damage files for stochastic simulations by a series of manipulations and spatial analyses using Manifold GIS. The preparation of the system damage file for deterministic simulations using Manifold GIS is described in **Section A.4 DETERMINISTIC SIMULATIONS** of Appendix A. Although the thought process of the input file preparation applies to other GIS and hydraulic analysis software, this demonstration uses Manifold System 7.1. Users should be familiar with GIRAFFE, EPANET, H2ONET, and Manifold before preparing GIRAFFE input files. For more information on EPANET, H2ONET, and Manifold, users can refer to the EPANET User Manual (Rossman, 2000), H2ONET User Manual (MWH Soft, Inc., 1999), and Manifold System User Manual (Manifold Net Ltd, 2006).

This appendix is tailored to the seismic performance evaluation of the Los Angeles water supply system, which is operated by Los Angeles Department of Water and Power (LADWP). For the details of the evaluation process, please refer to Wang (2006) and Shi (2006). For a brief description of LADWP seismic hazard characterization and H2ONET analysis of the LADWP water supply system, refer to **Section B.2 LADWP SEISMIC HAZARD CHARACTERIZATION** and **Section B.3 H2ONET ANALYSIS OF LADWP WATER SUPPLY SYSTEM** of Appendix B.

C.2 GIS SPATIAL ANALYSIS AND CALCULATION USING MANIFOLD

After the system characteristics of the LADWP system are exported from H2ONET, GIS spatial analysis is used to generate the system damage files in GIRAFFE format. This section describes how to use the GIRAFFE system damage tool, which is linked to Manifold in order to perform the spatial analyses and calculations necessary to generate the damage files. This section uses the Scenario 175 Verdugo earthquake as an illustration, and the same procedures apply to each of the 59 scenario earthquakes.

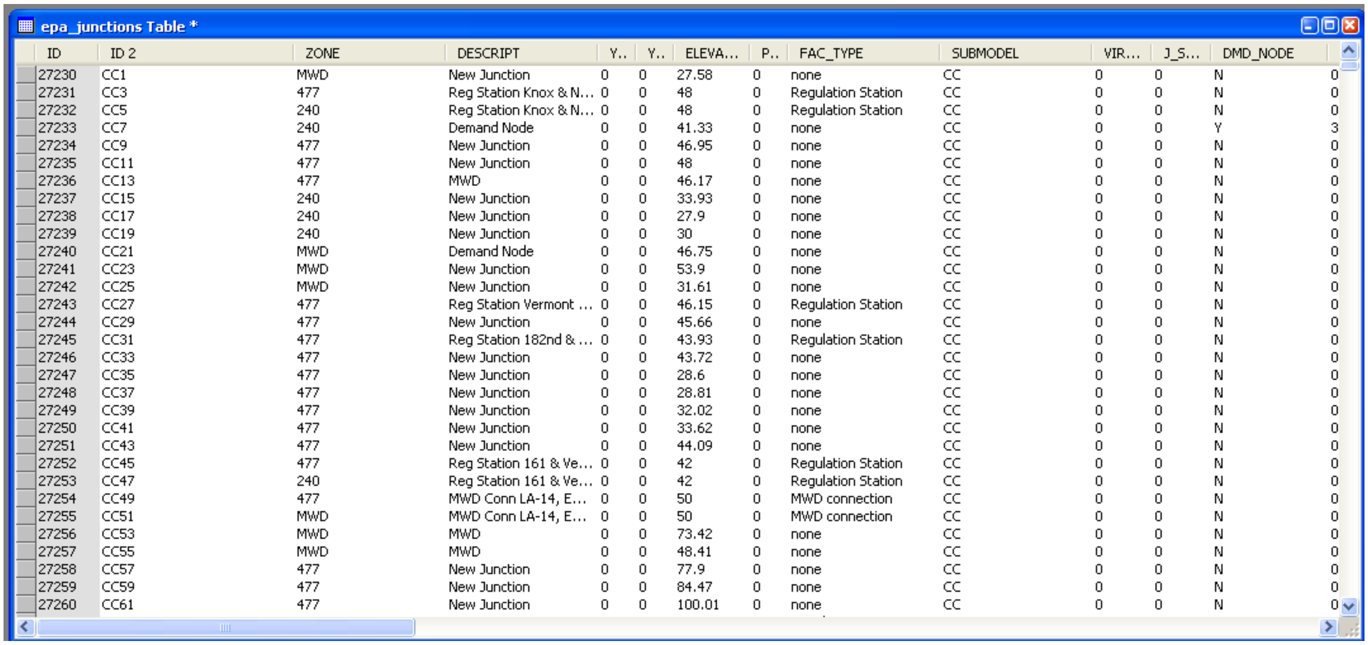
This section also describes how to use the Manifold System Damage Add-In, which formats the pipe data for use with the GIRAFFE system damage tool and performs the same function as the GIRAFFE system damage tool.

C.2.1. Importing and Formatting Required Data in Manifold GIS

GIRAFFE requires specific GIS files to calculate the system damage. The following files should be imported into a Manifold project and named exactly as shown unless otherwise indicated:

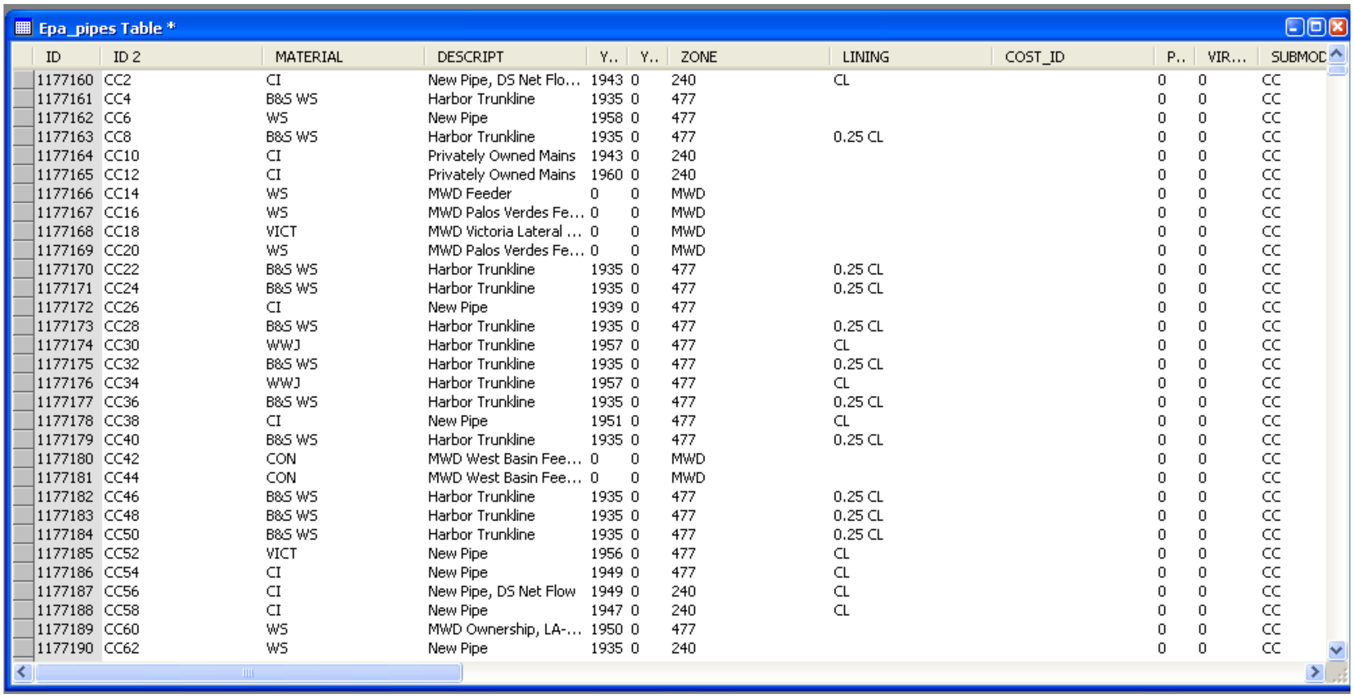
- ***epa_junctions.shp* –** Shapefile containing points that represent junction data for the entire system. Obtained by exporting data from H20NET model as explained in **Section B.3.3 Exporting Node-type Component Data to GIS**. See Figure C.1 for table format.
- ***Epa_pipes.shp* –** Shapefile containing lines that represent pipe data for the entire system. Pipes have been segmented into 1000’ pieces and segmented at the soil boundaries as described in **Section C.2.3, Table C.1**. Pipes must be segmented before running the tool, but this must only be done when the system is updated. Obtained by exporting data from H20NET model as explained in **Section B.3.2 Exporting Link-type Component Data to GIS**. See Figure C.2 for table format.
- ***Node_Pressure.dbf* –** Table containing pressure values for each node in the system. Created by exporting node pressure data from H20NET system model (see **Section B.4, Figure B.5** on pages 14-17). See Figure C.3 for table format. There must be a column named **node_pressure** (all lowercase letters).

- ***Soil_Category_NAD83 Drawing.shp*** **–** Shapefile containing polygons that represent the soil types in the area. Provided by California Geological Survey. See Figure C.4 for table format.
- ***Pgvsurf*** **–** User generated, empty surface in which scenario peak ground velocity (PGV) values are interpolated.



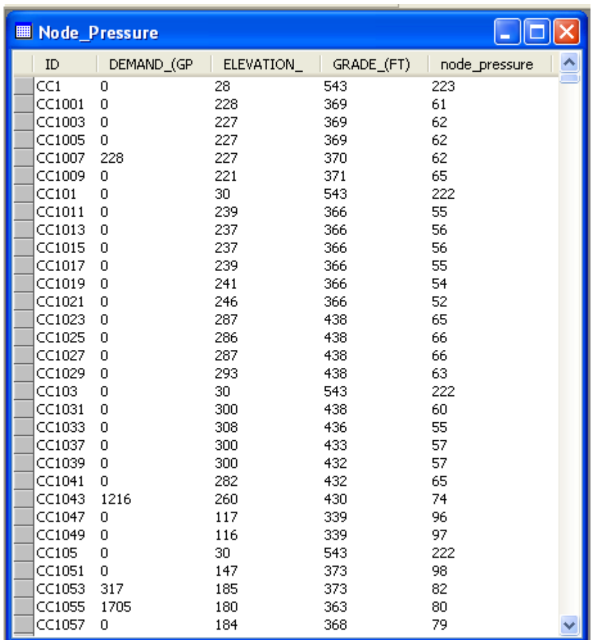
ID	ID 2	ZONE	DESCRIPT	Y..	Y..	ELEVA...	P..	FAC_TYPE	SUBMODEL	VIR...	J_S...	DMD_NODE	
27230	CC1	MWD	New Junction	0	0	27.58	0	none	CC	0	0	N	0
27231	CC3	477	Reg Station Knox & N...	0	0	48	0	Regulation Station	CC	0	0	N	0
27232	CC5	240	Reg Station Knox & N...	0	0	48	0	Regulation Station	CC	0	0	N	0
27233	CC7	240	Demand Node	0	0	41.33	0	none	CC	0	0	Y	3
27234	CC9	477	New Junction	0	0	46.95	0	none	CC	0	0	N	0
27235	CC11	477	New Junction	0	0	48	0	none	CC	0	0	N	0
27236	CC13	477	MWD	0	0	46.17	0	none	CC	0	0	N	0
27237	CC15	240	New Junction	0	0	33.93	0	none	CC	0	0	N	0
27238	CC17	240	New Junction	0	0	27.9	0	none	CC	0	0	N	0
27239	CC19	240	New Junction	0	0	30	0	none	CC	0	0	N	0
27240	CC21	MWD	Demand Node	0	0	46.75	0	none	CC	0	0	N	0
27241	CC23	MWD	New Junction	0	0	53.9	0	none	CC	0	0	N	0
27242	CC25	MWD	New Junction	0	0	31.61	0	none	CC	0	0	N	0
27243	CC27	477	Reg Station Vermont ...	0	0	46.15	0	Regulation Station	CC	0	0	N	0
27244	CC29	477	New Junction	0	0	45.66	0	none	CC	0	0	N	0
27245	CC31	477	Reg Station 182nd & ...	0	0	43.93	0	Regulation Station	CC	0	0	N	0
27246	CC33	477	New Junction	0	0	43.72	0	none	CC	0	0	N	0
27247	CC35	477	New Junction	0	0	28.6	0	none	CC	0	0	N	0
27248	CC37	477	New Junction	0	0	28.81	0	none	CC	0	0	N	0
27249	CC39	477	New Junction	0	0	32.02	0	none	CC	0	0	N	0
27250	CC41	477	New Junction	0	0	33.62	0	none	CC	0	0	N	0
27251	CC43	477	New Junction	0	0	44.09	0	none	CC	0	0	N	0
27252	CC45	477	Reg Station 161 & Ve...	0	0	42	0	Regulation Station	CC	0	0	N	0
27253	CC47	240	Reg Station 161 & Ve...	0	0	42	0	Regulation Station	CC	0	0	N	0
27254	CC49	477	MWD Conn LA-14, E...	0	0	50	0	MWD connection	CC	0	0	N	0
27255	CC51	MWD	MWD Conn LA-14, E...	0	0	50	0	MWD connection	CC	0	0	N	0
27256	CC53	MWD	MWD	0	0	73.42	0	none	CC	0	0	N	0
27257	CC55	MWD	MWD	0	0	48.41	0	none	CC	0	0	N	0
27258	CC57	477	New Junction	0	0	77.9	0	none	CC	0	0	N	0
27259	CC59	477	New Junction	0	0	84.47	0	none	CC	0	0	N	0
27260	CC61	477	New Junction	0	0	100.01	0	none	CC	0	0	N	0

Figure C.1. Illustration of *epa_junctions* table.



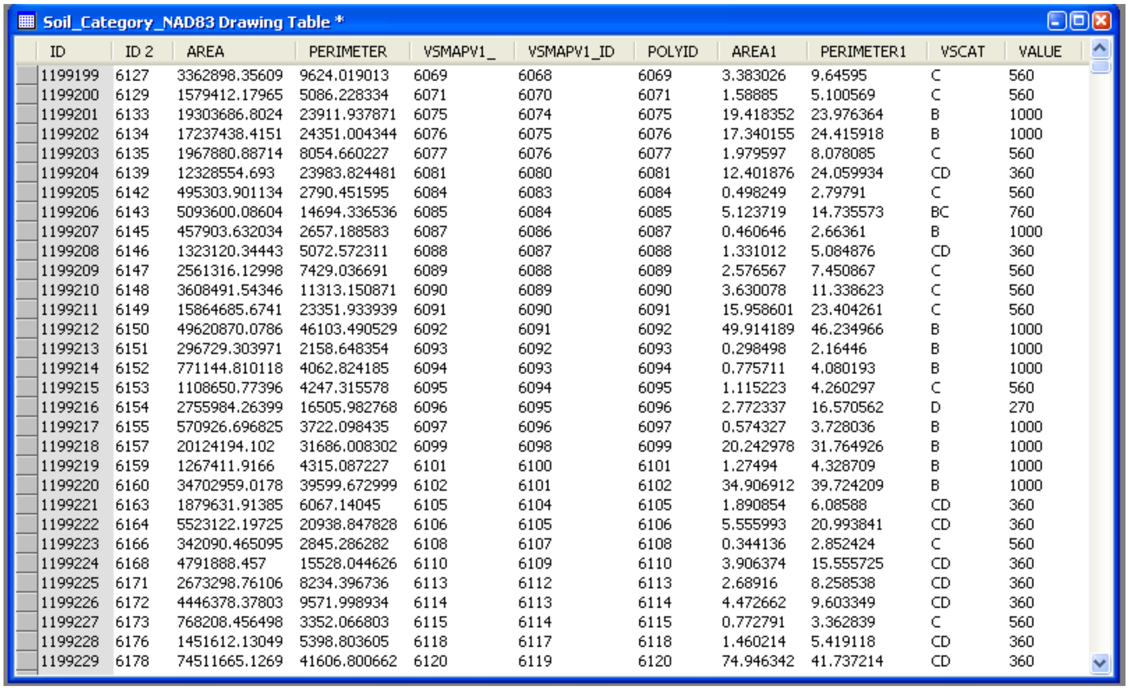
ID	ID 2	MATERIAL	DESCRIPT	Y..	Y..	ZONE	LINING	COST_ID	P..	VIR...	SUBMOD
1177160	CC2	CI	New Pipe, DS Net Flo...	1943	0	240	CL		0	0	CC
1177161	CC4	B&S WS	Harbor Trunkline	1935	0	477			0	0	CC
1177162	CC6	WS	New Pipe	1958	0	477			0	0	CC
1177163	CC8	B&S WS	Harbor Trunkline	1935	0	477	0.25 CL		0	0	CC
1177164	CC10	CI	Privately Owned Mains	1943	0	240			0	0	CC
1177165	CC12	CI	Privately Owned Mains	1960	0	240			0	0	CC
1177166	CC14	WS	MWD Feeder	0	0	MWD			0	0	CC
1177167	CC16	WS	MWD Palos Verdes Fe...	0	0	MWD			0	0	CC
1177168	CC18	VICT	MWD Victoria Lateral ...	0	0	MWD			0	0	CC
1177169	CC20	WS	MWD Palos Verdes Fe...	0	0	MWD			0	0	CC
1177170	CC22	B&S WS	Harbor Trunkline	1935	0	477	0.25 CL		0	0	CC
1177171	CC24	B&S WS	Harbor Trunkline	1935	0	477	0.25 CL		0	0	CC
1177172	CC26	CI	New Pipe	1939	0	477			0	0	CC
1177173	CC28	B&S WS	Harbor Trunkline	1935	0	477	0.25 CL		0	0	CC
1177174	CC30	WWJ	Harbor Trunkline	1957	0	477	CL		0	0	CC
1177175	CC32	B&S WS	Harbor Trunkline	1935	0	477	0.25 CL		0	0	CC
1177176	CC34	WWJ	Harbor Trunkline	1957	0	477	CL		0	0	CC
1177177	CC36	B&S WS	Harbor Trunkline	1935	0	477	0.25 CL		0	0	CC
1177178	CC38	CI	New Pipe	1951	0	477	CL		0	0	CC
1177179	CC40	B&S WS	Harbor Trunkline	1935	0	477	0.25 CL		0	0	CC
1177180	CC42	CON	MWD West Basin Fee...	0	0	MWD			0	0	CC
1177181	CC44	CON	MWD West Basin Fee...	0	0	MWD			0	0	CC
1177182	CC46	B&S WS	Harbor Trunkline	1935	0	477	0.25 CL		0	0	CC
1177183	CC48	B&S WS	Harbor Trunkline	1935	0	477	0.25 CL		0	0	CC
1177184	CC50	B&S WS	Harbor Trunkline	1935	0	477	0.25 CL		0	0	CC
1177185	CC52	VICT	New Pipe	1956	0	477	CL		0	0	CC
1177186	CC54	CI	New Pipe	1949	0	477	CL		0	0	CC
1177187	CC56	CI	New Pipe, DS Net Flow	1949	0	240	CL		0	0	CC
1177188	CC58	CI	New Pipe	1947	0	240	CL		0	0	CC
1177189	CC60	WS	MWD Ownership, LA-...	1950	0	477			0	0	CC
1177190	CC62	WS	New Pipe	1935	0	240			0	0	CC

Figure C.2. Illustration of *Epa_pipes* table.



ID	DEMAND_(GP	ELEVATION_	GRADE_(FT)	node_pressure
CC1	0	28	543	223
CC1001	0	228	369	61
CC1003	0	227	369	62
CC1005	0	227	369	62
CC1007	228	227	370	62
CC1009	0	221	371	65
CC101	0	30	543	222
CC1011	0	239	366	55
CC1013	0	237	366	56
CC1015	0	237	366	56
CC1017	0	239	366	55
CC1019	0	241	366	54
CC1021	0	246	366	52
CC1023	0	287	438	65
CC1025	0	286	438	66
CC1027	0	287	438	66
CC1029	0	293	438	63
CC103	0	30	543	222
CC1031	0	300	438	60
CC1033	0	308	436	55
CC1037	0	300	433	57
CC1039	0	300	432	57
CC1041	0	282	432	65
CC1043	1216	260	430	74
CC1047	0	117	339	96
CC1049	0	116	339	97
CC105	0	30	543	222
CC1051	0	147	373	98
CC1053	317	185	373	82
CC1055	1705	180	363	80
CC1057	0	184	368	79

Figure C.3. Illustration of *Node_Pressure* table.


Soil_Category_NAD83 Drawing Table *

ID	ID 2	AREA	PERIMETER	VSMAPV1_	VSMAPV1_ID	POLYID	AREA1	PERIMETER1	VSCAT	VALUE
1199199	6127	3362898.35609	9624.019013	6069	6068	6069	3.383026	9.64595	C	560
1199200	6129	1579412.17965	5086.228334	6071	6070	6071	1.58885	5.100569	C	560
1199201	6133	19303686.8024	23911.937871	6075	6074	6075	19.418352	23.976364	B	1000
1199202	6134	17237438.4151	24351.004344	6076	6075	6076	17.340155	24.415918	B	1000
1199203	6135	1967880.88714	8054.660227	6077	6076	6077	1.979597	8.078085	C	560
1199204	6139	12328554.693	23983.824481	6081	6080	6081	12.401876	24.059934	CD	360
1199205	6142	495303.901134	2790.451595	6084	6083	6084	0.498249	2.79791	C	560
1199206	6143	5093600.08604	14694.336536	6085	6084	6085	5.123719	14.735573	BC	760
1199207	6145	457903.632034	2657.188583	6087	6086	6087	0.460646	2.66361	B	1000
1199208	6146	1323120.34443	5072.572311	6088	6087	6088	1.331012	5.084876	CD	360
1199209	6147	2561316.12998	7429.036691	6089	6088	6089	2.576567	7.450867	C	560
1199210	6148	3608491.54346	11313.150871	6090	6089	6090	3.630078	11.338623	C	560
1199211	6149	15864685.6741	23351.933939	6091	6090	6091	15.958601	23.404261	C	560
1199212	6150	49620870.0786	46103.490529	6092	6091	6092	49.914189	46.234966	B	1000
1199213	6151	296729.303971	2158.648354	6093	6092	6093	0.298498	2.16446	B	1000
1199214	6152	771144.810118	4062.824185	6094	6093	6094	0.775711	4.080193	B	1000
1199215	6153	1108650.77396	4247.315578	6095	6094	6095	1.115223	4.260297	C	560
1199216	6154	2755984.26399	16505.982768	6096	6095	6096	2.772337	16.570562	D	270
1199217	6155	570926.696825	3722.098435	6097	6096	6097	0.574327	3.728036	B	1000
1199218	6157	20124194.102	31686.008302	6099	6098	6099	20.242978	31.764926	B	1000
1199219	6159	1267411.9166	4315.087227	6101	6100	6101	1.27494	4.328709	B	1000
1199220	6160	34702959.0178	39599.672999	6102	6101	6102	34.906912	39.724209	B	1000
1199221	6163	1879631.91385	6067.14045	6105	6104	6105	1.890854	6.08588	CD	360
1199222	6164	5523122.19725	20938.847828	6106	6105	6106	5.555993	20.993841	CD	360
1199223	6166	342090.465095	2845.286282	6108	6107	6108	0.344136	2.852424	C	560
1199224	6168	4791888.457	15528.044626	6110	6109	6110	3.906374	15.555725	CD	360
1199225	6171	2673298.76106	8234.396736	6113	6112	6113	2.68916	8.258538	CD	360
1199226	6172	4446378.37803	9571.998934	6114	6113	6114	4.472662	9.603349	CD	360
1199227	6173	768208.456498	3352.066803	6115	6114	6115	0.772791	3.362839	C	560
1199228	6176	1451612.13049	5398.803605	6118	6117	6118	1.460214	5.419118	CD	360
1199229	6178	74511665.1269	41606.800662	6120	6119	6120	74.946342	41.737214	CD	360

Figure C.4. Illustration of *Soil_Category_NAD83 Drawing* table.

A sample Manifold project (***manifold_giraffe.map***) has been included in the GIRAFFE program file in the folder **Example_Files | Appendix C**, which also includes the required files in the appropriate format. However, the user can also create a Manifold project to perform the same function. To do this, import and format the required data:

- Launch Manifold. Go to **File | Import | Drawing** to add the pipe (E***pa_pipes***) and junction data (***epa_junctions***), as shown in Figure C. 5. All shapefiles, including ***Soil_Category_NAD83*** can be imported in this way.
- Go to **File | Import | Table** to add the node pressure data (***Node_Pressure***), as shown in Figure C.6.
- Go to **File | Import | Surface** to add the surface to which PGV will be interpolated (***pgvsurf.grd***), as shown in Figure C.7.
- Alternatively to importing *pgvsurf*, the user can also create it (Figure C.8). Import a scenario shapefile (***175_data.shp*** in this example) and then,
  - Right-click to copy the scenario drawing.
  - Right-click in the project pane and select **Paste As | Surface**.
  - Enter the parameters shown in Figure C.8(b).

    - Rename the surface ***pgvsurf*** by right-clicking on the layer and selecting **Rename**.
- Format ***Node_Pressure.dbf*** by opening the table and right-clicking the header of the column **PRESSURE_(.** Select Rename.
    - In the pop-up input box, rename the column **node_pressure** (all lowercase letters for the column header is important). The column containing the node IDs should be named **ID** as shown in Figure C.3.
- Open the attribute tables of ***epa_junctions*** and E***pa_pipes***, and check that the columns containing the pipe and node IDs are named **ID 2** as shown in Figures C.1 and C.2. If the columns are named otherwise, rename them.
- Next, check that each file contains the necessary columns. In the ***epa_junctions*** attribute table, there should be a column named **Zone**. In the E***pa_pipes*** attribute table, there should be a column named **Material**. In the ***Soil_Category_NAD83 Drawing*** there should be a column named **VSCAT**, which describes the soil categories (Figure C.4). These columns must exist and contain valid data values for the tool to run correctly.
- The pipe objects in *Epa_pipes.shp* must also be segmented into 1000’ pieces and broken at the soil boundaries before running the system damage tool in GIRAFFE. If this has not already been done, use the **Segment Pipes for Repair Rate Calculation** tool in the Manifold System Damage Add-In as explained in ***Section C.2.3 Using the Manifold System Damage Add-In*.** After running the segment tool, the *Epa_pipes* file is ready to be used with the inbuilt GIRAFFE damage tool.

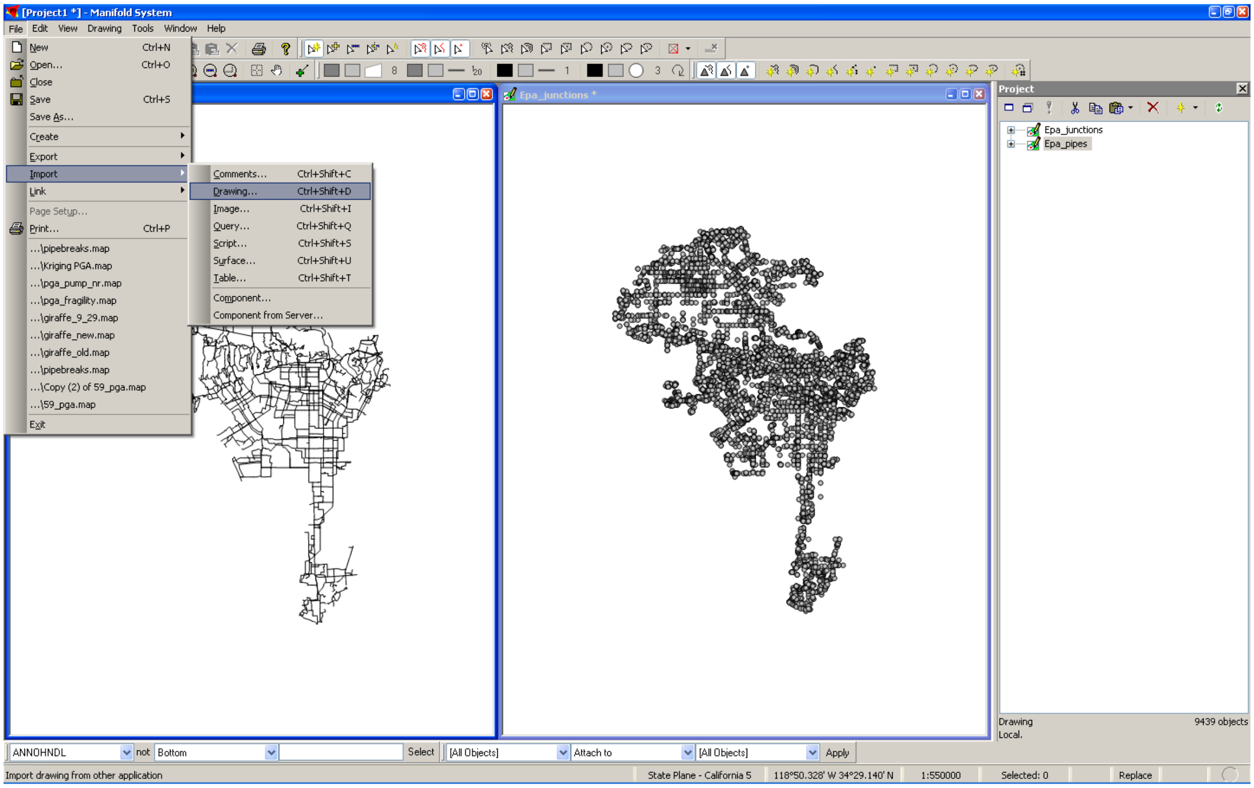
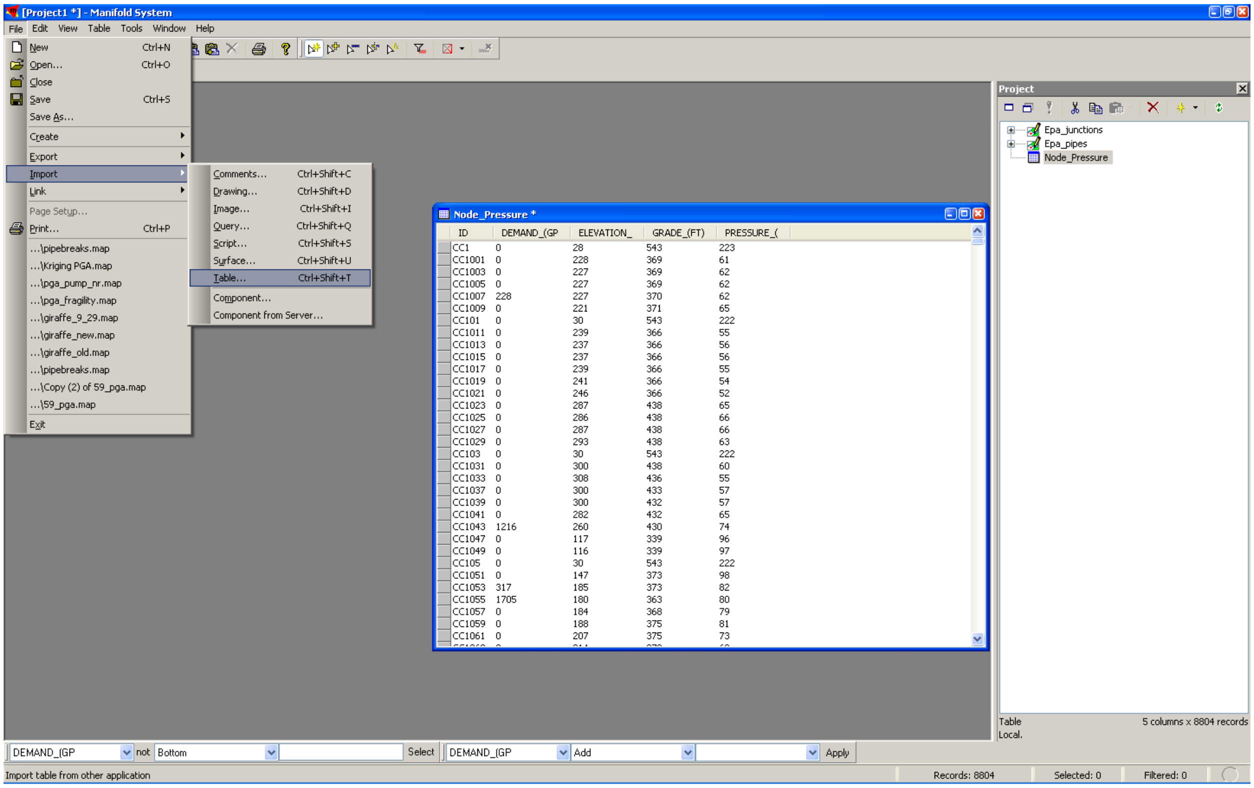


Figure C.5. Importing Pipe and Junction Data in GIS



Node_Pressure *

ID	DEMAND_(GP	ELEVATION_	GRADE_(FT)	PRESSURE_(
CC1	0	28	543	223
CC1001	0	228	369	61
CC1003	0	227	369	62
CC1005	0	227	369	62
CC1007	228	227	370	62
CC1009	0	221	371	65
CC101	0	30	543	222
CC1011	0	239	366	55
CC1013	0	237	366	56
CC1015	0	237	366	56
CC1017	0	239	366	55
CC1019	0	241	366	54
CC1021	0	246	366	52
CC1023	0	287	438	65
CC1025	0	286	438	66
CC1027	0	287	438	66
CC1029	0	293	438	63
CC103	0	30	543	222
CC1031	0	300	438	60
CC1033	0	308	436	55
CC1037	0	300	433	57
CC1039	0	300	432	57
CC1041	0	282	432	65
CC1043	1216	260	430	74
CC1047	0	117	339	96
CC1049	0	116	339	97
CC105	0	30	543	222
CC1051	0	147	373	98
CC1053	317	185	373	82
CC1055	1705	180	363	80
CC1057	0	184	368	79
CC1059	0	188	375	81
CC1061	0	207	375	73

Figure C.6. Importing Node Pressure Data in GIS

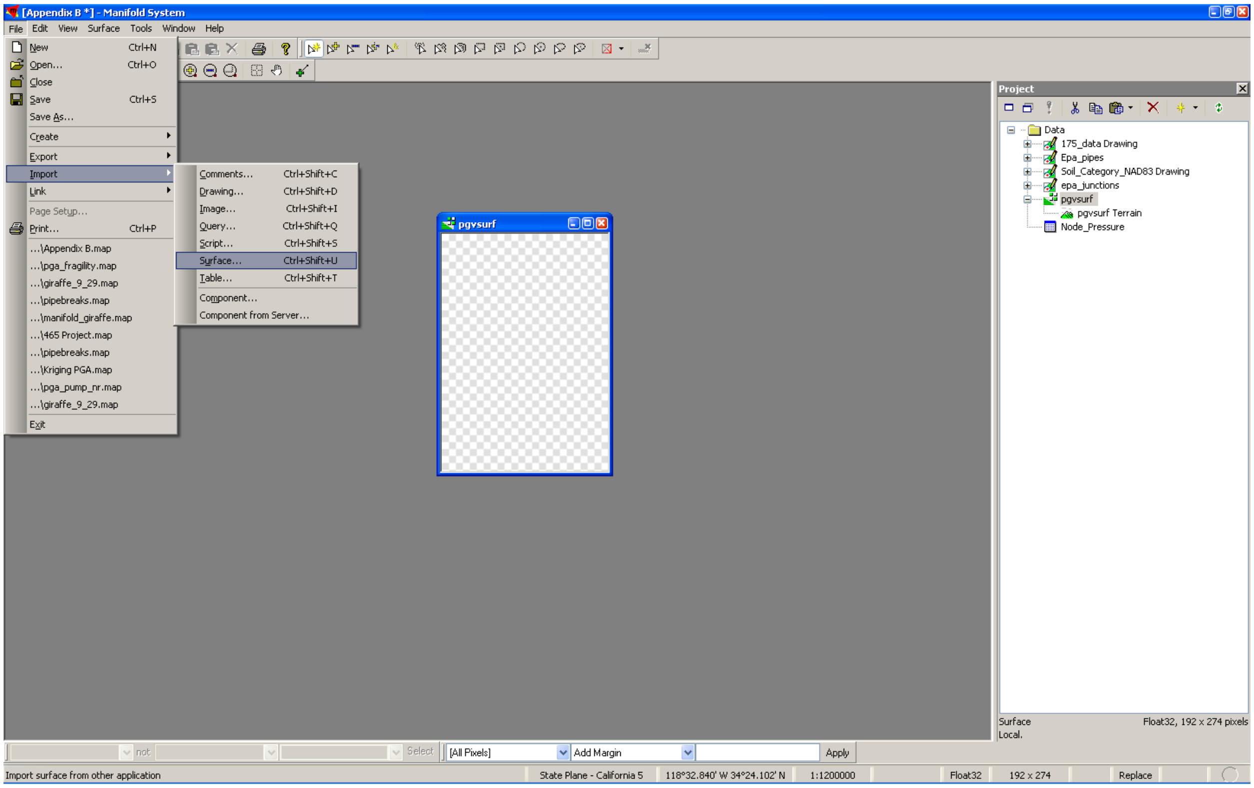
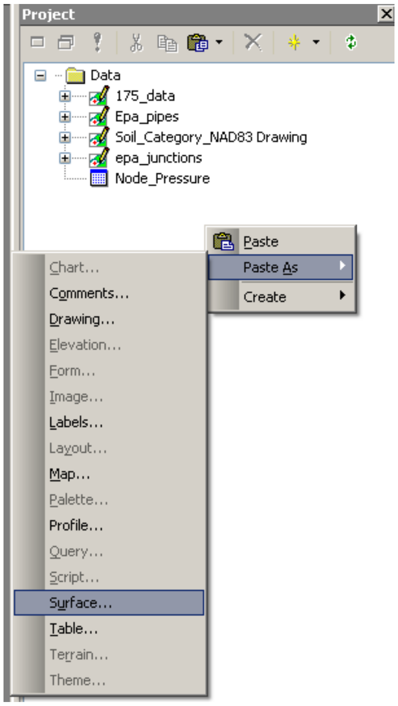
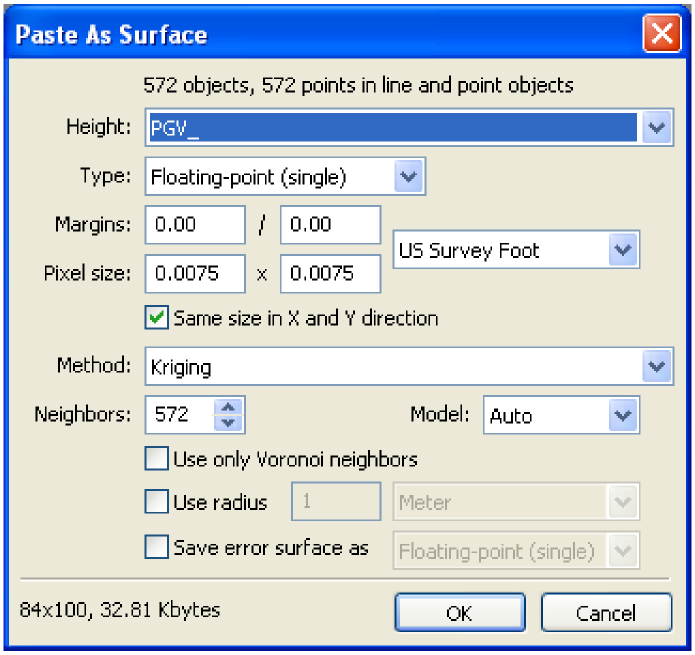


Figure C.7. Importing *Pgvsurf* in GIS



(a) Step 1

Figure C.8. Creating *pgvsurf*



572 objects, 572 points in line and point objects

Height: PGV_

Type: Floating-point (single)

Margins: 0.00 / 0.00

Pixel size: 0.0075 x 0.0075

US Survey Foot

☑ Same size in X and Y direction

Method: Kriging

Neighbors: 572

Model: Auto

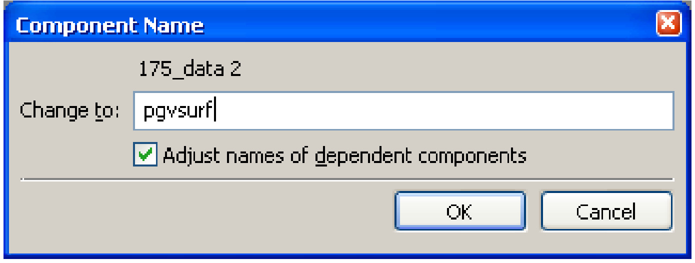
☐ Use only Voronoi neighbors

☐ Use radius 1 Meter

☐ Save error surface as Floating-point (single)

84x100, 32.81 Kbytes

(b) Step 2
Figure C.8. Creating *pgvsurf*



175_data 2

Change to: pgvsurf

☑ Adjust names of dependent components

(c) Step 3
Figure C.8. Creating *pgvsurf*

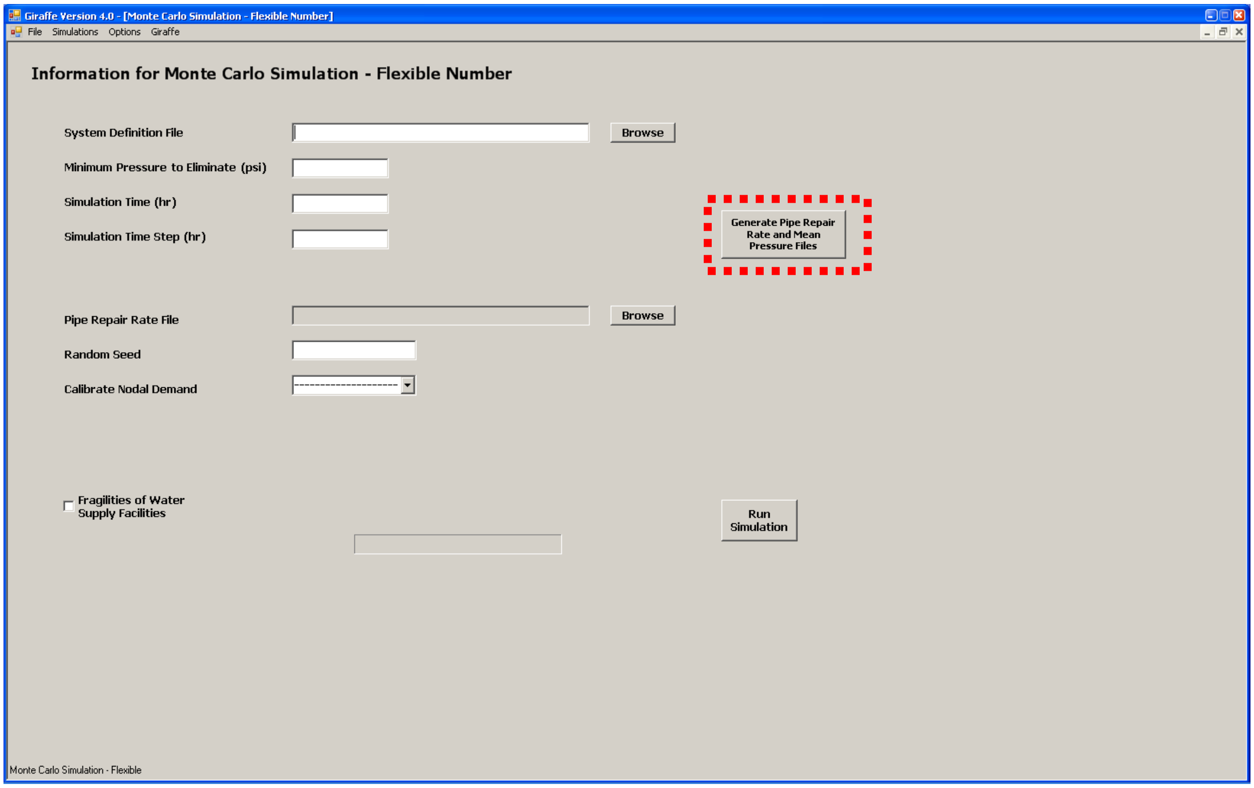
C.2.2. Running the System Damage Tool in GIRAFFE

Once the Manifold project has been created, open GIRAFFE and select either Monte Carlo Fixed or Flexible Simulations. To generate the system damage input files,

- click **Generate Pipe Repair Rate and Mean Pressure Files**, as shown in Figure C.9(a)
- A pop-up window will occur. Navigate to and select the Manifold project that contains the necessary data (in this example, ***manifold_giraffe.map***)

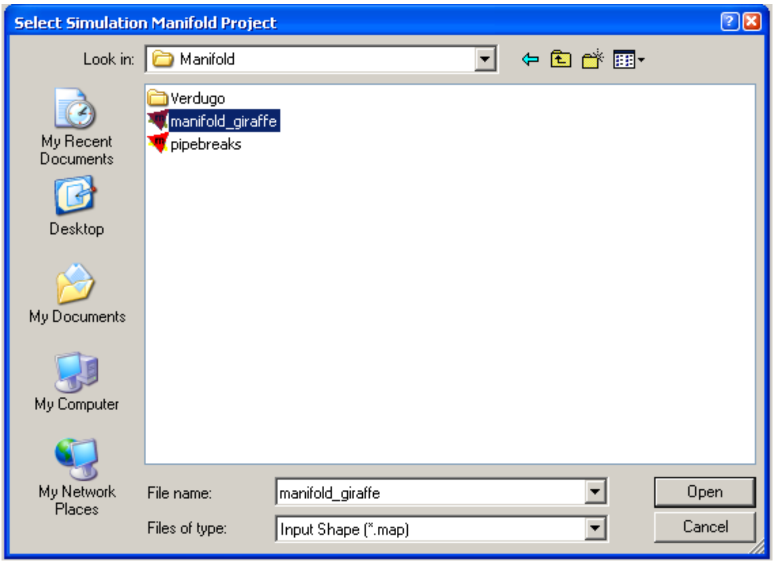
- In the next pop-up window, select the appropriate scenario shapefile (***175_data.shp***). This scenario should correspond to the scenario for which the simulation is being run. Selecting **Open** will begin the process.
- When the process is completed, a pop-up notice will occur. Click **OK**. The system damage files have now been generated for pipes and nodes, *RRInput.inp* and *LocalDemandInput.inp*, respectively, and can be found in the GIRAFFE program folder: **C:\Program Files\Cornell University\GIRAFFE\AppendixB***. The files are automatically placed the pipe repair rate and nodal demand boxes (if **Calibrate Nodal Demand** is set to **Yes**) in the GIRAFFE interface.

* For 64-bit users, the files will be outputted to the 64-bit directory (**C:\Program Files\Cornell University\Appendix B**), though this is not the location of the GIRAFFE program folder (32-bit directory: C:\Program Files (x86)\Cornell University\GIRAFFE).



(a) Step 1

Figure C.9. Generating System Damage Using Manifold-Linked Tool in GIRAFFE


Select Simulation Manifold Project

Look in: Manifold

Verdugo

manifold_giraffe

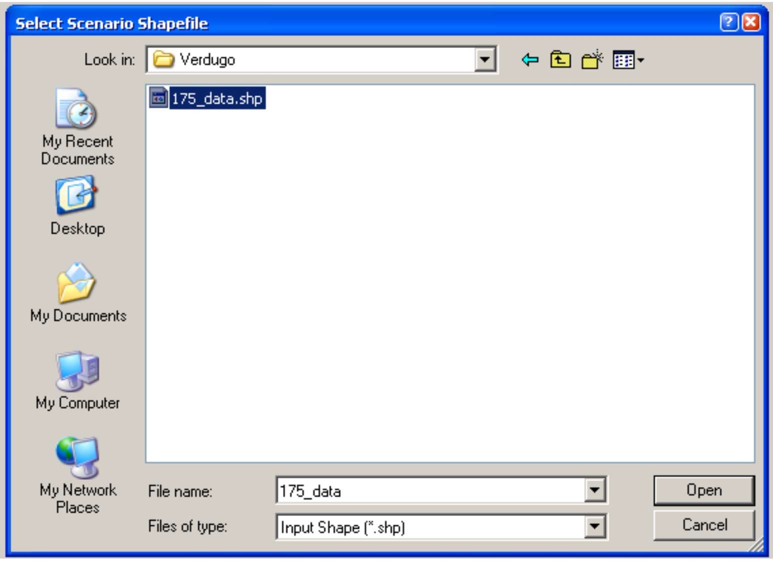
pipebreaks

File name: manifold_giraffe

Files of type: Input Shape (*.map)

(b) Step 2

Figure C.9. Generating System Damage Using Manifold-Linked Tool in GIRAFFE


Select Scenario Shapefile

Look in: Verdugo

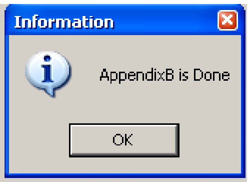
175_data.shp

File name: 175_data

Files of type: Input Shape (*.shp)

(c) Step 3

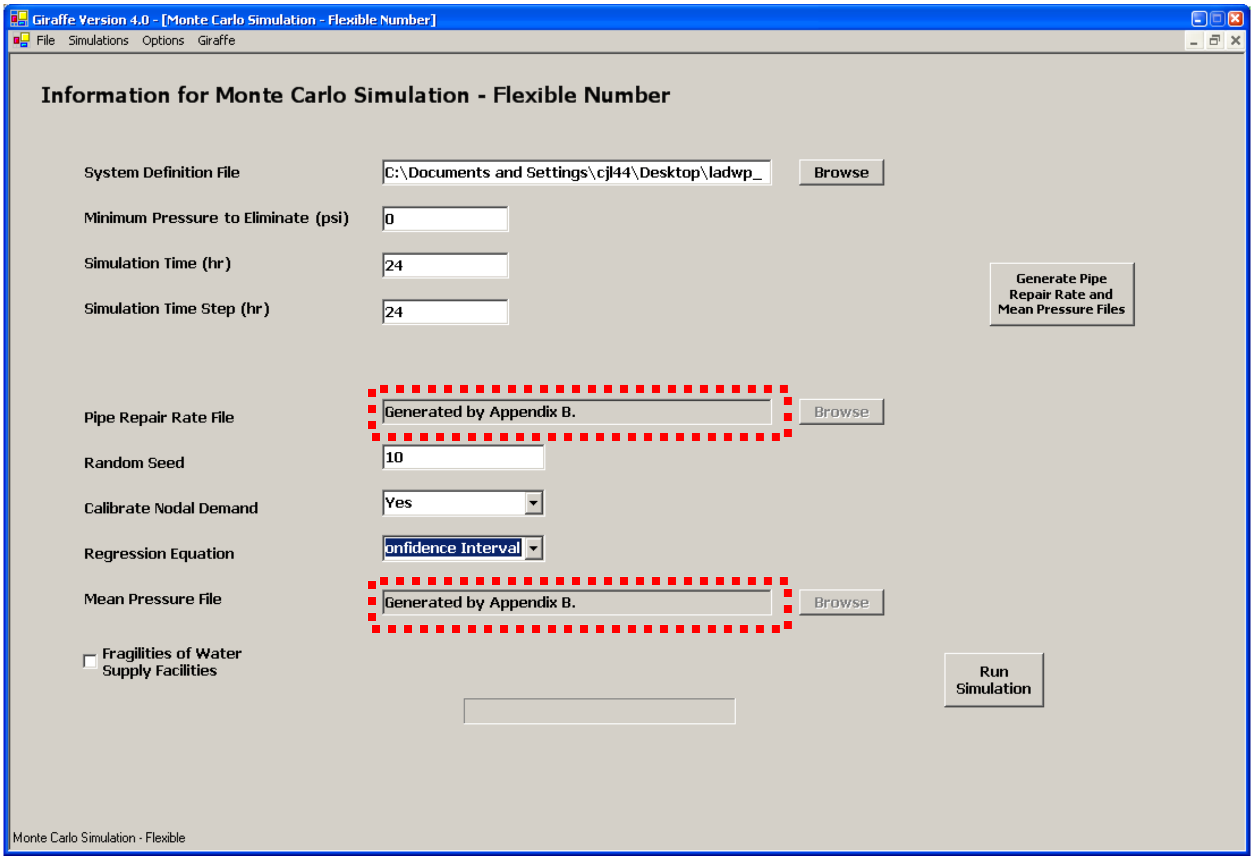
Figure C.9. Generating System Damage Using Manifold-Linked Tool in GIRAFFE


Information

AppendixB is Done

(d) Step 4

Figure C.9. Generating System Damage Using Manifold-Linked Tool in GIRAFFE



Information for Monte Carlo Simulation - Flexible Number

System Definition File: C:\Documents and Settings\cjl44\Desktop\ladwp_

Minimum Pressure to Eliminate (psi): 0

Simulation Time (hr): 24

Simulation Time Step (hr): 24

Pipe Repair Rate File: Generated by Appendix B.

Random Seed: 10

Calibrate Nodal Demand: Yes

Regression Equation: onfidence Interval

Mean Pressure File: Generated by Appendix B.

☐ Fragilities of Water Supply Facilities

(e) Step 5

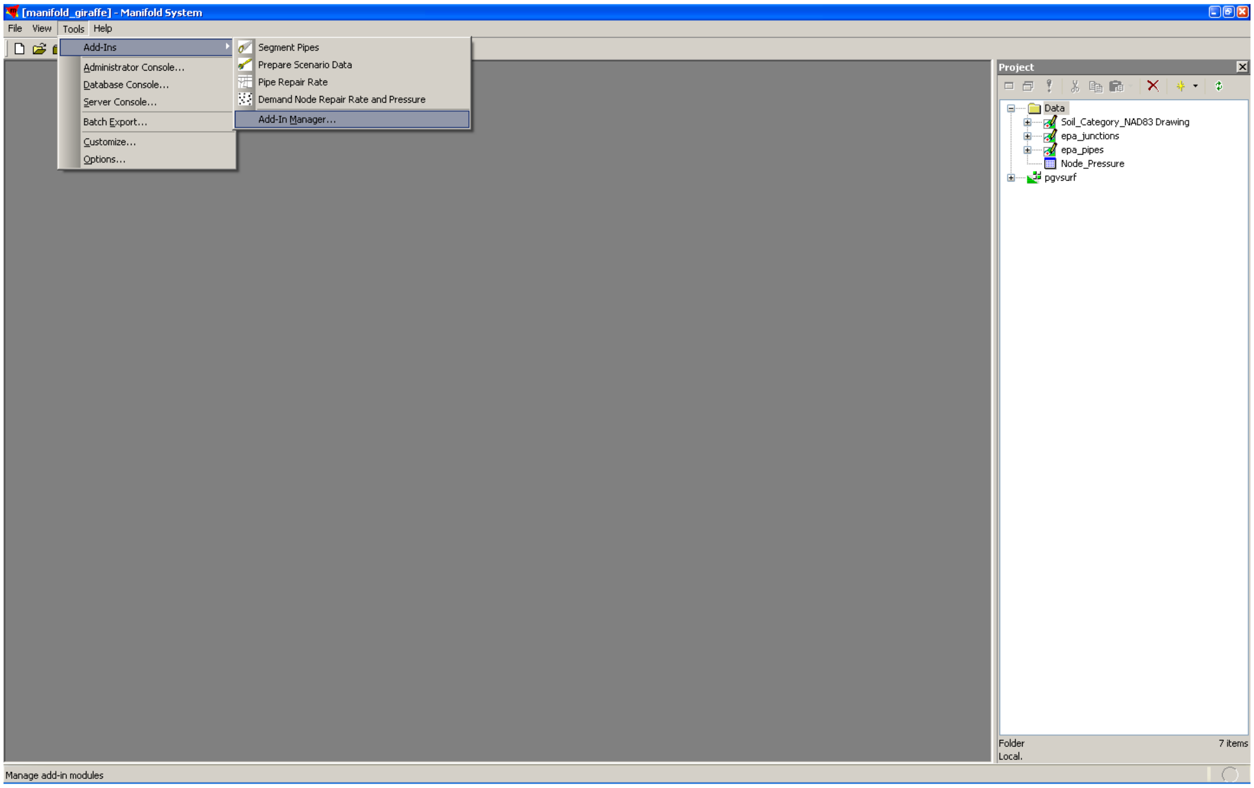
Figure C.9. Generating System Damage Using Manifold-Linked Tool in GIRAFFE

C.2.3. Using the Manifold System Damage Add-In

Alternatively to creating the system damage files in GIRAFFE, the user may create the files using the Manifold system damage add-in. The same files are required as for the system damage tool in GIRAFFE (***Epa_pipes, epa_junctions, pgvsurf, Soil_Category_NAD83 Drawing, Node_Pressure.dbf***). Using the add-in allows the user to view intermediate files generated during the system damage preparation. Also, the pipe repair rate input file and the nodal demand file can be prepared separately, which is useful if the user does not wish to calibrate nodal demand in a Monte Carlo simulation.

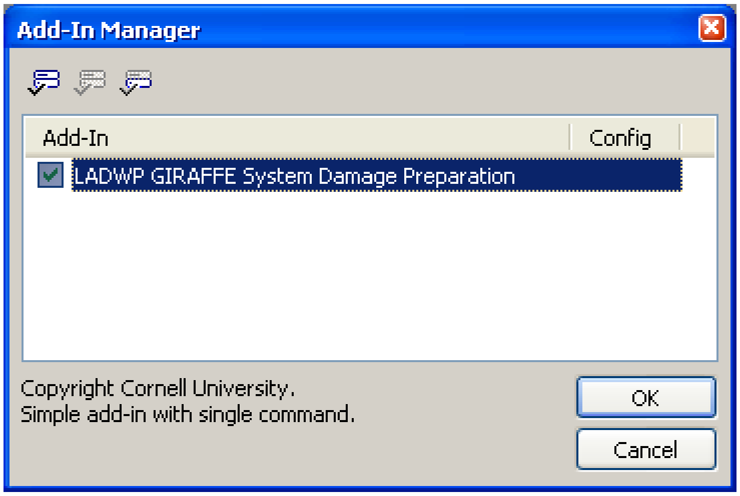
Additionally, if the water supply system is updated (*i.e.* pipes or nodes are added or removed) the user can prepare the data for use with the add-in or with the GIRAFFE system damage tool. Note that if the system is updated, the pipes file should be segmented before it is used in the GIRAFFE system damage tool because this tool does not segment the pipes. To use the system damage add-in,

- copy the **LADWP folder** from **Manifold Tools** in the GIRAFFE program folder (normally **C:\Program Files\Cornell University\GIRAFFE\Manifold Tools**) and paste it in the **Config folder** hierarchy for Manifold (normally **C:\Program Files\Manifold System\Config**).
- Launch Manifold and open the necessary files or a saved map containing the files. If the toolbar does not automatically appear, go to **Tools | Add-Ins | Add-In Manager** as shown in Figure C.10(a).
  - A window will pop up, and check the box next to **LADWP GIRAFFE System Damage Preparation**. Restart Manifold as directed.
  - The custom system damage add-in toolbar should now be visible.
- Before using the toolbar, import the scenario shapefile (for example, ***175_data***) into the Manifold project.



(a) Step 1

Figure C.10. Using the Manifold System Damage Add-In

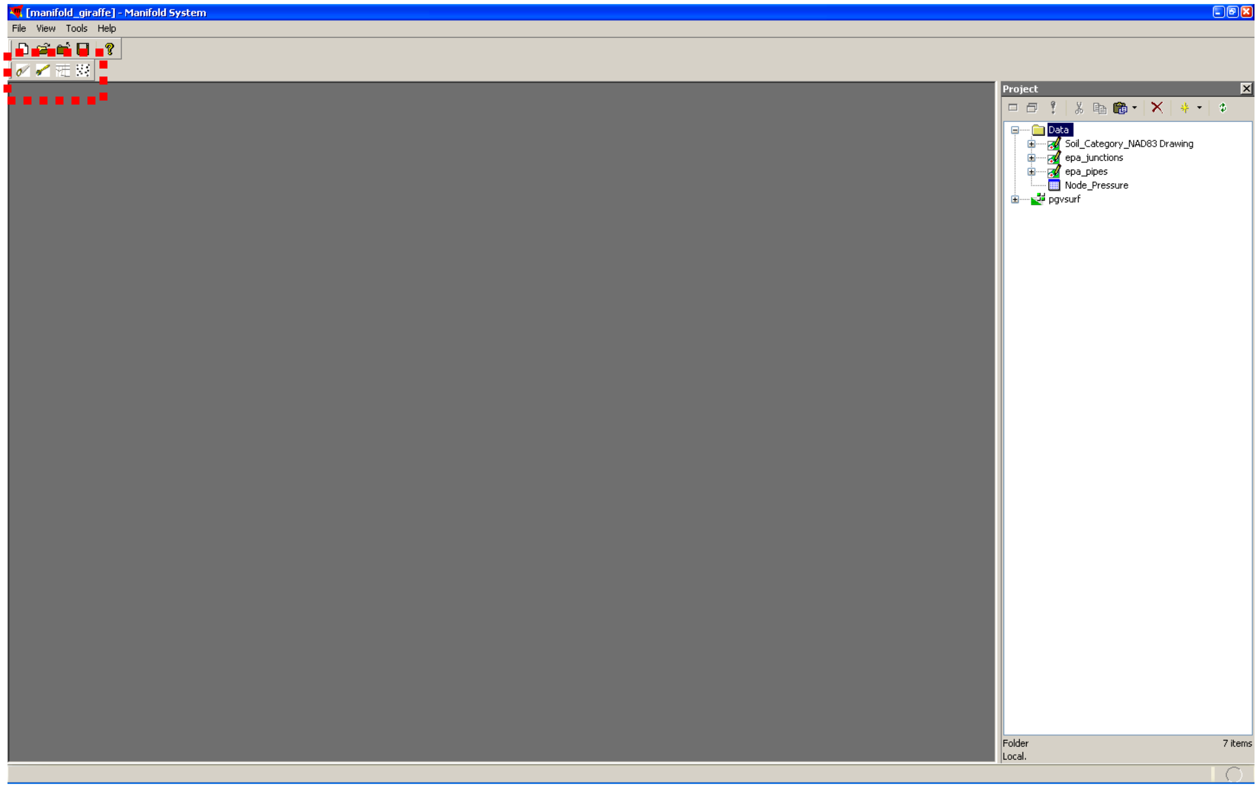


☑ LADWP GIRAFFE System Damage Preparation

Copyright Cornell University.
Simple add-in with single command.

(b) Step 2

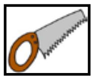
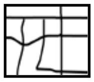
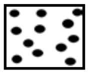
Figure C.10. Using the Manifold System Damage Add-In



(c) Step 3
Figure C.10. Using the Manifold System Damage Add-In

Each of the four buttons in the custom toolbar performs a different function in the system damage preparation. Table C.1 describes the function of each button and the files required to run each button. The system damage files generated are located in **C:\temp**, and they can be directly inserted into a GIRAFFE Monte Carlo simulation.

Table C.1 Using the Manifold System Damage Custom Toolbar

Icon	Name	Function	Required Files
	Segment Pipes for Repair Rate Calculation	This tool segments, or breaks, the pipes into 1000’ segments, and segments the pipes at the soil boundaries. This only needs to be run whenever a new, unbroken pipes shapefile is imported into the project or when the system is updated.	• *Soil_Category_NAD83 Drawing* • *Epa_pipes*
	Prepare Scenario Data for Repair Rate Calculation	This tool formats the scenario data PGV values and interpolates the PGV values onto a surface. This only needs to be run once per scenario, and must be done before using the following two tools.*	• *Pgvsurf* • Scenario shapefile
	Prepare Pipe Repair Rate Data	This tool calculates the soil-corrected PGV values and the repair rate for each pipe in the system, and then exports the results as *RRInput.inp*.† This tool should only be used after preparing the scenario data and segmenting the pipes.	• *Soil_Category_NAD83 Drawing* • *Epa_pipes* • *Pgvsurf*
	Prepare Earthquake Demand Simulation Data	This tool calculates the mean pressure and repair rate for each demand node in the system, and then exports the results as *LocalDemandInput.inp*.† This tool should only be used after preparing the scenario data.	• *Soil_Category_NAD83 Drawing* • *epa_junctions* • *Node_Pressure.dbf* • *Pgvsurf*

*Before using the Prepare Scenario Data for Repair Rate Calculation tool, the user must import the scenario data. This can be done by going to File | Import | Drawing and navigating to the appropriate file. Scenario data must be a shapefile.

† Files generated are located in **C:\temp**. These files can be used directly as input in a GIRAFFE Monte Carlo simulation.

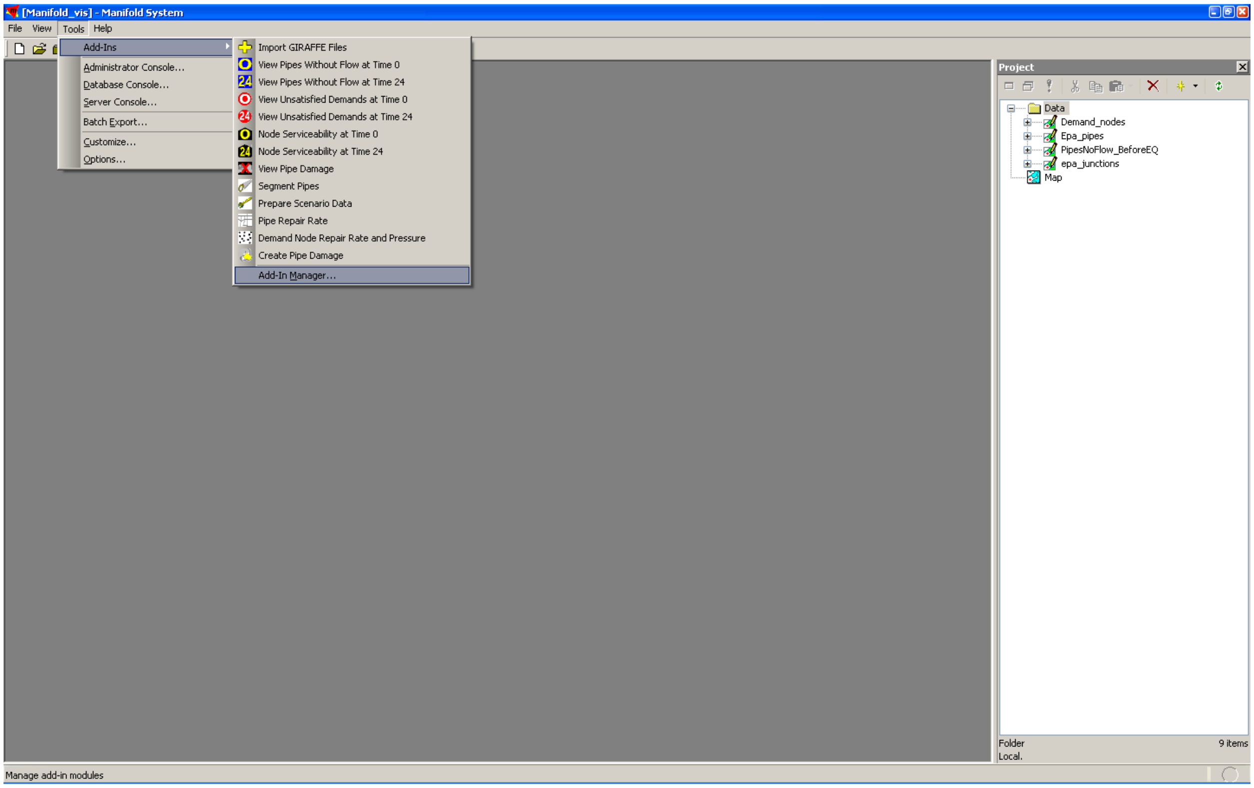
C.3 VISUALIZING GIRAFFE RESULTS IN MANIFOLD

After running a GIRAFFE simulation, the results can be visualized in Manifold. This allows the user to create maps for illustration purposes and to observe spatial patterns that may not be obvious in data tables.

C.3.1. Using the Manifold System Visualization Add-In

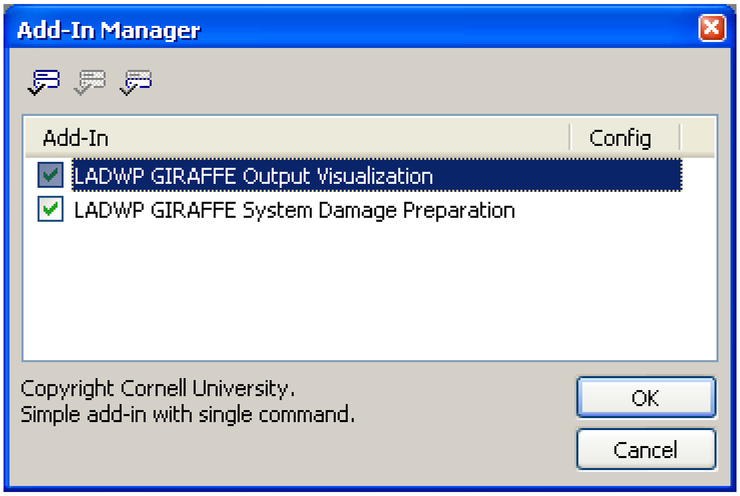
An additional custom Manifold add-in exists to help the user visualize GIRAFFE outputs in a meaningful way. To use the visualization add-in,

- copy the **LADWP folder** from **Manifold Tools** in the GIRAFFE program folder (normally **C:\Program Files\Cornell University\GIRAFFE\Manifold Tools**) and paste it in the **Config folder** hierarchy for Manifold (normally **C:\Program Files\Manifold System\Config**).
- Launch Manifold and open the necessary files or a saved map containing the files. If the toolbar does not automatically appear, go to **Tools | Add-Ins | Add-In Manager** as shown in Figure C.11(a).
  - A window will pop up, and check the box next to **LADWP GIRAFFE Output Visualization**. Restart Manifold as directed.
- The custom output visualization add-in toolbar should now be visible.



(a) Step 1

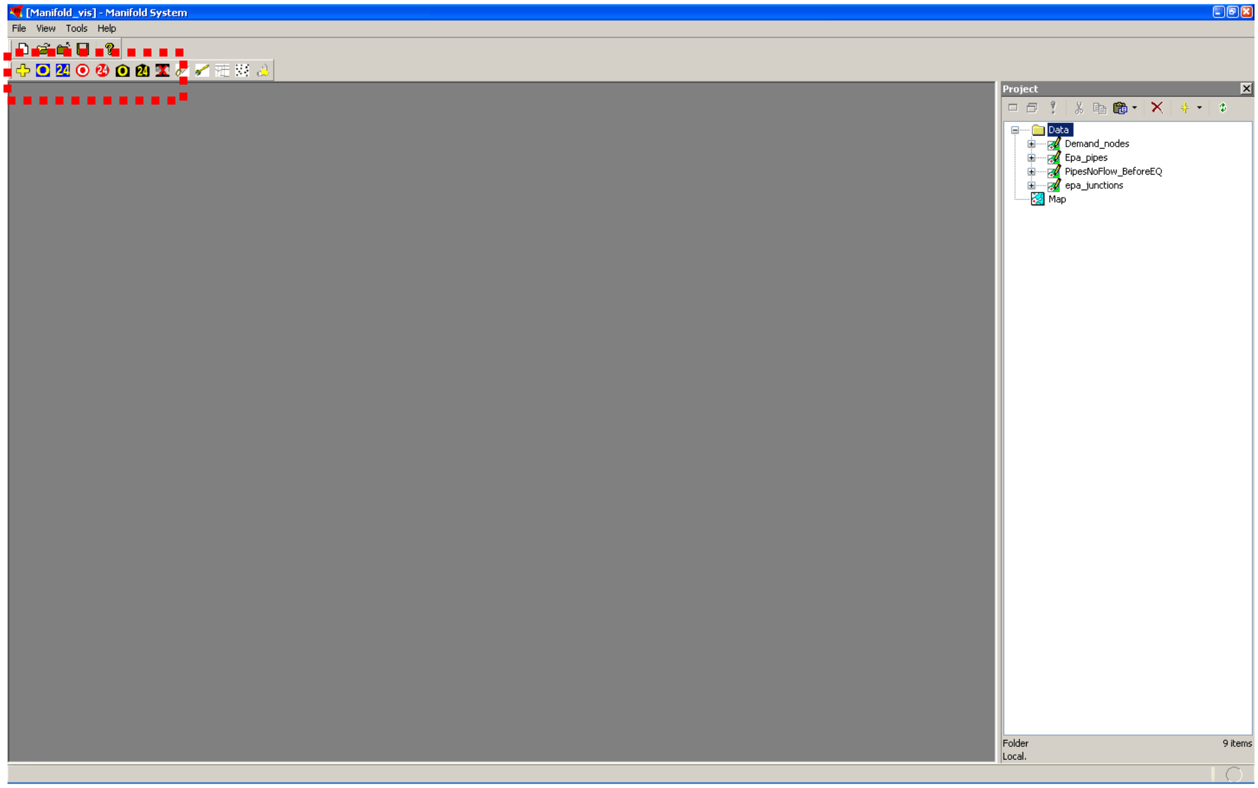
Figure C.11. Using the Manifold Visualization Add-In



Copyright Cornell University.
Simple add-in with single command.

(b) Step 2

Figure C.11. Using the Manifold Visualization Add-In



(c) Step 3

Figure C.11. Using the Manifold Visualization Add-In

Each of the eight buttons in the custom toolbar performs a different function for visualizing the data. Table C.2 describes what each button does and the files required to run each tool.

Table C.2 Using the Manifold Visualization Custom Toolbar

Icon	Name	Function	Required Files
✚	Import GIRAFFE Files	Imports GIRAFFE output files with *.*out* extension. This tool can only import one file at a time. Default folder is C:\Program Files\GIRAFFE.	None required.
O	View Pipe Flow at Time 0	Categorizes pipes by flow: unknown flow, no flow before and after earthquake, and flow. A new attribute, Flow_Category_0, is added to *Epa_pipes*.	• *LinkResults_Time0.out* • *Epa_pipes* • *Pipes_NoFlow_BeforeEQ*
24	View Pipe Flow at Time 24	Categorizes pipes by flow: unknown flow, no flow before and after earthquake, and flow. A new attribute, Flow_Category_24, is added to *Epa_pipes*.	• *LinkResults_Time24.out* • *Epa_pipes* • *Pipes_NoFlow_BeforeEQ*
O	View Unsatisfied Demands at Time 0	Selects unsatisfied demands at demand nodes immediately after earthquake damage. The user can then copy selected nodes into a new drawing.	• *Serviceability0.out* • *epa_junctions*
24	View Unsatisfied Demands at Time 24	Selects unsatisfied demands at demand nodes 24 hours after earthquake damage. The user can then copy selected nodes into a new drawing.	• *Serviceability24.out* • *epa_junctions*
O	Node Serviceability at Time 0	Creates a new layer containing serviceability data for all demand nodes immediately after earthquake damage (time 0).	• *Serviceability0.out* • *epa_junctions*
24	Node Serviceability at Time 24	Creates a new layer containing serviceability data for all demand nodes 24 hours after earthquake damage (time 24).	• *Serviceability24.out* • *epa_junctions*
X	View Pipe Damage	Creates two new layers showing pipes with breaks and leaks. The points are located at the centroid of each pipe and don’t represent the exact location of damage.	• *Epa_pipes* • *Damage_Info_Dert*.txt*

A sample Manifold project (manifold_vis.map) has been included on the GIRAFFE installation CD in the Example Data folder, which includes the required files in the appropriate format. Each tool requires different files, which should be imported into a Manifold project and named exactly as shown unless otherwise indicated. Explanations of GIRAFFE output files can be found in Appendix A and in the User Manual.

- ***Epa_pipes.shp*** **–** represents pipe data for entire system. See Figure C.2 for table format and *Section C.2.1.* ***Importing and Formatting Required Data in Manifold GIS*** for detailed explanation of file contents. Note that pipes should not be segmented as for the system damage toolbar.
- ***epa_junctions.shp*** **–** represents junction data for entire system. See Figure C.1 for table format and *Section C.2.1.* ***Importing and Formatting Required Data in Manifold GIS*** for detailed explanation of file contents.
- ***Pipes_NoFlow_BeforeEQ.shp*** **–** represents pipes that had no flow before the earthquake. Table format should be the same as *Epa_pipes.shp* and the layer name should be exactly as shown. This layer is created by running a stochastic hydraulic simulation without any damage to pipes (*i.e.* all pipe repair rates are equal to zero in the pipe damage input file) and without nodal calibration, and then using flow values from *LinkResults_Time0.out* to select pipes with flow equal to zero.

When using the visualization tools, all GIRAFFE output files should be from the same simulation folder of the GIRAFFE results or, if the results are not from the same simulation folder, the user should clearly state this on the map. To assist the user in using only results from the same simulation folder, the View Unsatisfied Demands and View Pipe Damage tools both prompt the user to input the simulation number (*i.e*. folder number from the GIRAFFE results). Therefore, when importing GIRAFFE results into a Manifold project it is vital that the user ensure that all output files are from the same simulation.

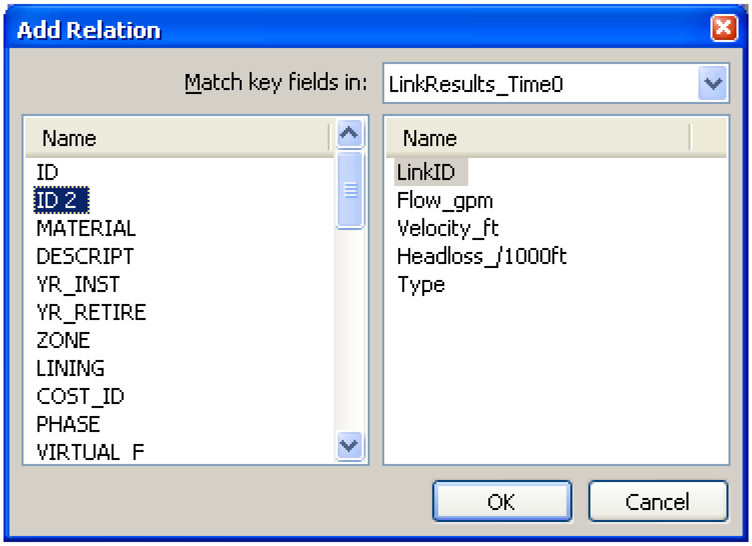
When using the visualization tools for analysis, it is important to keep in mind that the maps will only show a snapshot of what the system could look like after an earthquake. Due to the stochastic nature of the process, there will be some variation in results depending on which simulation is viewed and the parameters specified for the GIRAFFE simulation run.

Before using any of the pipe flow or damage visualization tools, you must first change the settings in Manifold so that length and area are reported in feet. This is necessary only if the drawings' projection is in units of feet (such as State Plane). If the drawings' projection is in units of meters (such as Universal Transverse Mercator) then this additional step is unnecessary. If you do not know the units of the projected drawings, right-click on any of the drawings and go to Assign Projection. In the pop-up window there is a drop-down menu that displays the units of the projection. If the units are feet, then go to **Tools | Options** and, under the Miscellaneous heading, check the box next to **Use English measurements units**. According to the Manifold Help file, if this option is checked, units for projected drawings will be reported in feet. If it is not checked, units for projected drawings will be reported in meters.

When creating a map of pipe flow it is very important to distinguish between pipes that had no flow *before* the earthquake and pipes that have no flow *because of* the earthquake. Therefore, the pipe flow visualization tools require a shapefile, ***Pipes_NoFlow_BeforeEQ***, showing pipes with no flow before the earthquake. To create this file:

- Run a stochastic hydraulic simulation without any earthquake damage. In the pipe repair rate input file, set all of the repair rate values equal to zero. Select "No" for Nodal Demand Calibration.
- After running the simulation, import ***LinkResults_Time0.out*** from the last simulation. Make a copy of ***Epa_pipes*** and name it ***Pipes_NoFlow_BeforeEQ***. Open ***Pipes_NoFlow_BeforeEQ Table*** and go to **Table | Relations** in the main Manifold toolbar to create a relation between LinkResults and the layer.
- Click on the **Add Relation** button. In the pop-up window enter the parameters shown in Figure C.13(a) to match the IDs of the pipes in each file. Click 'OK'. You should now see the new relation in the Table Relations window. Put a check next to the column **Flow_gpm** as shown in Figure C.13(b). Click 'OK'.
- The column Flow_gpm should now be in Pipes_NoFlow_BeforeEQ Table. In the **Query Toolbar**, enter the parameters shown in Figure C.13(c) so that pipes with flow not equal to zero will be selected. Click 'Select' then press the **Delete** key on your keyboard to delete the selected pipes.

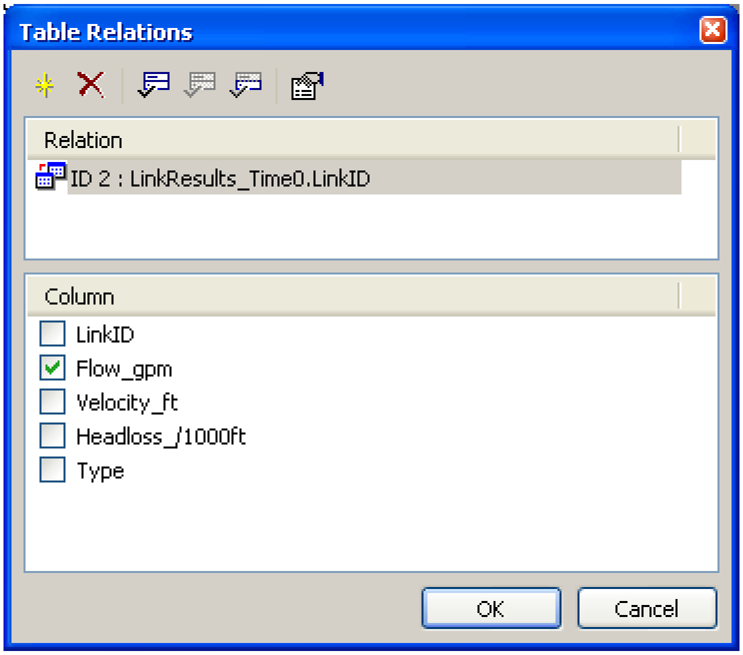
- There should be approximately 2000 pipes left in the drawing. This file only has to be created whenever pipes are added or removed from the system, or when flow in pipes is manually shut off.



Match key fields in: LinkResults_Time0

(a) Step 1

Figure C.13. Create Pipes_NoFlow_BeforeEQ layer.



ID 2 : LinkResults_Time0.LinkID

☐ LinkID
☑ Flow_gpm
☐ Velocity_ft
☐ Headloss_/1000ft
☐ Type

(b) Step 2

Figure C.13. Create Pipes_NoFlow_BeforeEQ layer.

Flow_gpm not Equal to 0

(c) Step 3

Figure C.13. Create Pipes_NoFlow_BeforeEQ layer.

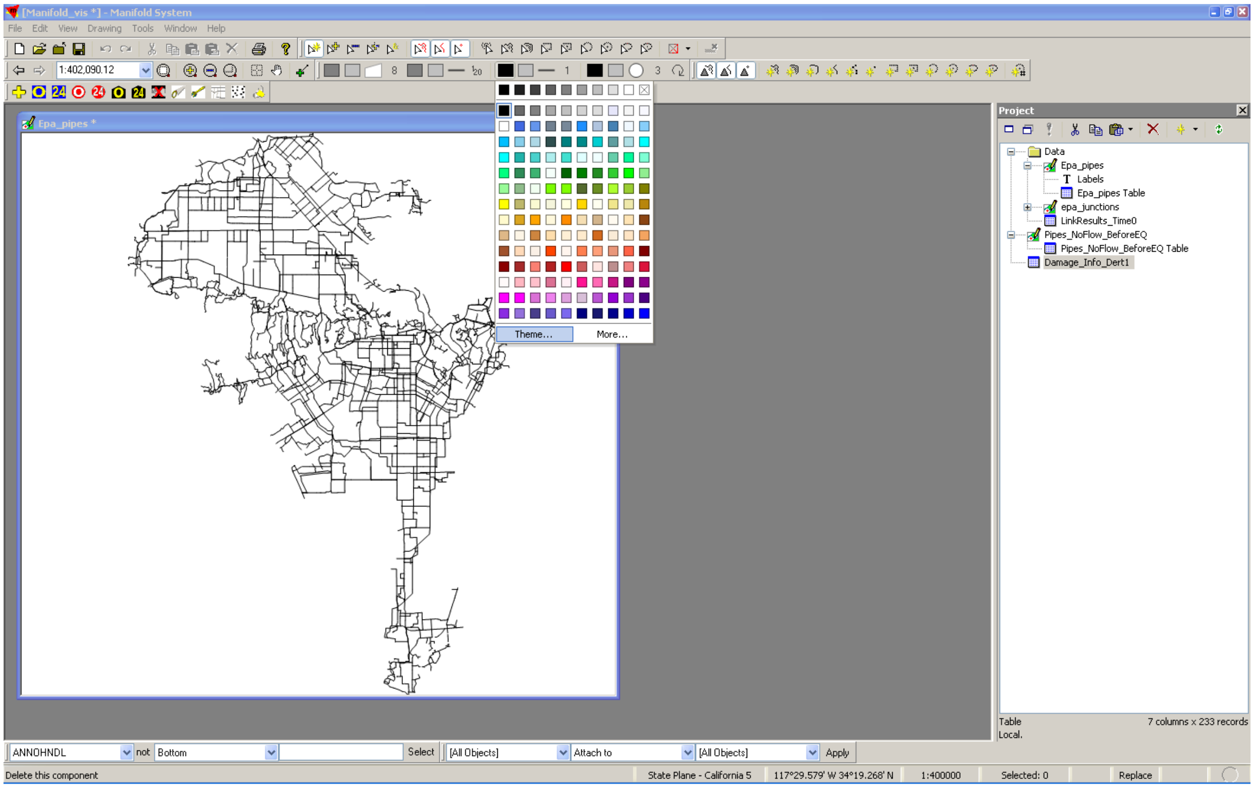
C.3.2 Creating Maps in Manifold System Using Outputs from the Visualization Add-In

Although the visualization tools are generally self-explanatory and easy to use, the pipe flow tool requires three files and obliges the user to color the pipes based on their flow category. The four flow categories are:

- Flow – pipes with flow greater than zero after the earthquake.
- Removed – that were removed from the results due to negative pressures.
- Damaged – pipes with damage (leaks or breaks). Flow data can be found in LinkResults.
- No Flow Before – pipes with no flow before the earthquake.
- No Flow After – pipes with no flow because of the earthquake.

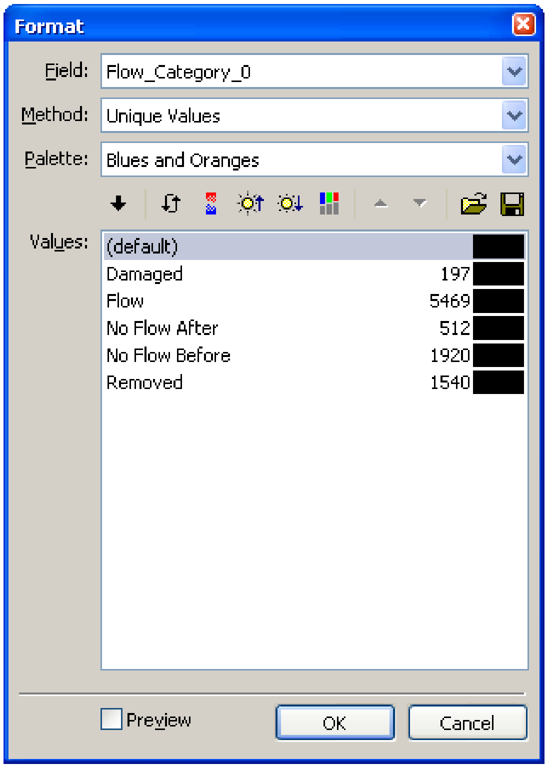
For the user's convenience, several legends have been saved for easy display of pipe flow data. The legends are saved as **.xml* files, and can be found in the GIRAFFE program folder under **Example_Files | Appendix C**. After running the pipe flow tools in the visualization toolbar, open ***Epa_pipes*** and then:

- Click on the background color well for lines and choose theme from the pull-down color choice menu, as shown in Figure C.14 (a).
- Choose **Flow_Category_0** (or Flow_Category_24) as the Field. Then click on the Load from File button (Figure C.14(b)).
- In the pop-up window, navigate to the GIRAFFE program folder and then to **Example_Files | Appendix C**. Select ***Flow0Legend.xml*** (or *Flow24Legend.xml*) and click Open, as shown in Figure C.14(c).
- Click OK in the thematic formatting dialogue, or change the colors as desired. The pipes should now be colored according to flow at time 0.
- Additionally, a legend can be added to the map by going to **View | Legend** and checking the **Show Legend** box. The legend can be customized to suit the user (Figure C.14(e)). The final map is shown in Figure C.14(f).
- When visually examining pipe flow, the map should also display valves, pumps, tanks, and reservoirs in the system to completely and accurately depict pipe flow in the system. These shapefiles can be found in the GIRAFFE directory under **Example_Files/Appendix D**.



(a) Step 1

Figure C.14 Displaying Pipe Flow Data



Format

Field: Flow_Category_0

Method: Unique Values

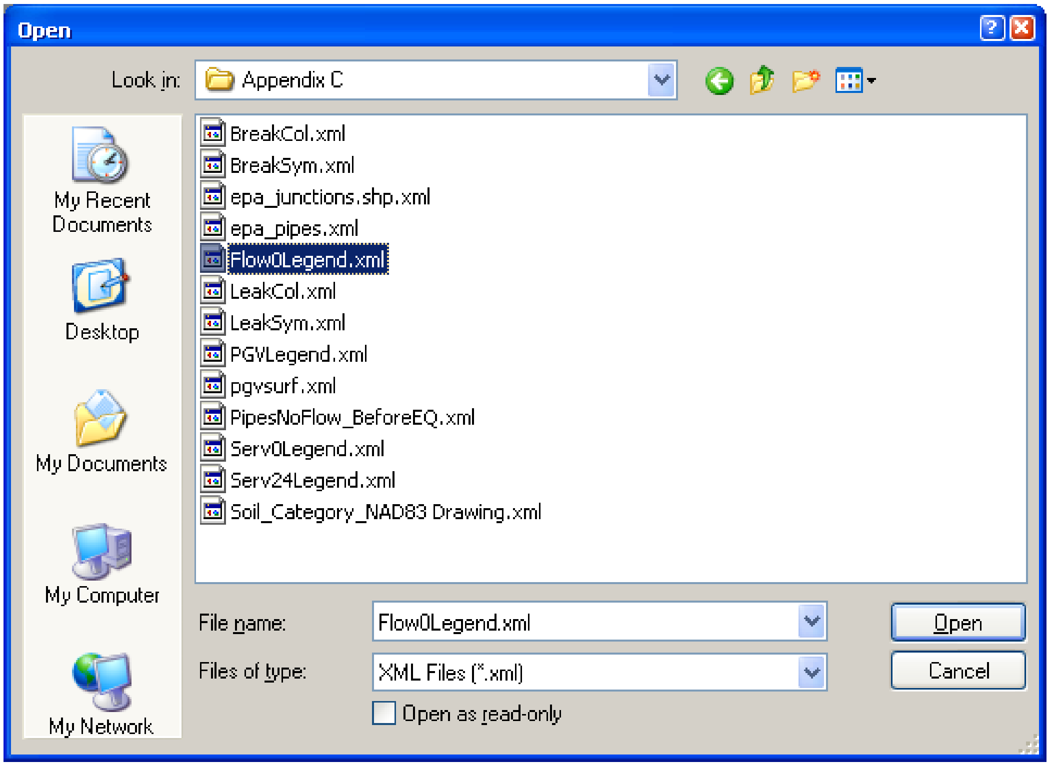
Palette: Blues and Oranges

Values:

(default)	
Damaged	197
Flow	5469
No Flow After	512
No Flow Before	1920
Removed	1540

(b) Step 2

Figure C.14 Displaying Pipe Flow Data



Look in: Appendix C

- BreakCol.xml
- BreakSym.xml
- epa_junctions.shp.xml
- epa_pipes.xml
- Flow0Legend.xml
- LeakCol.xml
- LeakSym.xml
- PGVLegend.xml
- pgvsurf.xml
- PipesNoFlow_BeforeEQ.xml
- Serv0Legend.xml
- Serv24Legend.xml
- Soil_Category_NAD83 Drawing.xml

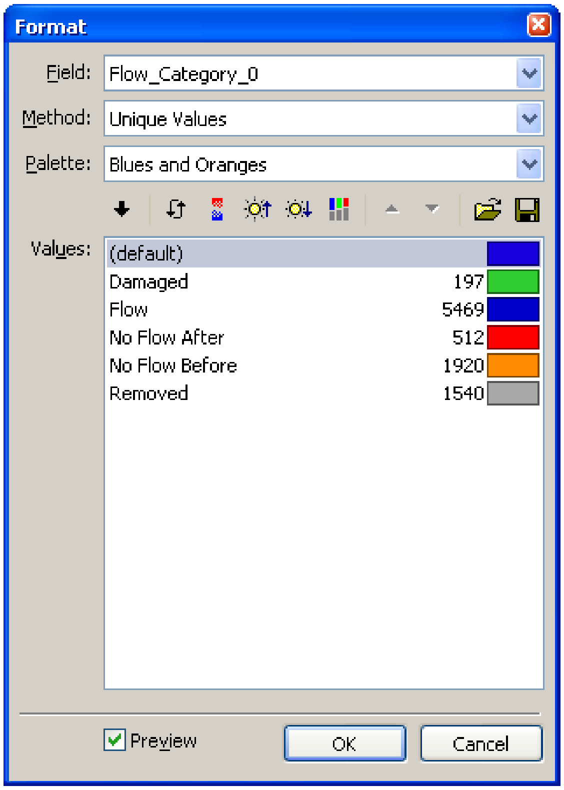
File name: Flow0Legend.xml

Files of type: XML Files (*.xml)

☐ Open as read-only

(c) Step 3

Figure C.14 Displaying Pipe Flow Data



Field: Flow_Category_0

Method: Unique Values

Palette: Blues and Oranges

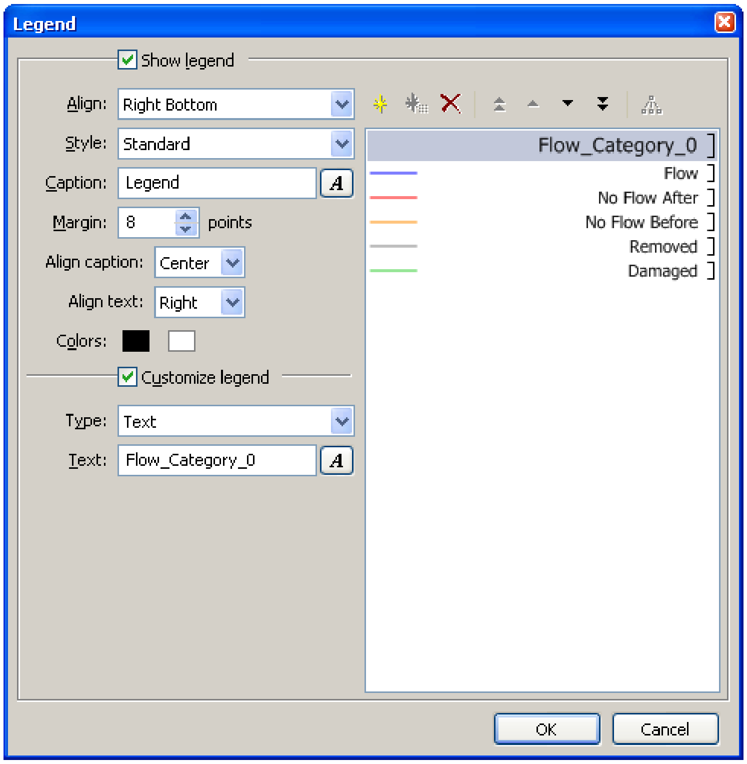
Values:

(default)		🟦
Damaged	197	🟩
Flow	5469	🟦
No Flow After	512	🟥
No Flow Before	1920	🟧
Removed	1540	⬜

☑ Preview

(d) Step 4

Figure C.14 Displaying Pipe Flow Data



☑ Show legend

Align: Right Bottom

Style: Standard

Caption: Legend

Margin: 8 points

Align caption: Center

Align text: Right

Colors: ■ □

☑ Customize legend

Type: Text

Text: Flow_Category_0

Flow_Category_0

Flow

No Flow After

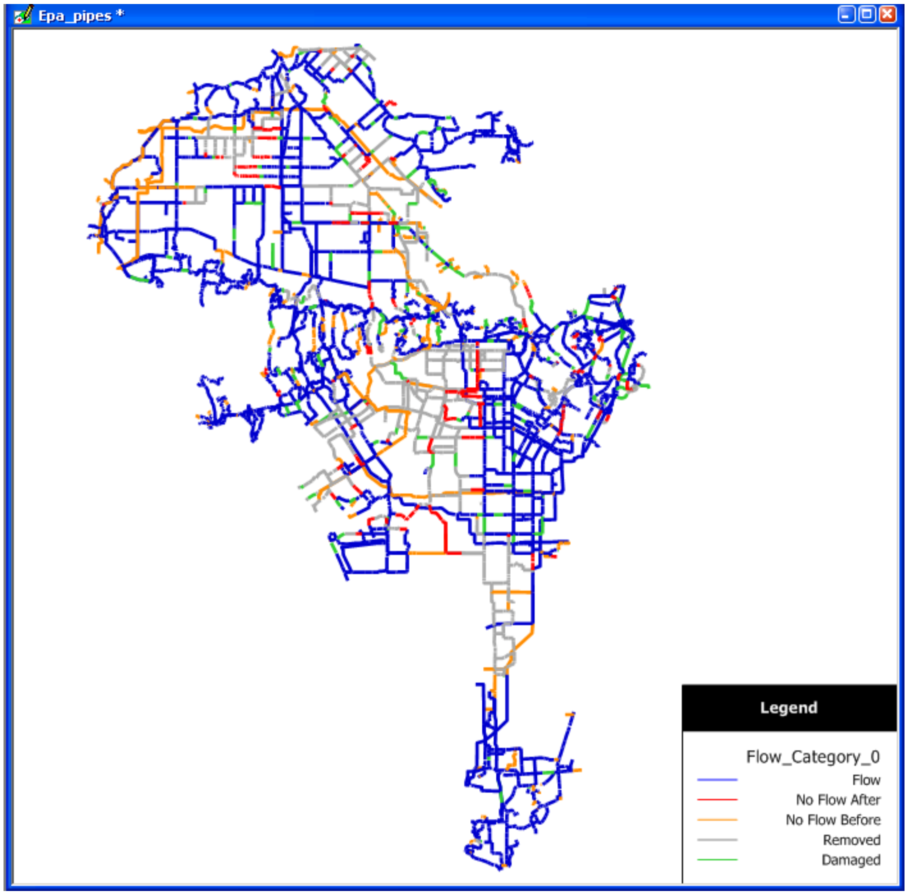
No Flow Before

Removed

Damaged

(e) Step 5

Figure C.14 Displaying Pipe Flow Data

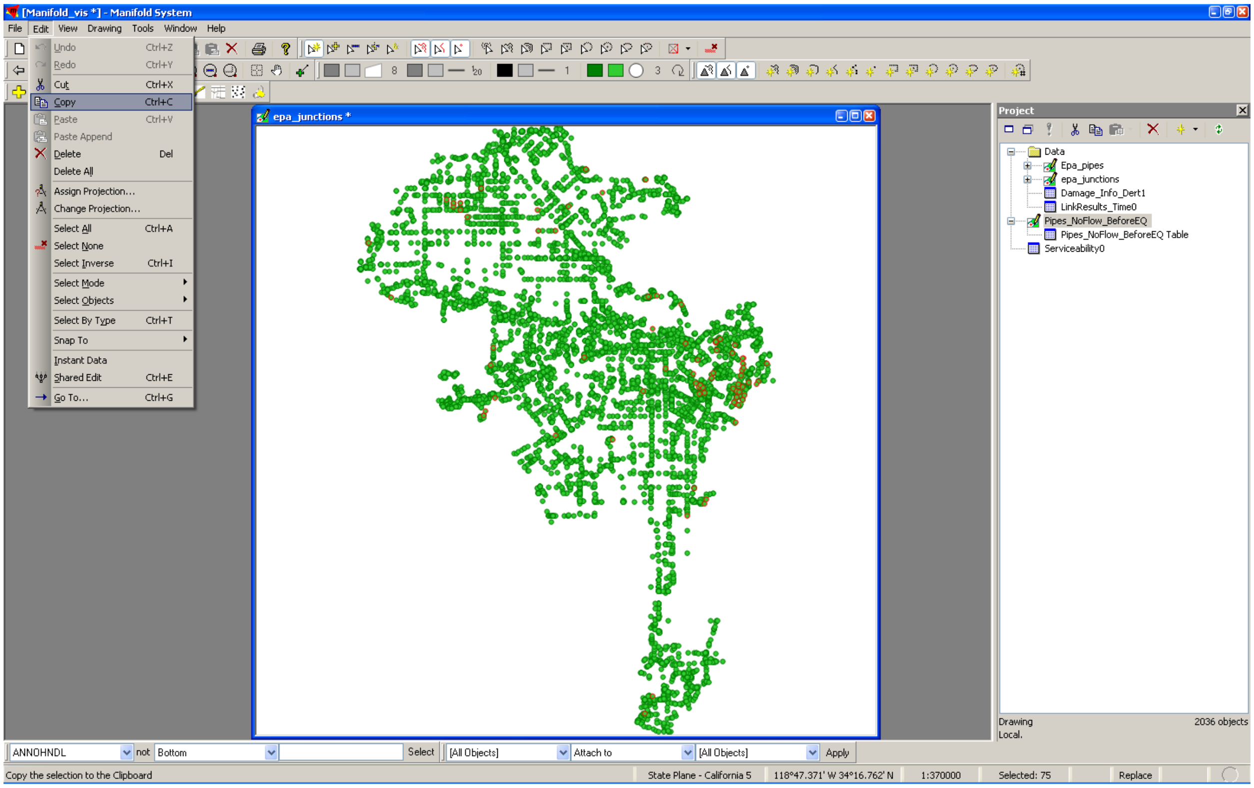


(f) Step 6

Figure C.14 Displaying Pipe Flow Data

As noted in **Table C.2** Using the Manifold Visualization Custom Toolbar, when the nodes have been selected using the unsatisfied demands tools, the selected nodes can be copied into a new layer for use in a map. To do this,

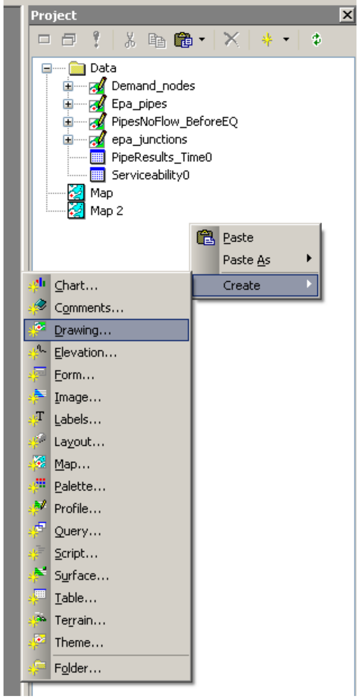
- Run any of the two unsatisfied demands tools
- Make sure that ***epa_junctions*** is open. Go to **Edit | Copy,** as shown in Figure C.15(a), to copy all of the selected objects in the layer.
- Right-click in the project pane and select **Create | Drawing** as shown in Figure C.15(b). Name the drawing. The new drawing should appear in the project pane.
- Double-click on the new drawing (***UnsatisfiedDemands_Time0***) to open the layer. Go to **Edit | Paste**. Select **OK** in the Paste Objects pop-up window. The objects copied from the original file in Step 1 should now appear in the layer as shown in Figure C.15(h).



Copy the selection to the Clipboard

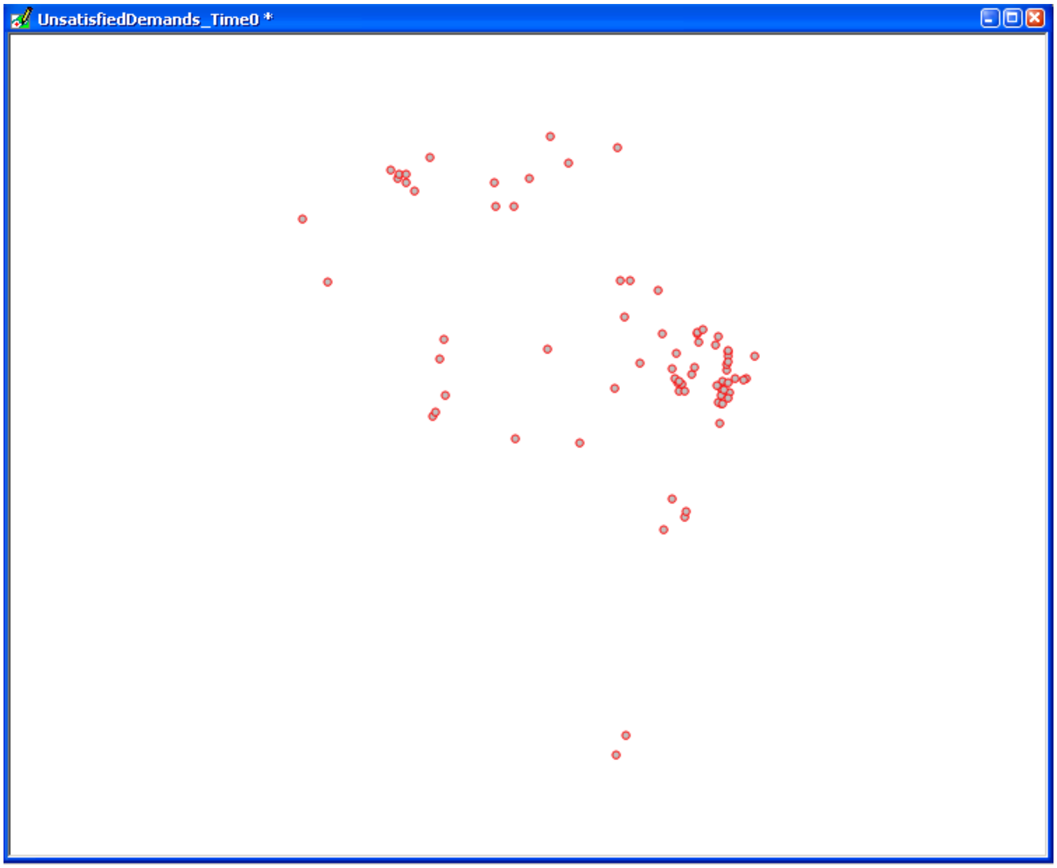
(a) Step 1

Figure C.15. Creating a new node layer.



(b) Step 2

Figure C.15. Creating a new node layer.



(c) Step 3

Figure C.15. Creating a new node layer.

For the user's convenience, several legends have been saved for easy display of serviceability, pipe damage, and PGV data. The legends are saved as *.*xml* files, and can be found in the GIRAFFE program folder under **Example_Files | Appendix C**. After creating node serviceability layers using the visualization toolbar, open the layer and then:

- Click on the background color well for points and choose theme from the pull-down color choice menu.
- Choose **Serviceability0** (or Serviceability24) as the Field. Then click on the Load from File button.
- In the pop-up window, navigate to the GIRAFFE program folder and then to **Example_Files | Appendix C**. Select ***Serv0Legend.xml*** (or *Serv24Legend.xml*) and click Open.
- Click OK in the thematic formatting dialogue, or change the colors/intervals as desired. The nodes should now be colored according to serviceability at time 0.

Similarly, the results from the View Pipe Damage tool can also be viewed using pre-made color schemes. However, in this case legends exist for the shape of the point as well as the color. After running the pipe damage visualization tool, there should be two new layers called *Breaks Drawing* and *Leaks Drawing*. These show which pipes in the system have breaks and leaks, and the extent of the damage. Changing the colors and symbols of the two damage layers is very similar to changing the color theme of the Serviceability and Pipe Flow layers (Figure C.15):

- In Manifold, open either ***Breaks Drawing*** or ***Leaks Drawing***. Click on the symbol button (next to the color wells) in the color toolbar and go to Theme.
- Choose **BreakNo** or **LeakNo** as the Field. Then click on the Load from File button.
- In the pop-up window, navigate to the GIRAFFE program folder and then to **Example_Files | Appendix C**. Select ***BreakSym.xml*** (or *LeakSym.xml*) and click Open.
- Click OK in the symbol formatting dialogue, or change the symbols as desired.
- This can also be done to change the color theme of the two layers, using the saved legends ***BreakCol.xml*** and ***LeakCol.xml***.
- To create a map of the breaks and leaks, right-click in the project pane and select **Create | Map**. Check the boxes next to ***Breaks Drawing***, ***Leaks Drawing***, and ***Epa_pipes***, and click OK. To create a legend, go to **View | Legend** in the main Manifold toolbar, and select the box next to **Show legend**. The final result should look similar to the map in Figure C.16.

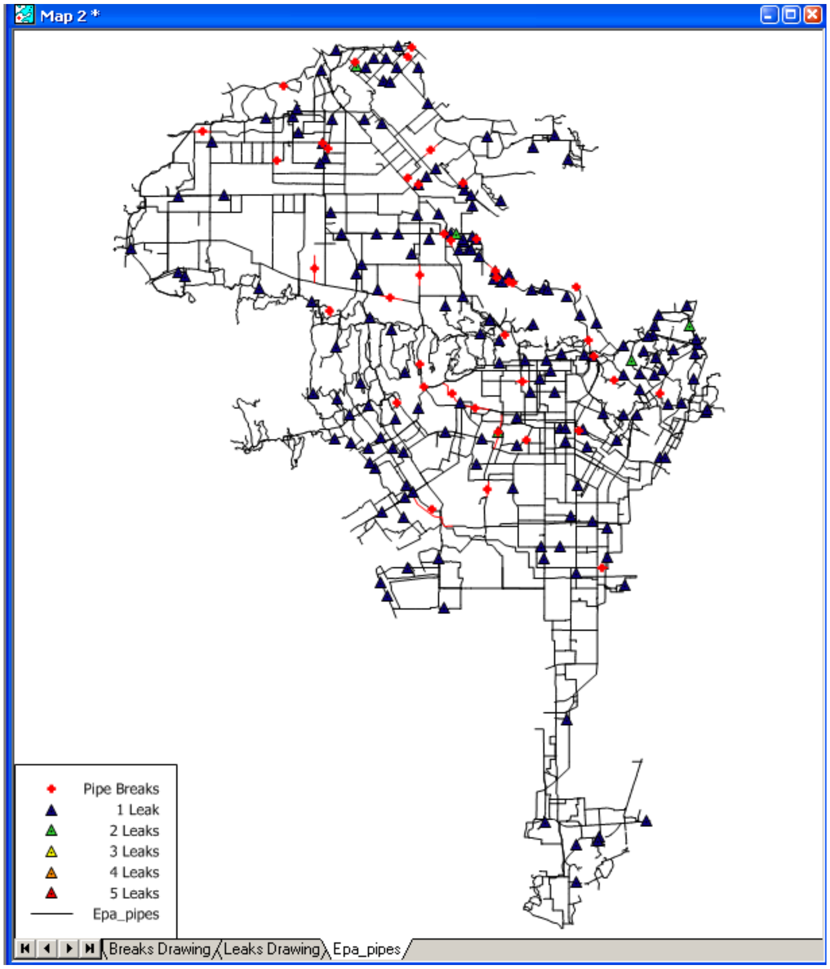
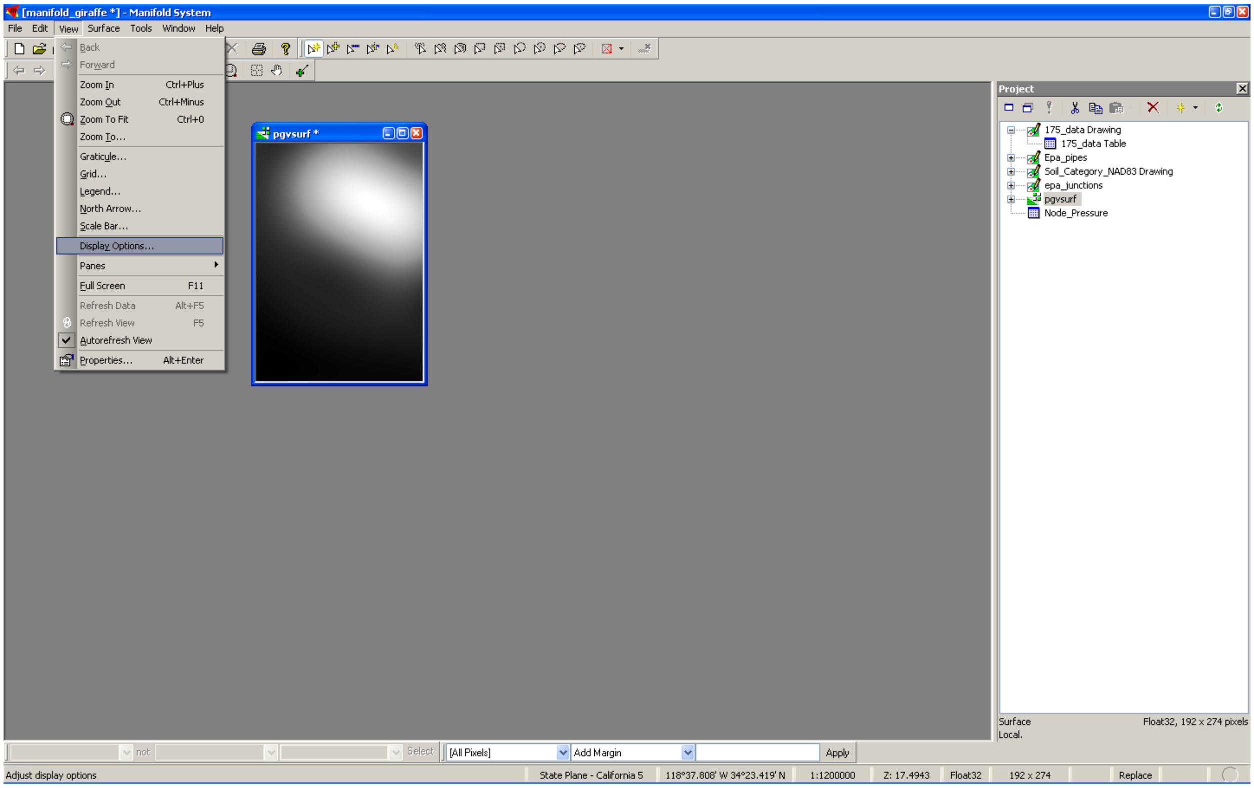


Figure C.16 Map of Pipe Breaks and Leaks

A saved legend also exists for the peak ground velocity (PGV) surface described in **Section C.2 GIS Spatial Analysis and Calculation Using Manifold GIS**. This surface (*pgvsurf*) can be used as a background for maps in order to demonstrate the location of the earthquake's epicenter. If ***pgvsurf*** has not already been created for the scenario, refer to **Sections C.2.1 and C.2.3** for how to create it in Manifold. For this example, refer to the example project

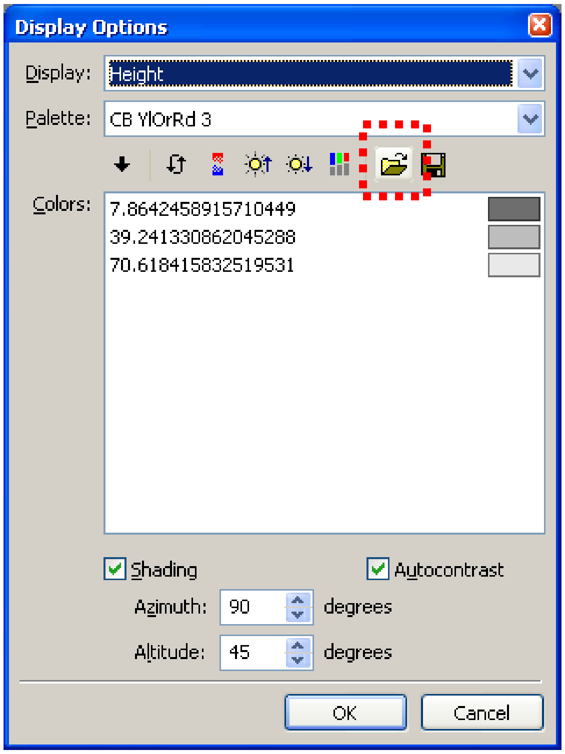
manifold_giraffe.map, which is located in the GIRAFFE program folder under **Example_Files | Appendix C**. To change the colors of *pgvsurf*:

- Go to **View | Display Options**. In the pop-up window, click on the **Load from File** button (Figure C.17(b)).
- Navigate to the GIRAFFE program folder and go to **Example_Files | Appendix C**. Select ***PGVLegend.xml*** and press Open, as shown in Figure C.17(c).
- After pressing OK in the thematic color dialogue box, *pgvsurf* should now appear as a gradient of oranges and reds (Figure C.17(d)).



(a) Step 1

Figure C.17 Displaying *pgvsurf*.



Display: Height

Palette: CB YlOrRd 3

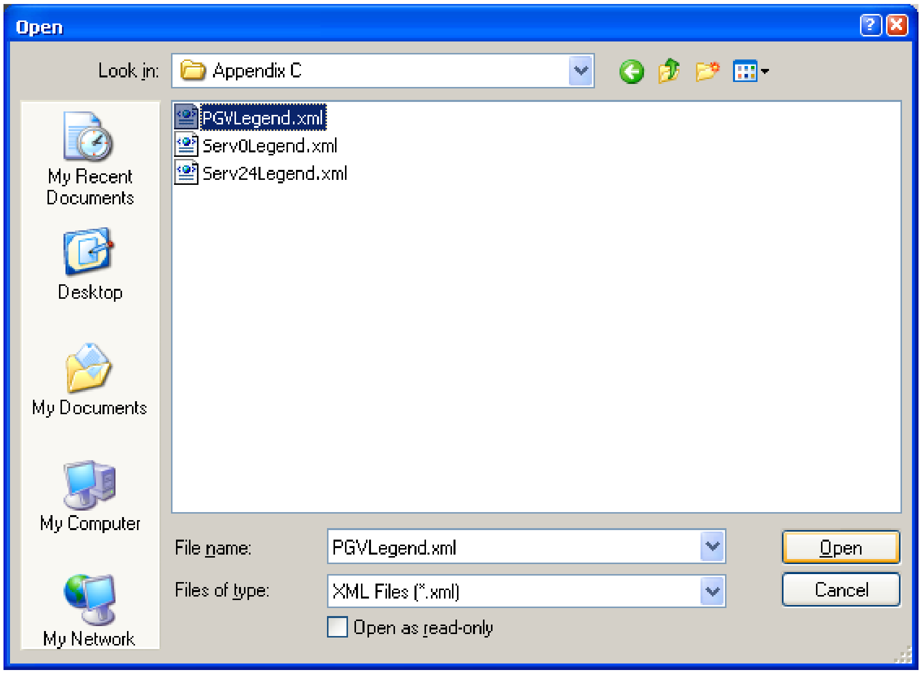
Colors:
7.8642458915710449
39.241330862045288
70.618415832519531

☑ Shading ☑ Autocontrast

Azimuth: 90 degrees

Altitude: 45 degrees

(b) Step 2
Figure C.17 Displaying *pgvsurf*.



Look in: Appendix C

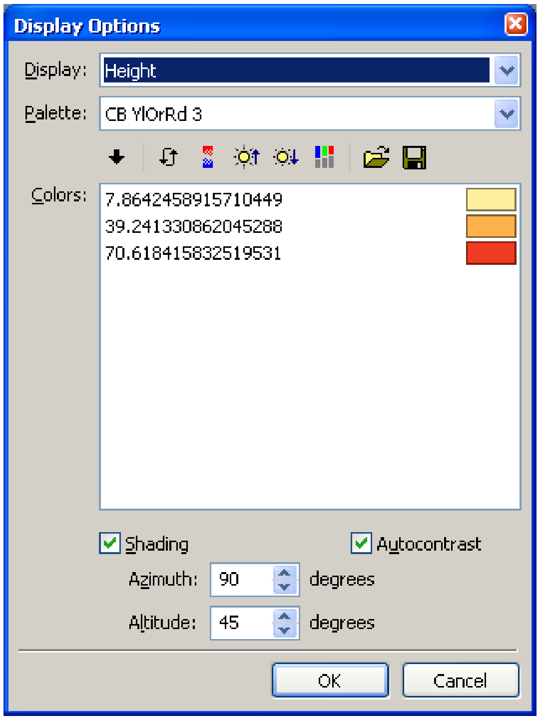
PGVLegend.xml
Serv0Legend.xml
Serv24Legend.xml

File name: PGVLegend.xml

Files of type: XML Files (*.xml)

☐ Open as read-only

(c) Step 3
Figure C.17 Displaying *pgvsurf*.



Display: Height

Palette: CB YlOrRd 3

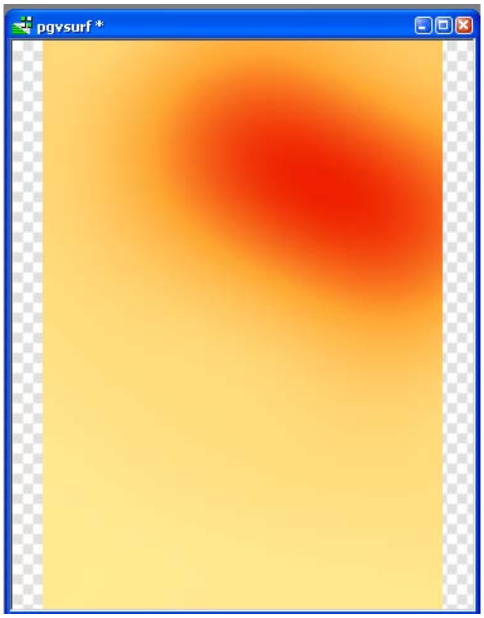
Colors:
7.8642458915710449
39.241330862045288
70.618415832519531

☑ Shading ☑ Autocontrast

Azimuth: 90 degrees

Altitude: 45 degrees

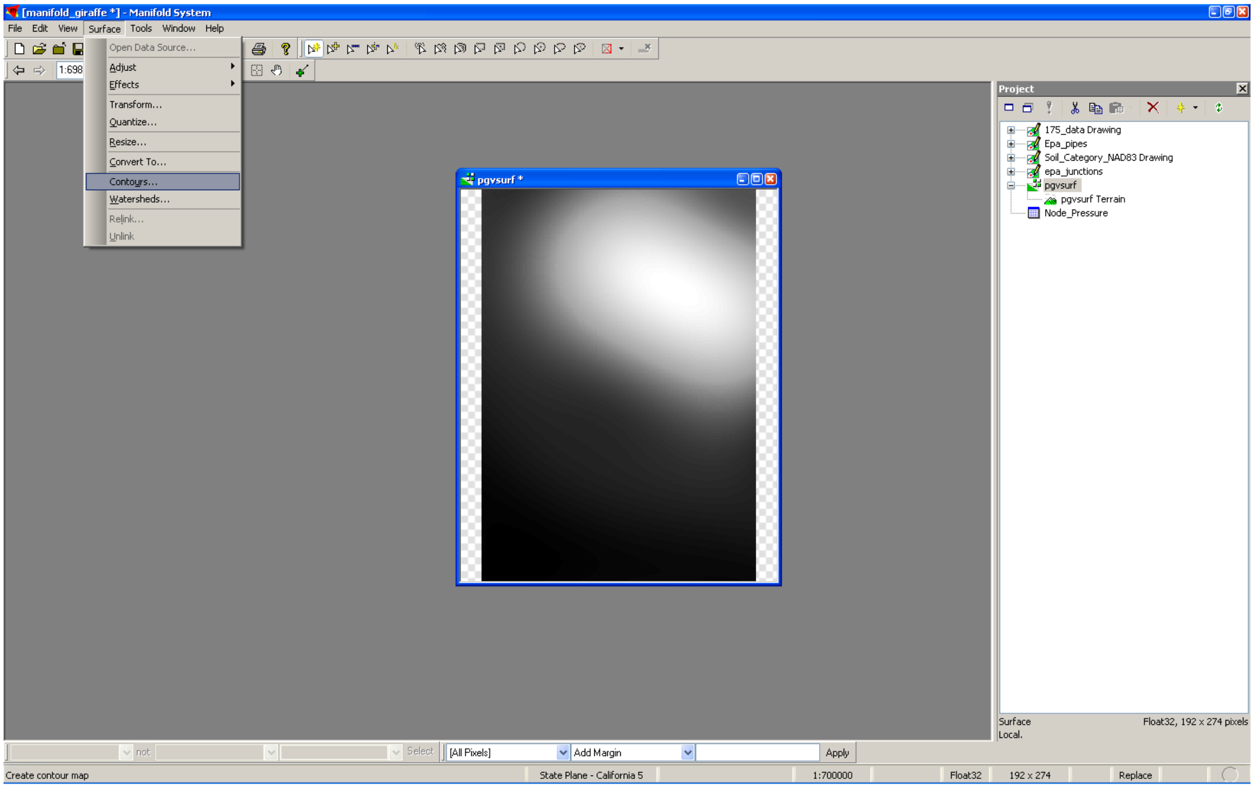
(d) Step 4
Figure C.17 Displaying *pgvsurf*.



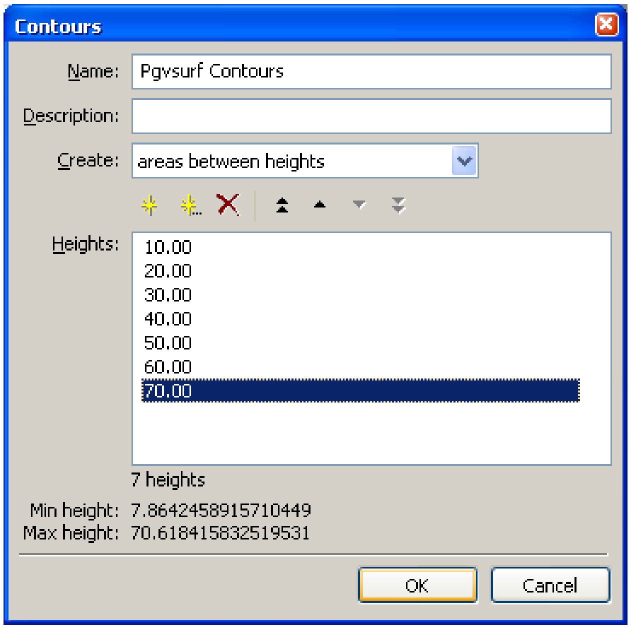
(e) Step 5
Figure C.17 Displaying *pgvsurf*.

Alternatively, the PGV surface can be visualized as contours. These are easy to make in Manifold:

- With the ***pgvsurf*** layer open, go to **Surface | Contours** as shown in Figure C.17(a).
- Select OK in the pop-up window, or change the intervals if desired (Figure C.17(b)).
- ***Pgvsurf Contours*** should appear in the project pane. Double-click to open this layer. Click on the areas color well and select **Theme** to change the colors.



(a) Step 1
Figure C.17 Creating *PGV Contours*.



Name: Pgvsurf Contours

Description:

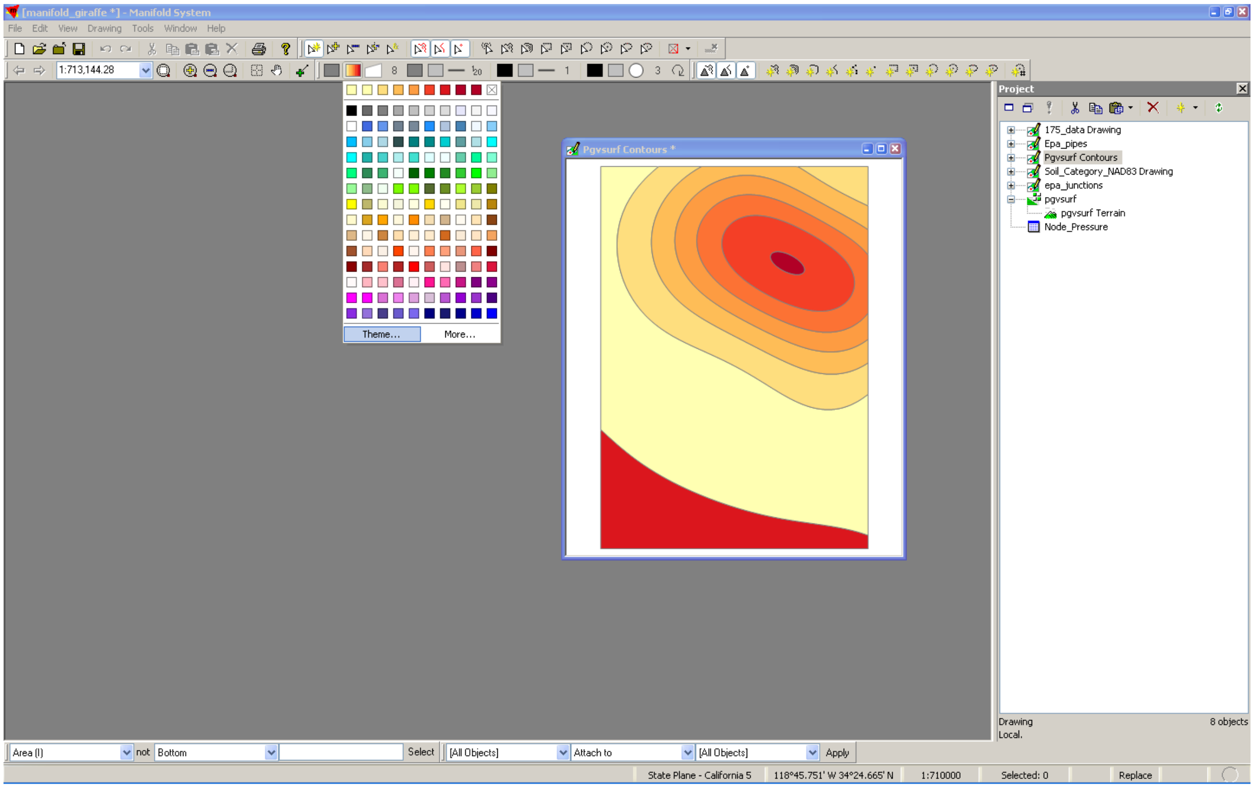
Create: areas between heights

Heights:
10.00
20.00
30.00
40.00
50.00
60.00
70.00

7 heights

Min height: 7.8642458915710449
Max height: 70.618415832519531

(b) Step 2
Figure C.17 Creating *PGV Contours*.



(c) Step 3
Figure C.17 Creating *PGV Contours*

REFERENCES

Manifold Net Ltd, 2006. *Manifold System 7x User Manual*. Carson City, NV

Federal Emergency Management Agency (FEMA, 2003). *FEMA-450: NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*. 2003 Edition, Washington, D. C., Developed by the Building Seismic Safety Council (BSSC) for FEMA.

MWH Soft, Inc. (1999). *H2ONET User Guide*. Pasadena, CA.

Rossman, L.A. (2000). *EPANET 2 User Manual*. National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, OH.

Shi, P. (2006). “Seismic Response Modeling of Water Supply Systems.” *Ph.D. Dissertation*, Cornell University, Ithaca, NY.

Wang, Y. (2006). “Seismic Performance Evaluation of Water Supply Systems.” *Ph.D. Dissertation*, Cornell University, Ithaca, NY.

APPENDIX D
FRAGILITY MODULE

D.1 INTRODUCTION

This appendix provides information on the Fragility Module, which is a part of GIRAFFE version 4.0. The Fragility Module is available for the “Deterministic”, “Monte Carlo Fixed” and “Monte Carlo Flexible” options in GIRAFFE (Figure D.1).

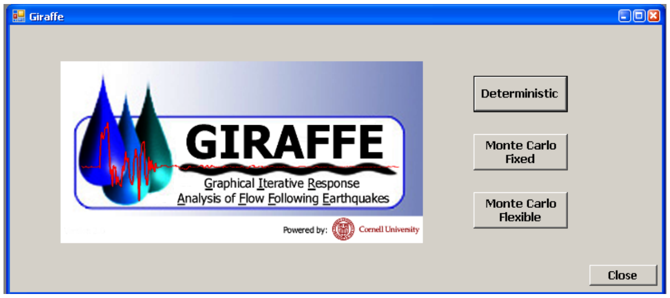
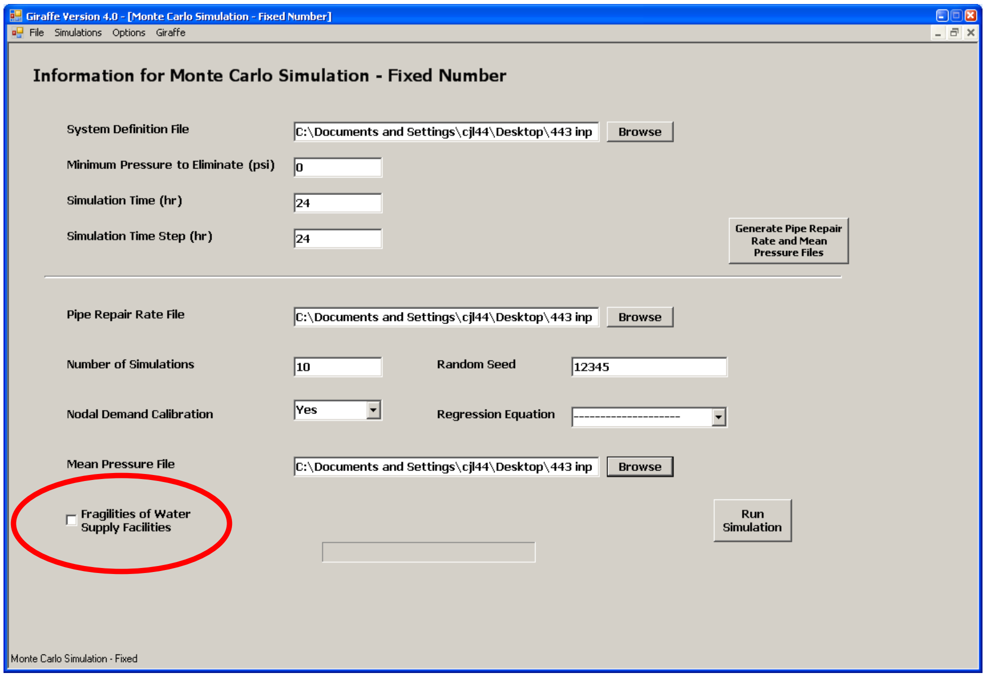


Figure D.1. GIRAFFE Version 4 Main Window.

Figure D.2 shows the user interface for the “Monte Carlo Fixed” option, and the check box for activating the Fragility Module.



Information for Monte Carlo Simulation - Fixed Number

System Definition File: C:\Documents and Settings\cjl44\Desktop\443 inp

Minimum Pressure to Eliminate (psi): 0

Simulation Time (hr): 24

Simulation Time Step (hr): 24

Pipe Repair Rate File: C:\Documents and Settings\cjl44\Desktop\443 inp

Number of Simulations: 10

Random Seed: 12345

Nodal Demand Calibration: Yes

Regression Equation: --------------------

Mean Pressure File: C:\Documents and Settings\cjl44\Desktop\443 inp

☐ Fragilities of Water Supply Facilities

Figure D.2. Fragility Module Activation.

D.2 INPUT FILES

Once the Fragility Module is activated the user should supply four files delivering the seismic intensities (peak ground accelerations in units of g) at the locations of system components including tanks, reservoirs, pumps and valves. Figure D.3 shows the user interface of the Fragility Module.

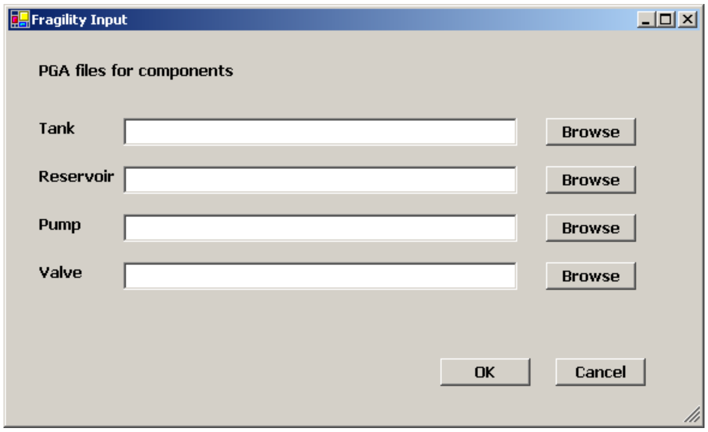
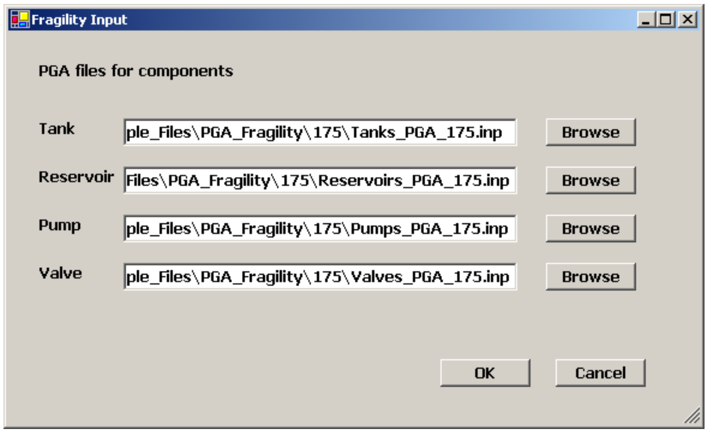


Figure D.3. Fragility Module User Interface.

The four files containing the peak ground accelerations (in g units) at the locations of the tanks, reservoirs, pumps and valves are different for each scenario earthquake. Fragility Module provides these four files for all of the 59 scenario earthquakes. The user can browse to locate the files corresponding to the selected scenario event. Figure D.4 shows complete input for the Verdugo Earthquake scenario.



Tank `ple_Files\PGA_Fragility\175\Tanks_PGA_175.inp`

Reservoir `Files\PGA_Fragility\175\Reservoirs_PGA_175.inp`

Pump `ple_Files\PGA_Fragility\175\Pumps_PGA_175.inp`

Valve `ple_Files\PGA_Fragility\175\Valves_PGA_175.inp`

Figure D.4. Fragility Module User Interface for the Verdugo Earthquake.

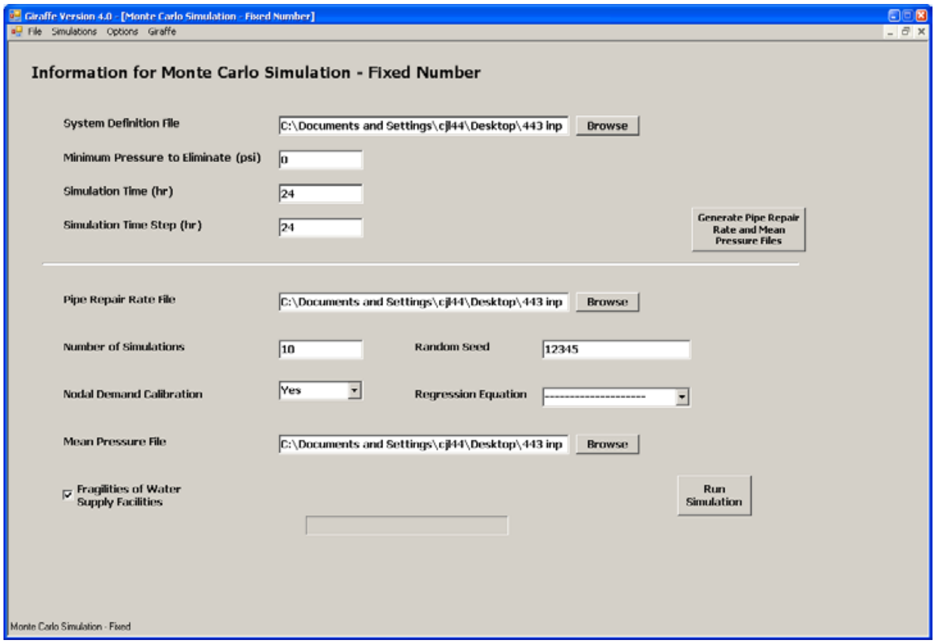
The format of these input files is predetermined. Figure D.5 presents an example file with the name *Tanks_PGA_175.inp*, for the peak ground accelerations in units of g at the location of the tanks using the Verdugo Earthquake scenario (scenario 175).

```
Scenario 175
ID     PGA_Soil_g
H4050  0.20774774
H4040  0.20774774
H4030  0.197544669
H4020  0.20777472
H4090  0.237838532
H4010  0.23248291
H4160  0.23248291
CC4040 0.399021763
...
```

Figure D.5. Tanks Seismic Intensity File for the Verdugo Earthquake.

The first line contains the scenario ID for the selected earthquake. The second line contains the column names. From the third line on, the first column contains the identification numbers (IDs) of all the tanks in the H2ONet database and the second column contains the peak ground accelerations (PGA, in g units) corresponding to each tank location. The format of the pump, reservoir and valve files is similar to that of the tank file.

After providing the necessary input for the Fragility Module the user goes back to the main window of the “Monte Carlo Fixed” option by clicking the “OK” button (Figure D.4) and can start the simulation by just clicking the “Run Simulation” button (Figure D.7).



Information for Monte Carlo Simulation - Fixed Number

System Definition File: C:\Documents and Settings\cjl44\Desktop\443 inp

Minimum Pressure to Eliminate (psi): 0

Simulation Time (hr): 24

Simulation Time Step (hr): 24

Pipe Repair Rate File: C:\Documents and Settings\cjl44\Desktop\443 inp

Number of Simulations: 10

Random Seed: 12345

Nodal Demand Calibration: Yes

Regression Equation: --------------------

Mean Pressure File: C:\Documents and Settings\cjl44\Desktop\443 inp

☑ Fragilities of Water Supply Facilities

Figure D.7. Monte Carlo Fixed Option with Activated Fragility Module.

D.3 OUTPUT FILE

After reading in the necessary files, the Fragility Module performs fragility analyses for each component and delivers the damaged components (details are given in Section D.5). The damaged components are passed to GIRAFFE through a file called *Fragility_output.inp*. This file is created in the directory where the Fragility Module is located. The *Fragility_output.inp* file is also saved in the directory where all other output files are created for the current simulation given a scenario earthquake. The name and the format of the file are predetermined. An example for the *Fragility_output.inp* file for the Verdugo Earthquake scenario is shown in Figure D.6.

```
[SCENARIO_NO]
175

[SIMULATION_NO]
1

[PUMPS]

[VALVES]

[TANKS]
SM4010
HH4180
MW4130
MW4140
HP4010
HP4050
GH4000
EH4050
ST4020
ST4060
GH4020
FH4030
FH4040

[RESERVOIRS]
```

Figure D.6. Fragility Module Output File.

IMPORTANT NOTE: If a component in the system definition input file is not present in the provided database files (PGA files or tank type file), then the worst case is assumed, that is, the PGA at the location of this component is assumed to be equal to the highest PGA in all component PGA databases, and if this component is a tank then it is assumed that this tank is an unanchored concrete tank (resulting in largest failure probability). This situation will happen when a new component is added to the LADWP 2002 H2ONet model.

D.4 INTEGRATION BETWEEN GIRAFFE AND FRAGILTY MODULE (DETAILS)

The Fragility Module consists of *fragility.exe, fragility.ctf* and the files installed by the *MCRInstaller.exe*. The main file is *fragility.exe* and is called within GIRAFFE.

D.4.1 Input for the Fragility Module: FragilityReport.fra

The *FragilityReport.fra* file is created automatically by GIRAFFE and is located in the same directory with the fragility module (*fragility.exe* and *fragility.ctf* files). The file contains the location and the filenames for the peak ground accelerations (in g units) for each component of the system (tanks, reservoirs, pumps, valves), the location and the filename of the random numbers for damage assessment for the scenario earthquake under consideration, and the location and the filename of the component identity numbers (IDs) in the current system file. The locations and the filenames for the peak ground accelerations for tanks, reservoirs, pumps and valves are provided by the user through the user interface of GIRAFFE. The location and the filename of the random numbers file (*RandomFile.fra*) and the component ID file (*ComponentFile.fra*) are predetermined. The *RandomFile.fra* and the *ComponentFile.fra* are located in the same directory with the fragility module and is recreated by GIRAFFE for each simulation.

The order of the filenames in the *FragilityReport.fra* file is fixed, that is, lines 1, 2, 3 and 4 should contain the location and name of files containing ground motion intensities (accelerations in g units) for pumps, valves, tanks and reservoirs, respectively, line 5 should contain the location and name of the random number file, and line 6 should contain the location and name of the component ID file. The fragility module locates these files and reads the content. Therefore, the format of these files are predetermined.

Following are examples providing the format of the files *FragilityReport.fra, Tanks_PGA_175.inp* (the format of the files for pumps, valves and reservoirs is similar to that of the tanks), *RandomFile.fra* and *ComponentFile.fra* for Verdugo Earthquake scenario (scenario 175).

FragilityReport.fra:

```
E:\...\Giraffe\Example files\PGA_Fragility\175\Pumps_PGA_175.inp
E:\...\Giraffe\Example files\PGA_Fragility\175\Valves_PGA_175.inp
E:\...\Giraffe\Example files\PGA_Fragility\175\Tanks_PGA_175.inp
E:\...\Giraffe\Example files\PGA_Fragility\175\Reservoirs_PGA_175.inp
E:\...\Giraffe\Fragility\RandomFile.fra
E:\...\Giraffe\Fragility\ComponentFile.fra
```

Figure D.8. *FragilityReport.fra* File for Verdugo Earthquake Scenario.

Tanks_PGA_175.inp: (PGA's should be in g units)

```
Scenario 175
ID     PGA_Soil(g)
H4050  0.20774774
H4040  0.20774774
H4030  0.197544669
H4020  0.20777472
H4090  0.237838532
H4010  0.23248291
H4160  0.23248291
CC4040 0.399021763
…
```

Figure D.9. *Tanks_PGA_175.inp* File for Verdugo Earthquake Scenario.

RandomFile.fra:

```
[SIMULATION_NO]
1

[PUMPS]
0.8626
…
0.3562

[VALVES]
0.8230
…
0.0253

[TANKS]
0.7531
…
0.5625

[RESERVOIRS]
0.3339
…
0.5363
```

Figure D.10. *RandomFile.fra* File for Verdugo Earthquake Scenario.

ComponentFile.fra:

```
[PUMPS]
H5000
H5140
H5130
…
FH5080

[VALVES]
H6060
H6050
CC6010
…
GH7050

[TANKS]
H4050
H4040
H4030
…
FH4050

[RESERVOIRS]
H4000
H4180
H4060
…
VF5880
```

Figure D.11. *ComponentFile.fra* File for Verdugo Earthquake Scenario.

D.4.2 Output of the Fragility Module: Fragility_output.inp

After reading in the necessary files, the fragility module performs fragility analysis for each component and delivers the damaged components. The damaged components are passed to GIRAFFE through a file called *Fragility_output.inp*. This file is created in the directory where Fragility Module is located. The *Fragility_output.inp* file is also saved in the directory where all other output files are created for the current simulation given a scenario earthquake. The name and the format of the file are predetermined. An example file is provided below.

Fragility_output.inp:

```
[SCENARIO_NO]
175

[SIMULATION_NO]
1

[PUMPS]

[VALVES]

[TANKS]
MW4130
MW4140
HH4190
SM4120
HP4140
SM4010
HP4010
HP4070
ST4020
VF5540
FH4030
FH4040

[RESERVOIRS]
```

Figure D.12. *Fragility_output.inp* File for Verdugo Earthquake Scenario.

D.5 FRAGILITY INFORMATION FOR TANKS, RESERVOIRS, PUMPS AND VALVES IN THE 2002 LADWP H2ONET MODEL

D.5.1 Tank types

The water tanks in the 2002 LADWP H2ONet Model are divided into 4 groups according to their type:

- Group-1: Steel
- Group-2: Concrete, anchored
- Group-3: Concrete, unanchored
- Group-4: Buried

All welded, riveted and bolted steel tanks are assigned to Group-1. Prestressed concrete tanks and reinforced concrete tanks built after 1950 are assigned to Group-2. Reinforced concrete tanks built during and before 1950 are assigned to Group-3. All buried tanks are assigned to Group-4. Section D.5.5 summarizes the name, type, date of construction and Group ID for all tanks and some in-ground storage facilities (reservoirs, buried tanks and pipes) in the 2002 LADWP H2ONet Model. Please note that another file for reservoirs also exists in the 2002 LADWP H2ONet Model.

D.5.2 Tank damage states

Two damage states are defined, in accordance with the seismic performance analysis of the whole water system, to characterize the seismic performance of water tanks:

- DS-1: A tank is hydraulically 100% functional during the first 24 hours after an event.
- DS-2: A tank is non-functional during the first 24 hours after a seismic event.

Damaged water tanks can be incorporated in the recovery/restoration model accordingly.

D.5.3 Tank fragility curves

Group-1: The fragility information of the tanks in Group-1 was obtained from O’Rourke and So (2000). The paper uses one of the five HAZUS damage states to define the seismic performance of a tank. It is assumed that a tank is in DS-1 (defined above) for HAZUS damage states 1, 2, 3, and that it is in DS-2 (defined above) for HAZUS damage states 4 and 5. A lognormal curve is fitted to the data (all tanks with HAZUS damage state≥ 4) pro vided in Table 4 from O'Rourke and So (2000). Figure D.13 shows the data points from the paper, fitted lognormal fragility curve, 90% confidence bounds and a pseudo-R^2 measuring the goodness of the fit, for steel tanks in DS-2. Please note that defining a lognormal fragility curve for the HAZUS damage state 4 sets the maximum threshold for damage that impairs functionality, and is thus associated with the DS-2 defined above. Defining DS-2 in this manner automatically covers HAZUS damage states 4 and 5.

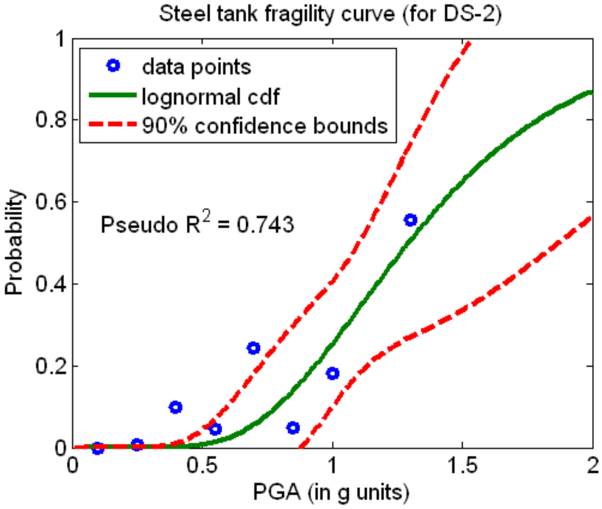


Figure D.13. Fragility Curve for Steel Tanks (Group-1).

Group-2 and 3: The fragility information of the tanks in Groups 2 and 3 are obtained from the HAZUS-MH Technical Manual (FEMA, 2006). The HAZUS manual provides the parameters of lognormal fragility curves for five damage states for several types of water tanks (Table 8.9). Group-2 and Group-3 defined above correspond to classifications PST1 and PST2 in the HAZUS-MH Technical Manual, respectively. It is assumed that a tank is in DS-1 for HAZUS damage states 1 (no damage), 2 (slight/minor) and 3 (moderate), and that it is in DS-2 for HAZUS damage states 4 (extensive) and 5 (collapse). Figure D.14 shows the lognormal fragility curves for anchored and unanchored concrete tanks in DS-2. These fragility curves are identical to those for HAZUS damage state ≥ 4 associated with PST1 and PST2.

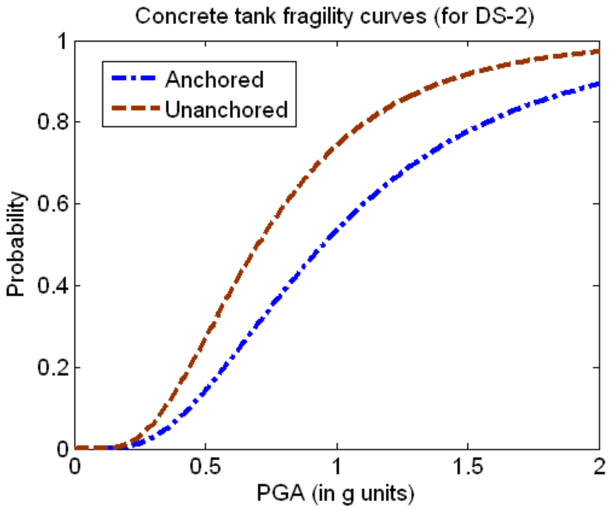


Figure D.14. Fragility Curves for Concrete Tanks (Group-2 and 3).

Group-4: LADWP experience indicates that in-ground storage facilities perform well under seismic events or need to be characterized on a more detailed, site-specific basis. Accordingly, it is assumed that a Group-4 tank or reservoir would not fail due to seismic ground motions. We have used a dummy lognormal fragility curve resulting in zero failure probabilities for all possible seismic intensity levels. The dummy lognormal fragility curve used in the fragility module can be easily replaced in the future when and if new data are acquired that can help delineate a more appropriate fragility curve. Figure D.15 illustrates the dummy lognormal fragility curve for in-ground storage facilities.

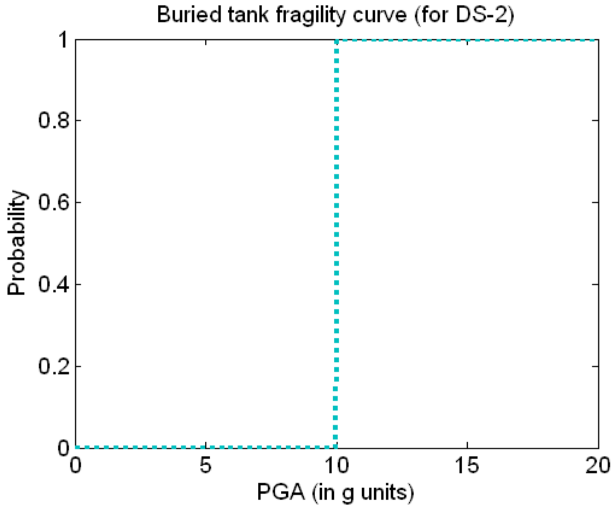


Figure D.15. Fragility Curve for Buried Tanks (Group-4).

Table D.1 shows the parameters of the lognormal fragility curves for the 4 tank and reservoir types defined above. Figure D.16 shows the lognormal fragility curves for the 4 tank types.

Table D.1. Parameters of Lognormal Fragility Curves for Water Tanks.

Group	**Median (in *g* units)**	**Dispersion**
1 (steel)	1.294	0.387
2 (anchored concrete)	0.950	0.600
3 (unanchored concrete)	0.700	0.550
4 (buried)	10.000	0.001

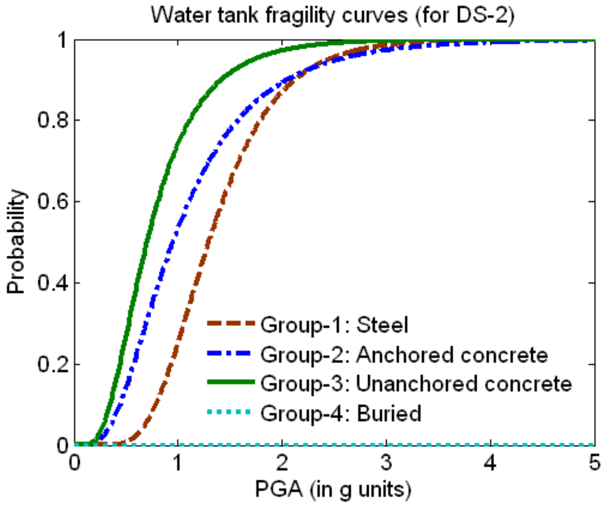


Figure D.16. Fragility Curves for Water Tanks.

Note: A tank that is not in the 2002 LADWP H2ONet Model is assumed to be in Group-3, which results in the largest failure probability (hence a conservative assumption).

D.5.4 Modeling Reservoirs as Tanks

In some cases, it is necessary to model a reservoir as a “tank” such that the level of the reservoir could vary with time. In such a case, the reservoir will have a tank ID that will be subject to the tank fragility code, and since this tank ID did not appear at the time tank IDs were assigned to Groups (this is hard-coded as a part of the tank fragility module) it will be assumed to be in Group-3, which results in the largest failure probability (the most conservative assumption) . In reality, reservoirs are large, buried structures and should not be subject to tank damage. A trick can be used to prevent these reservoirs (classified as tanks) from being subject to the tank fragility module. Open the *Tanks_PGA_Scenario#.inp* file and add the tank IDs for the reservoirs being classified as tanks and give each an extremely low PGA value of 0.000001g. The PGA value cannot be zero due to calculation restrictions. It is not necessary, but would be good practice to then remove the reservoir IDs from the *Reservoirs_PGA_Scenario#.inp* file since it now appears in the *Tanks_PGA_Scenario#.inp* file. Before each simulation, be sure you are using the appropriate tank and reservoir PGA files that capture what you are actually modeling. During each simulation using the tank fragility module, check the *Fragility_output.inp* file created to see which tank IDs are being damaged. If a reservoir you were trying to prevent from being damaged is appearing as damaged with each simulation, you have a clue to double check the PGA input files you are using.

D.5.4 Other components (pumps, valves, reservoirs)

Experience indicates that pumps, valves and reservoirs perform very well under seismic events. Hence the dummy lognormal fragility curve used for the buried tanks, resulting in no damage, is used for these components as well. Similarly, if new data are acquired that can help delineate a more appropriate fragility curve, the new curve can be easily implemented in the module.

D.5.5 A summary of LADWP tanks and in-ground storage facilities

H2ONet ID	Name	Type	Date	Group
H4040	summerland tank no2	welded steel covered	1968	1
H4030	9th street tank	riveted steel covered	1926	1
H4010	harbor heights tank no2	welded steel covered	1962	1
H4160	harbor hills tank	steel		1
CC4040	baldwin hills tank	welded steel elevated	1952	1
SY4010	paseo miramar tank	riveted steel pipe inclined, buried	1941	4
WS4010	sawtelle tank	welded steel covered	1986	1
SM4030	blue jay tank	welded steel covered	1961	1
SM4040	briarcrest tank	welded steel covered	1938	1
SM4090	lookout mountain tank no1	welded steel dome covered	1933	1
SM4100	lookout mountain tank no2	welded steel covered	1960	1
SM4230	cyprean tank	welded steel covered	1958	1
SM4050	coldwater canyon tank no2	prestressed concrete covered	2000	2
SM4080	firenze tank no2	prestressed concrete		2
HH4000	griffith park tank no2	welded steel covered	1975	1
EH4010	corbin tank	welded steel covered	1987	1
SY4040	temescal tank	prestressed concrete covered	1992	2
SY4050	trailer tank	prestressed concrete covered	1985	2
SY4060	marquez knolls tank	welded steel covered	1963	1
SM4060	eastridge tank no2	welded steel covered	1970	1
SM4110	roscomare tank no1	hewitt type circular conrete	1941	3
SM4120	roscomare tank no2	prestressed concrete covered	1956	2
SM4150	summitridge tank	welded steel	1962	1
SM4280	mountain gate tank	welded steel covered	1983	1
HH4010	hollywood knolls tank no2	welded steel covered	1970	1
HH4050	innsdale tank	riveted steel covered	1931	1
HH4060	mulholland tank	riveted steel covered	1931	1
HH4090	tyrolean tank no2	welded steel covered	1961	1
MW4070	elysian park tank	riveted steel covered	1926	1
MW4080	edendale tank	concrete encased steel covered	1906	3
SM4000	alta view tank	welded steel covered	1964	1
SM4010	beverly glen tank no2	prestressed concrete covered	2000	2
SM4020	beverly ann tank	welded steel covered	1966	1
EH4000	calneva tank	welded steel covered	1959	1
EH4040	sepulveda tank	welded steel	1966	1
EH4080	zelzah tank	welded steel covered	1948	1
CC4750	rowena tank	prestressed concrete covered	2000	2
HH4170	los feliz tank	prestressed concrete covered	2000	2
HH4180	toyon tank (north)	prestressed concrete covered	2000	2
HH4190	toyon tank (south)	prestressed concrete covered	2000	2
MW4000	ascot tank	prestressed concrete covered	1990	2
HP4040	lomitas tank	bolted steel covered	1929	1
HP4140	bairdstown tank no1	riveted steel covered	1923-1930	1
HP4150	bairdstown tank no2	welded steel covered	1948	1
MW4130	mount washington tank no1	concrete circular covered	1948	3
MW4140	mount washington tank no2	reinforced concrete covered	1954	2
MW4150	meridian tank	welded steel	1996	1
HP4010	highland park tank	hewitt type circular conrete	1937	3
HP4020	verdugo tank	welded steel covered	1939	1
HP4050	kulli tank	concrete covered	1923	3
HP4070	hillmont tank no2	welded steel covered	1980	1
GH4000	donick tank	welded steel covered	1982	1

H2ONet ID	Name	Type	Date	Group
GH4070	kittridge tank no3	welded steel covered	1973	1
GH4080	kittridge tank no4	welded steel covered	1973	1
EH4050	topanga tank	welded steel covered	1936	1
ST4020	higway highlands tank	welded steel covered	1958	1
ST4040	estepa tank no2	welded steel covered	1964	1
ST4060	sunland tank	riveted steel covered	1938	1
VF5540	tujunga tank	prestressed concrete covered	1993	2
ST4010	apperson tank	reinforced concrete covered	1929-1951	3
ST4030	irma tank	welded steel covered	1953	1
ST4080	rim canyon tank	welded steel covered	1956	1
VF5070	clear well tank	welded steel covered	1986	1
GH4060	lakeside tank no2	bolted steel covered	1954	1
ST4070	sister elsie tank	welded steel covered	1956	1
GH4020	susana tank	prestressed concrete covered	1990	2
FH4030	maclay tank no1	prestressed concrete covered	1992	2
FH4040	maclay tank no2	prestressed concrete covered	1992	2
FH4010	alta vista tank no1	riveted steel covered	1929	1
FH4020	alta vista tank no2	welded steel covered	1954	1
HH4110	wonderview tank	horizontal welded steel pipe, buried	1941	4
H4050	summerland res. no1	concrete covered sunken, buried	1934	4
H4020	18th street res.	concrete covered, buried	1921	4
H4090	harbor city res.	concrete covered, buried	1929	4
VF4140	laurel canyon res.	circular concrete sunken covered, buried	1931	4
SM4070	firenze res. no1	concrete covered, buried	1941	4
SM4160	woodrow wilson res.	sunken concrete circular, buried	1931	4
SM4220	eastridge res. (no1)	concrete covered, buried	1950	4
SM4140	mandeville res.	concrete covered, buried	1950	4
EH4060	winnetka res. no2	concrete covered, buried	1957	4
EH4070	winnetka res. no1	concrete covered, buried	1950	4
VF4270	north hollywood forebay	concrete sump		4
ST4050	redmont res.	excavated concrete lined covered, buried	1920-1951	4
SY4000	pacific palisades res.	concrete covered, buried	1929	4
CC4250	franklin res. no2 (lower)	earth fill dam, A. C.	1982	4
SY4030	santa ynez canyon res.	earth fill dam, asphalt	1970	4
CC4220	ivanhoe res.	earth reservoir	1906-1952	4
CC4230	silver lake res.	earth fill dam, A. C.	1908-1953	4
CC4240	elysian res.	earth fill dam, A. C.	1903-1943	4
MW4100	solano res.	concrete lined covered, buried	1904	4
WS4020	stone canyon res. (lower)	earth fill dam, natural	1921-1956	4
WS4030	stone canyon res. (upper)	earth fill dam, A. C.	1954	4
VF5550	encino res.	earth fill dam, natural	1921	4
CC4280	hazard res.	excavated concrete lined covered, buried	1902-1918	4
HP4030	garvanza res.	concrete lined covered, buried	1902-1907	4
HP4060	eagle rock res.	earth fill dam, A. C.	1953	4
FH4000	green verdugo res.	earth fill dam, A. C.	1953	4
GH4150	de soto res.	cut and fill res. covered, buried	1941	4
FH4050	maclay res.	concrete lined covered, buried	1917	4

Table D.2. A Summary of LADWP Tanks and In-Ground Storage Facilities.

Note: Another file for reservoirs also exists in the 2002 LADWP H2ONet Model. The reservoir file includes all the reservoirs in the table above, as well as other reservoirs in the system.

D.5.6 Seismic hazard at the location of tanks, pumps, valves and reservoirs

The peak ground accelerations at the location of tanks, pumps, valves and reservoirs are obtained by scaling the peak ground accelerations at the level of bedrocks (provided by the URS) by factors depending on the local soil conditions. The scaling factors that are used for this purpose for different NEHRP site classes are provided in Table D.3.

Site Class	**Correction Factor**				
	(PGA<=0.15)	**(PGA >0.15 AND PGA <= 0.25)**	**(PGA >0.25 AND PGA <= 0.35)**	**(PGA >0.35 AND PGA <= 0.45)**	**(PGA > 0.45)**
A	0.8	0.8	0.8	0.8	0.8
B	1	1	1	1	1
C	1.2	1.2	1.1	1	1
D	1.6	1.4	1.2	1.1	1
E	2.5	1.7	1.2	0.9	0.9*
AB	0.9	0.9	0.9	0.9	0.9
BC	1	1	1	1	1
CD	1.4	1.3	1.15	1.05	1
DE	2.05	1.55	1.2	1	0.95*

Table D.3. Site Amplification Factors for PGA

Values shown with an asterisk (*) in Table D.3 were not provided in NEHRP Provisions and are based on judgment (Source: HAZUS – MH Technical Manual).

REFERENCES

Federal Emergency Management Agency (FEMA), Multi-Hazard Loss Estimation Methodology - Earthquake Model. Department of Homeland Security, Federal Emergency Management Agency, Mitigation Division, HAZUS-MH MR2 Technical Manual, 2006.

O'Rourke, M. J. and So, P., Seismic Fragility Curves for On-Grade Steel Tanks. Earthquake Spectra, Vol. 16, No. 4, 2000, pp. 801-815.

APPENDIX E
FLOW AND NETWORK NONLINEARITIES

E.1 INTRODUCTION

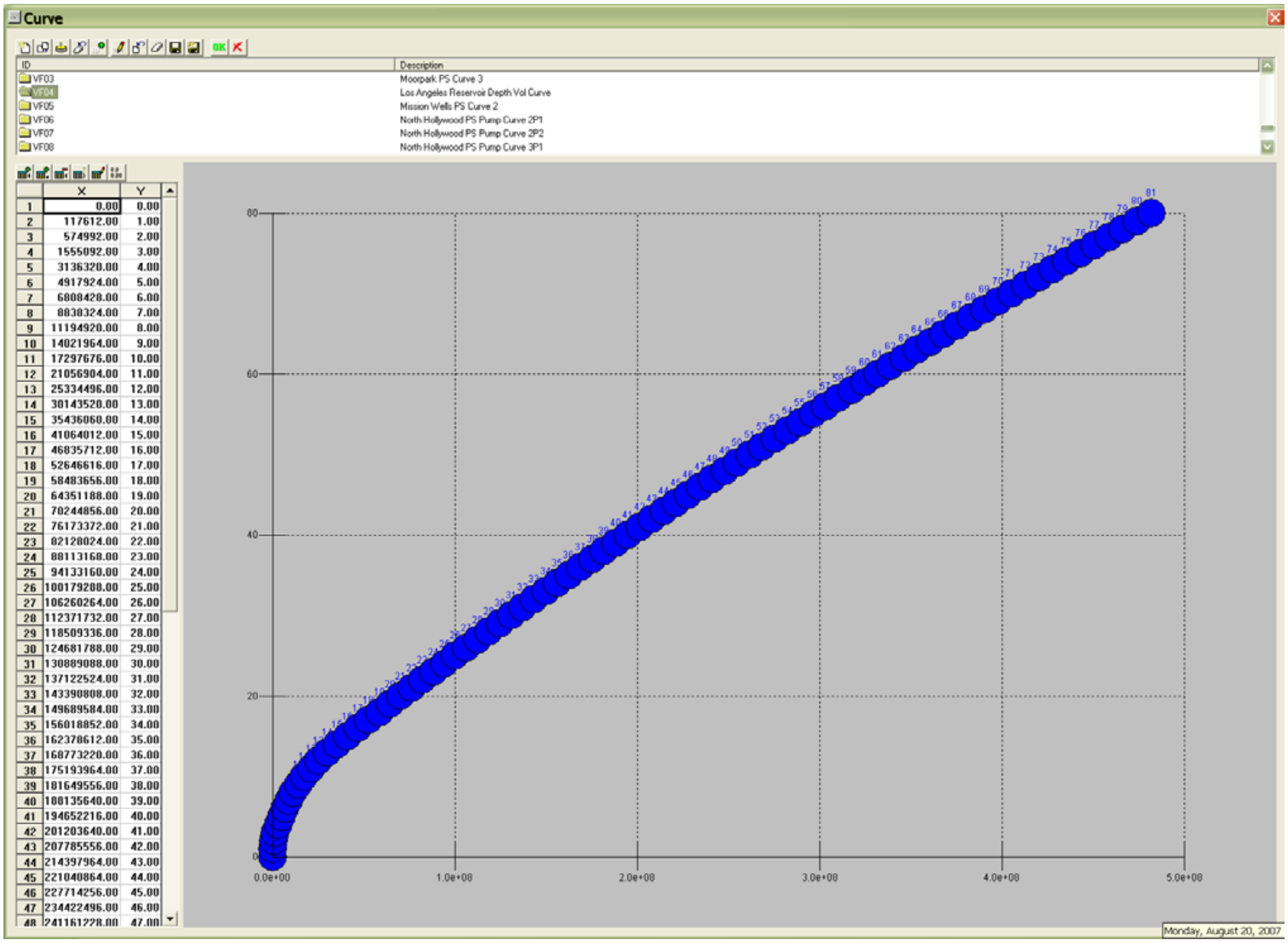
This appendix highlights examples of flow and network nonlinearities that are time dependent are affected by network modeling choices. Network models that include tanks with the ability to drain and fill over time can display nonlinear flow characteristics. Special consideration should be given to how these types of tanks interact with others nearby, as well as the selection of the size of time step for simulation. Examples illustrating the importance of these factors are presented in the following sections.

E.2 VARYING TANK LEVELS

The model created for the 2007 LADWP water system contains two types of tanks which allow tank levels to vary with time: cylindrical tanks and variable area tanks. A cylindrical tank is defined by a bottom elevation (feet), initial height of water above the bottom elevation (feet) and tank diameter (in feet). The tank is assumed to have a constant diameter and the volume of water (cubic feet) in the tank is calculated at each time step based on the current height of water and the diameter of the tank. As an alternative to a constant diameter tank, a user may specify a variable area tank where the volume of water is defined by a curve that relates water volume (cubic feet) to the height of water in the tank (feet). EPANET linearly interpolates the water volume based on the user defined curve.

An example of a variable area tank curve for the Los Angeles Reservoir is shown in Figure E.1(a). It should be noted that when viewing a variable area tank curve in AutoCad/H20Net, the x-axis represents the water volume in cubic feet, and the y-axis represents the water height in feet. In the GIRAFFE input file, the values for the curves are listed under the heading [CURVES] and an example is shown in Figure E.2(b). The values are listed following the Curve ID (in this case, “VF04”) with the first number representing the height of water in feet, and the second value representing water volume in cubic feet.

A user may also specify a minimum and maximum height of water (feet) or a minimum volume of water (cubic feet), and the level of the tank will vary within these boundaries. If the water height in a tank drops below the minimum level (the tank is empty), the outgoing pipe is automatically closed and no further water can exit the tank. Similarly, if the water height reaches the maximum level (the tank is full), the incoming pipe is closed and no further water can enter the tank.



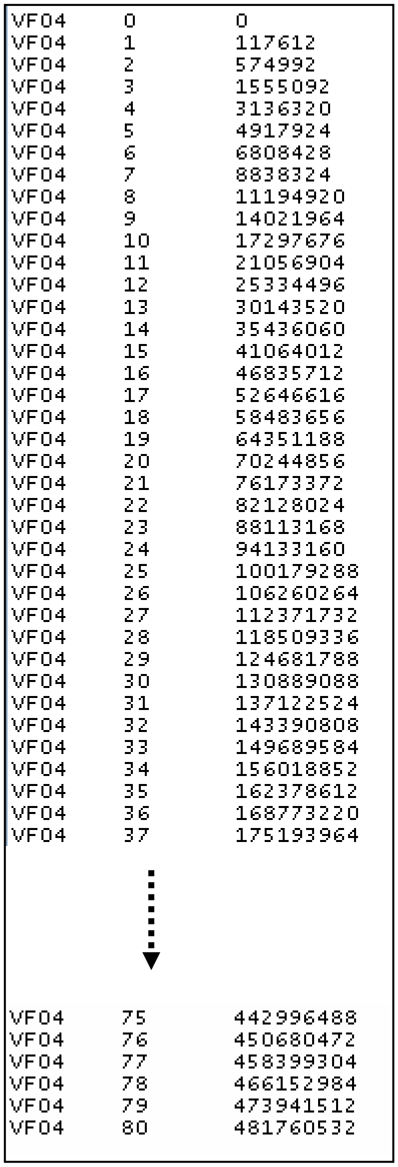
ID	Description
VF03	Moorpark PS Curve 3
VF04	Los Angeles Reservoir Depth Vol Curve
VF05	Mission Wells PS Curve 2
VF06	North Hollywood PS Pump Curve 2P1
VF07	North Hollywood PS Pump Curve 2P2
VF08	North Hollywood PS Pump Curve 3P1

	X	Y
1	0.00	0.00
2	117612.00	1.00
3	574992.00	2.00
4	1555092.00	3.00
5	3136320.00	4.00
6	4917924.00	5.00
7	6808428.00	6.00
8	8838324.00	7.00
9	11194920.00	8.00
10	14021964.00	9.00
11	17297676.00	10.00
12	21056904.00	11.00
13	25334496.00	12.00
14	30143520.00	13.00
15	35436060.00	14.00
16	41064012.00	15.00
17	46835712.00	16.00
18	52646616.00	17.00
19	58483656.00	18.00
20	64351188.00	19.00
21	70244856.00	20.00
22	76173372.00	21.00
23	82128024.00	22.00
24	88113168.00	23.00
25	94133160.00	24.00
26	100179288.00	25.00
27	106260264.00	26.00
28	112371732.00	27.00
29	118509336.00	28.00
30	124681788.00	29.00
31	130889088.00	30.00
32	137122524.00	31.00
33	143390808.00	32.00
34	149689584.00	33.00
35	156018852.00	34.00
36	162378612.00	35.00
37	168773220.00	36.00
38	175193964.00	37.00
39	181649556.00	38.00
40	188135640.00	39.00
41	194652216.00	40.00
42	201203640.00	41.00
43	207785556.00	42.00
44	214397964.00	43.00
45	221040864.00	44.00
46	227714256.00	45.00
47	234422496.00	46.00
48	241161228.00	47.00

Monday, August 20, 2007

Figure E.1(a). Variable Area Tank Curve for Los Angeles Reservoir in Autocad/H20Net.

Curve ID | **Water Height (ft)** | **Water Volume (cu. ft.)**



```
VF04     0        0
VF04     1        117612
VF04     2        574992
VF04     3        1555092
VF04     4        3136320
VF04     5        4917924
VF04     6        6808428
VF04     7        8838324
VF04     8        11194920
VF04     9        14021964
VF04     10       17297676
VF04     11       21056904
VF04     12       25334496
VF04     13       30143520
VF04     14       35436060
VF04     15       41064012
VF04     16       46835712
VF04     17       52646616
VF04     18       58483656
VF04     19       64351188
VF04     20       70244856
VF04     21       76173372
VF04     22       82128024
VF04     23       88113168
VF04     24       94133160
VF04     25       100179288
VF04     26       106260264
VF04     27       112371732
VF04     28       118509336
VF04     29       124681788
VF04     30       130889088
VF04     31       137122524
VF04     32       143390808
VF04     33       149689584
VF04     34       156018852
VF04     35       162378612
VF04     36       168773220
VF04     37       175193964

           ↓

VF04     75       442996488
VF04     76       450680472
VF04     77       458399304
VF04     78       466152984
VF04     79       473941512
VF04     80       481760532
```

Figure E.1(b). Variable Area Tank Curve for Los Angeles Reservoir in GIRAFFE input file.

E.3 SELECTION OF TIME STEP

The architecture of the GIRAFFE program makes the size of the simulation time step critical to obtaining accurate results. GIRAFFE assumes all demands and tank levels remain constant for the duration of the time step, and only updates these values at the start of the next time step. Thus, choosing a large time step may obscure some network subtleties that would otherwise be observed with a smaller time step.

Consider the simple network model shown in Figure E.2. Tank 1 is modeled as a Fixed Head Reservoir which means the level of water in the tank remains constant. Tank 2 is modeled as a Cylindrical Tank which allows the water level to vary dynamically. Tanks 1 and 2 are connected by a pipe with a check valve such that water can only flow from Tank 1 to Tank 2 (water will never flow from Tank 2 towards Tank 1).

At the start of a simulation, Tanks 1 and 2 have the same elevation head, thus no flow occurs between them for the first time step. As Tank 2 drains with time, the elevation head will drop below that of the Fixed Head Reservoir, Tank 1, and flow will be induced from Tank 1 to Tank 2. To illustrate the importance of time step selection, consider two 24-hour simulations for this network with different time step increments: time step of 6 hours, and time step of 1 hour. For the purposes of this example, assume Tank 2 starts with 4 million gallons of water, and supplies a demand of 56,000 gpm.

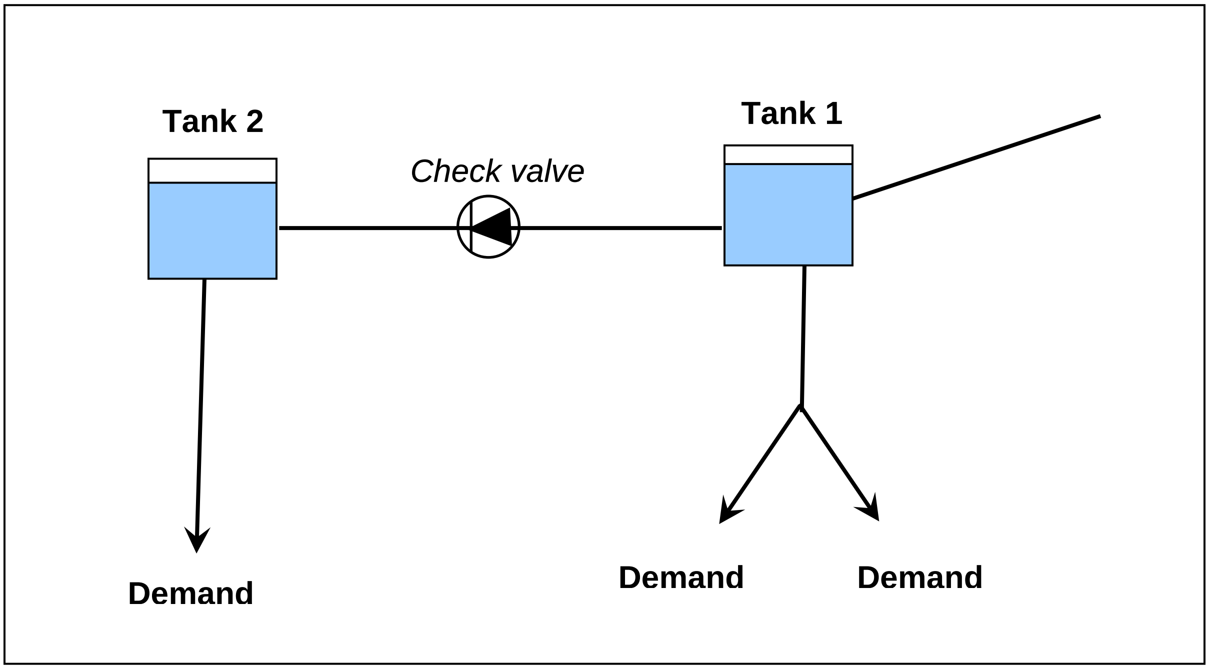


Figure E.2. Example Network Model.

24 Hour Simulation with 6 Hour Time Step

GIRAFFE assumes that all tank levels and demand values remain constant for the duration of a time step. To calculate how much water is lost from Tank 2 during the first 6 hour time step, GIRAFFE computes:

Tank Volume – [(Demand on tank) x (No. of Hours in Time Step)]
4 mil. Gal. – [(56,000gpm) x (6 hrs)] = -16,160,000 Gal.

Clearly, the tank cannot have a negative amount of water – the above computation shows that the tank goes dry during the 6 hour time step. The tank goes dry after only 71 minutes in this example, and as the GIRAFFE simulation continues negative pressure nodes develop around this dry tank as the demand remains at 56,000gpm and the tank and connection pipes are removed from the system.

24 Hour Simulation with 1 Hour Time Step

To calculate how much water is lost from Tank 2 during the first 1 hour time step, GIRAFFE computes:

Tank Volume – [(Demand on tank) x (No. of Hours in Time Step)]
4 mil. Gal. – [(56,000gpm) x (1 hrs)] = 640,000 Gal.

Tank 2 has lost 84% of its original volume, but has not been removed due to negative pressure occurrences as seen with the 6 hour time step example. At the end of this time step, GIRAFFE updates all tank levels and demand values. Since Tank 2 has drained it now sits at a lower elevation head than Tank 1, and in the next time step water will flow through the pipe connecting the two tanks and Tank 1 will be replenished and remain in-service for the duration of the next time step. Over the full 24 hours, this interaction continues and Tank 2 is continually replenished by Tank 1 and all demands remained satisfied.

This example illustrates how important time step selection can be. In large-scale modeling it is difficult to predict and catch where interactions such as these occur and the ramifications of not capturing these subtle types of network behavior can be widespread. It is recommended that the user always select the smallest possible time increment (1 hour) so as not to miss any important network interactions.