Integrating the ArcGIS Water Distribution Data Model into PipelineNet

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Abstract

A new version of PipelineNet has been developed that integrates the EPANET hydraulic model and ArcGIS. This integration also incorporates the ArcGIS water distribution data model to represent both the GIS pipe network and associated infrastructure. The data model has been extended to include operational hydraulic modeling input parameters (e.g., pump controls, water demands) so that a complete EPANET input file can be constructed from the data model components. PipelineNet simulates the flow and concentration of biological or chemical contaminants in a city or municipality's water distribution system from single and multiple sources, simulates water tracing and ageing, aids in the location of monitoring sites, provides tools for regulatory compliance and helps to evaluate contamination mitigation alternatives (e.g., system isolation or flushing). The integrated system calculates, locates, and maps the population and critical customers at risk from the introduction of contaminants to the public water supply.

Purpose

The purpose of this project was to upgrade PipelineNet to be compatible with new GIS technology. This was ensured by migrating the existing PipelineNet Application from an ESRI ArcView 3.x platform to an ESRI ArcGIS 9.0 platform. PipelineNet is a Windows stand-alone PC application that integrates hydraulic and water quality models from EPA's EPANET 2.0 with existing databases to give emergency managers real time information for estimating the risks to public water supplies.

The core components of PipelineNet include the ArcView GIS and the modeling engine EPANET. The ArcGIS 9.0 version of PipelineNet will retain the same functionality and modeling engine as the ArcView 3.x version. The new PipelineNet version uses the ArcGIS Water Utility Data Model to represent both the GIS pipe network and its corresponding hydraulic description. An enhanced agent database has also been incorporated into the new system.

Background

While the threat of terrorist attacks may not be a daily worry for water utilities, terrorist threats are of significant concern because of their potentially large public health and economic impacts. Conceivable terrorist threats to drinking water systems include the physical destruction of facilities or equipment, airborne release of hazardous chemicals stored onsite, sabotage of Supervisory Control and Data Acquisition (SCADA) and other computer systems, and the introduction of chemical, biological, or radiological contaminants into the water supply. Explosive and flammable agents that could cause physical destruction of facilities may be the most likely threats to drinking water systems because of the ease of obtaining the necessary equipment, the repeated past use of these agents as terrorists' weapons of choice, and the general ease of access to water facilities, such as storage tanks and pumping stations. However, purposeful contamination hazards may pose a more significant threat because they could result in major public health and economic impacts and long-lasting psychological impacts.

The EPA has responsibility for protecting public health by ensuring safe drinking water from critical ground and surface water infrastructures under Title IV of the Public Health Security and Bioterrorism Response Act of 2002 (PL 107-188). Under the Act, EPA is authorized to conduct research to prevent, detect, and respond to the intentional introduction of chemical, biological, or radiological contaminants into community water systems and source water for these systems. The PipelineNet model was developed to support and augment detection and response capabilities resulting from intentional contamination events in public water supply systems. PipelineNet is a Geographic Information System (GIS) - based software tool with integrated data base capability that can be used to model the flow and concentration of contaminants in a city's drinking water pipeline infrastructure. It contains a pipe network hydraulic model (Rossman, 2000), maps, and a US Census population database. PipelineNet was initially developed in support of security efforts for the 2002 Winter Olympic Games (Bahadur et al, 2001a).

The PipelineNet model simulates the flow and concentration of biological or chemical contaminants through the water distribution system (Bahadur et al, 2001b). The integrated model is a powerful tool for both routine planning and emergency response (see figure 1). It gives emergency managers real-time information in estimating risks to public water supplies and populations at risk. The model can calculate, locate, and map the population at risk from the introduction of contaminants to the public water supply.

The initial development of these models was begun by the Federal Emergency Management Agency (FEMA). FEMA's mission is to reduce the loss of life and property and protect our institutions from all hazards by supporting comprehensive risk-based emergency management

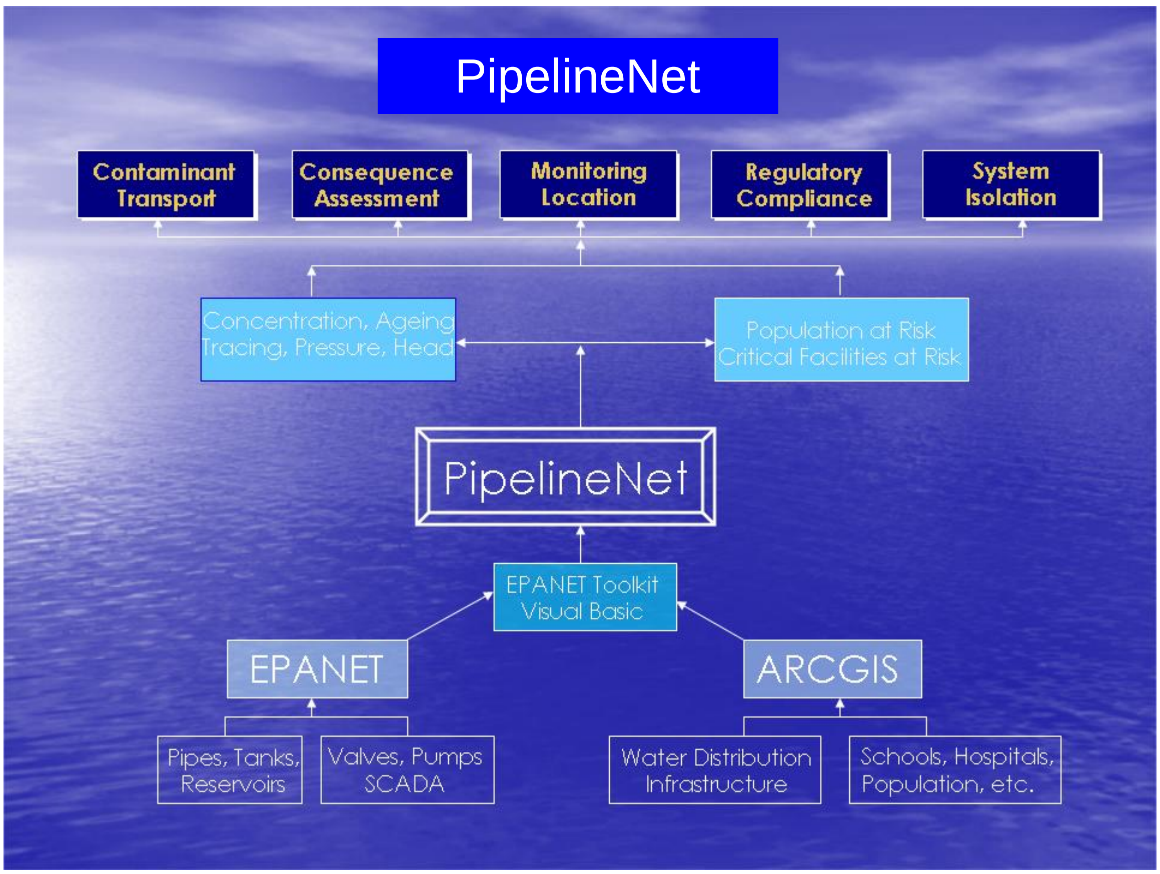

Figure 1. PipelineNet schematic diagram.

programs of mitigation, preparedness, response and recovery. Due to the complex nature of addressing natural and man-made disasters, EPA and FEMA are both involved in responding to the public and the environment in order to provide rapid and comprehensive emergency response.

Water utilities nationwide need special purpose hydraulic and water quality models to help prepare them to prevent contamination of drinking water distribution facilities as well as to respond to such events to help prevent or minimize the exposure of customers to harmful contaminants. These models were designed to help water utilities prepare for disruptions from terrorist events and naturally-occurring contamination events.

Automated Conversion of Hydraulic Model Input Data

PipelineNet – Arcview Version

PipelineNet being a GIS based system needs hydraulic model infrastructure data in ArcView shape file format. The hydraulic model infrastructure data contains nodes, tanks, reservoirs, pipes, pumps, and valves. PipelineNet operates from a GIS platform and needs all the input data in a GIS compatible format. PipelineNet has an import tool that will convert the EPANET input data file into ArcView shape files for PipelineNet (see figure 2). Junctions, tanks, reservoirs, pipes, pumps, and valves are six water distribution parameters needed for PipelineNet. PipelineNet automatically converts an EPANET text input file into ArcView shape file using the Create PipelineNet Spatial Database Network Tool.

All PipelineNet modeling operations require a suite of spatial GIS layers that represent the pipeline network (i.e. pipes and nodes) and a hydraulic model that characterizes the corresponding distribution piping system (Bahadur et al, 2003; Samuels et al, 2003). The GIS layers are illustrated as shapefiles and the hydraulic model is contained a standard EPANET text file. The “Pipe-Ids” and the “Node-Ids” link the GIS layers and the hydraulic model together. PipelineNet currently allows the user to automatically convert an exported EPANET text file into PipelineNet compatible pipeline and node networks. The resulting networks can be projected into any of the standard ESRI coordinate systems.

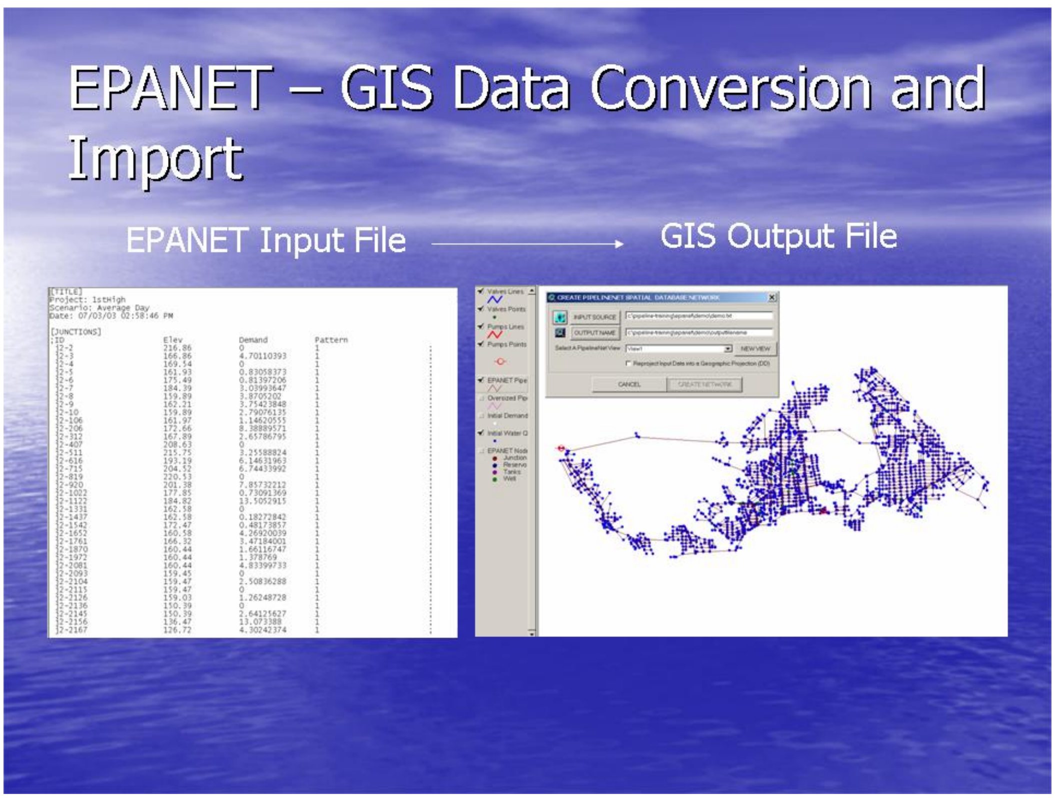

Figure 2. Conversion of EPANET input data file to GIS output for use in PipelineNet (Arcview version).

PipelineNet – GIS and Data Model Upgrade

Water Utility Data Model (Geodatabase)

Adapting PipelineNet to the ArcGIS Water Utility Data Model is one of the principal database modifications in this project (SAIC 2004). The data model replaces both the GIS shape files that currently represent the spatial network and the hydraulic model that characterizes the distribution piping system (see figure 3). The ArcGIS Water Utility Data Model is an established standard that includes an essential set of water object classes and properties and a set of rules and relationships that define object behaviors. Consequently, all the parameters required to run the analysis and spatially illustrate the network are included in a single model.

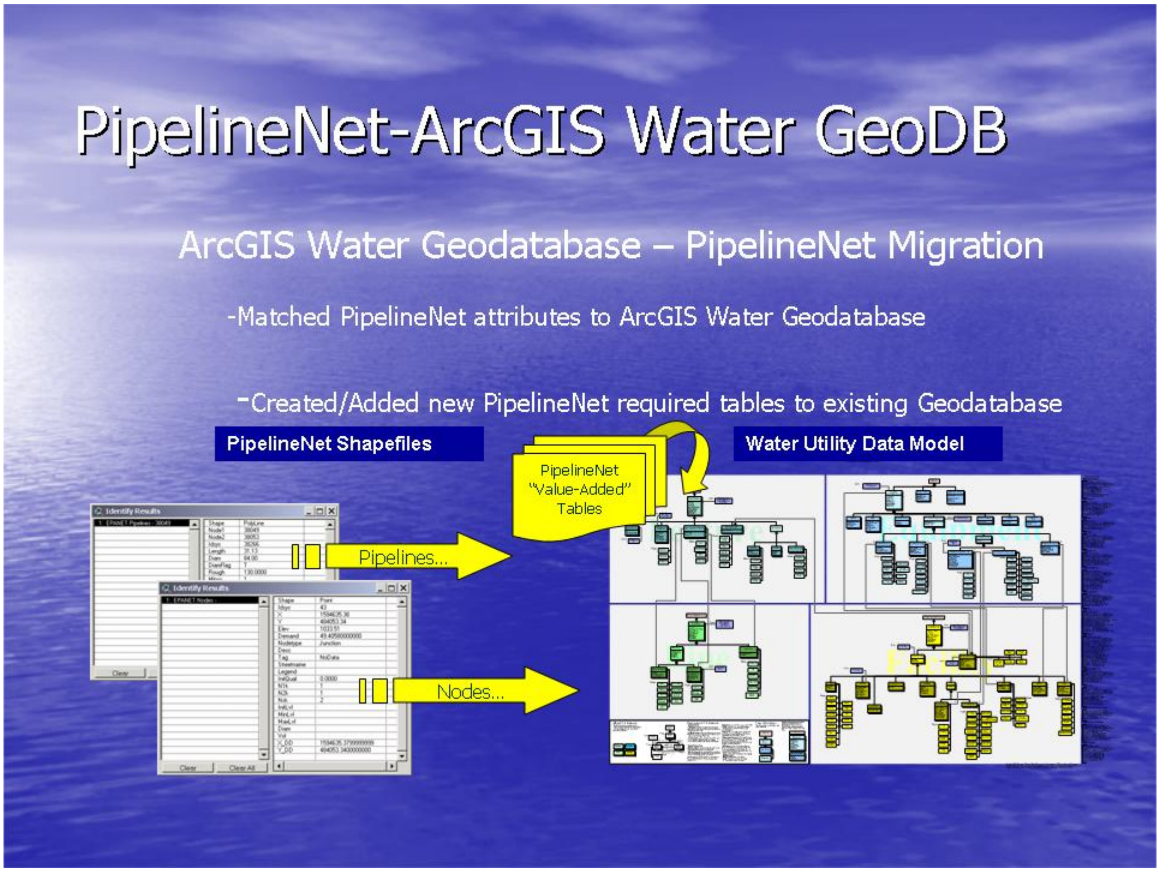

Figure 3. Conversion of PipelineNet shapefiles into the Water Utility Data Model.

The Water Utility Data Model (see figure 4) was extended to allow for storage of hydraulic modeling parameters required by EPANET. Basically for each section of the EPANET input file, a value added attribute table was created in the Water Utility Geodatabase to hold information for that section. EPANET models a water distribution system as a collection of links connected to nodes. The links represent pipes, pumps, and control valves. The nodes represent junctions, tanks, and reservoirs. Information associated with nodes and links includes: spatial and temporal changes in water demands, demand patterns, pump controls, valve status, pump curves, tanks, wells, etc. For example, junctions are points in the network where links join together and where water enters or leaves the network. The basic input data required for junctions are: (1) elevation above some reference (usually mean sea level), (2) water demand (rate of withdrawal from the network) and (3) initial water quality. The output results computed for junctions at all time periods of a simulation are: hydraulic head (internal energy per unit weight of fluid), pressure and water quality. Junctions can also: have their demand vary with time, have multiple categories of demands assigned to them, have negative demands indicating that water is entering the network, be water quality sources where constituents enter the network, and contain emitters (or sprinklers) which make the outflow rate depend on the pressure. This type of additional detailed information is accounted for in the value added attribute tables added to the Water Utility Data Model.

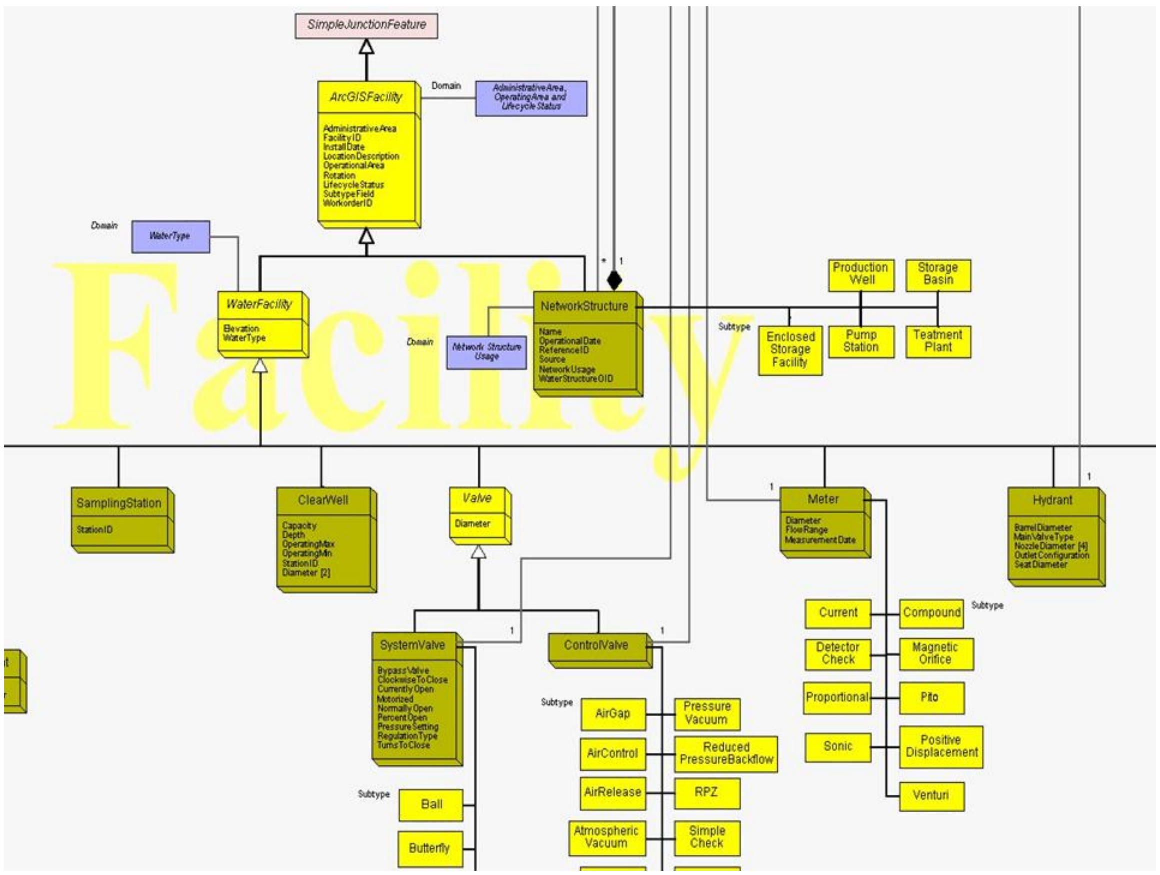

Figure 4. Portion of the Water Utility Data Model for facility information.

Conversion to ARCGIS

The conversion of PipelineNet from Arcview 3.x to ARCGIS (version 9) involved re-coding the Avenue scripts and dialogs using Visual Basic and ARCOBJECTS. The graphical user interface (GUI) and portrayal of a water distribution network in ARCGIS is shown in figure 5. The GUI is organized into a series of tabs which allow for data import and conversion, analysis (concentration, ageing, tracing, hydraulics, post processing (e.g., consequence assessment), running EPANET in stand-alone mode and help. An example of the water quality concentration function is shown in figure 6.

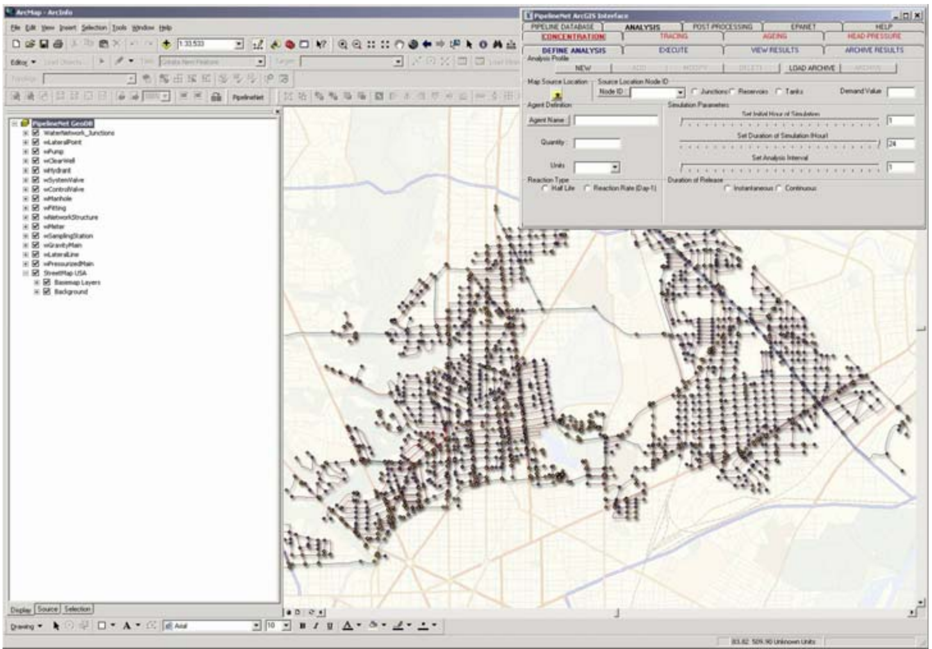

Figure 5. ARCGIS version of PipelineNet.

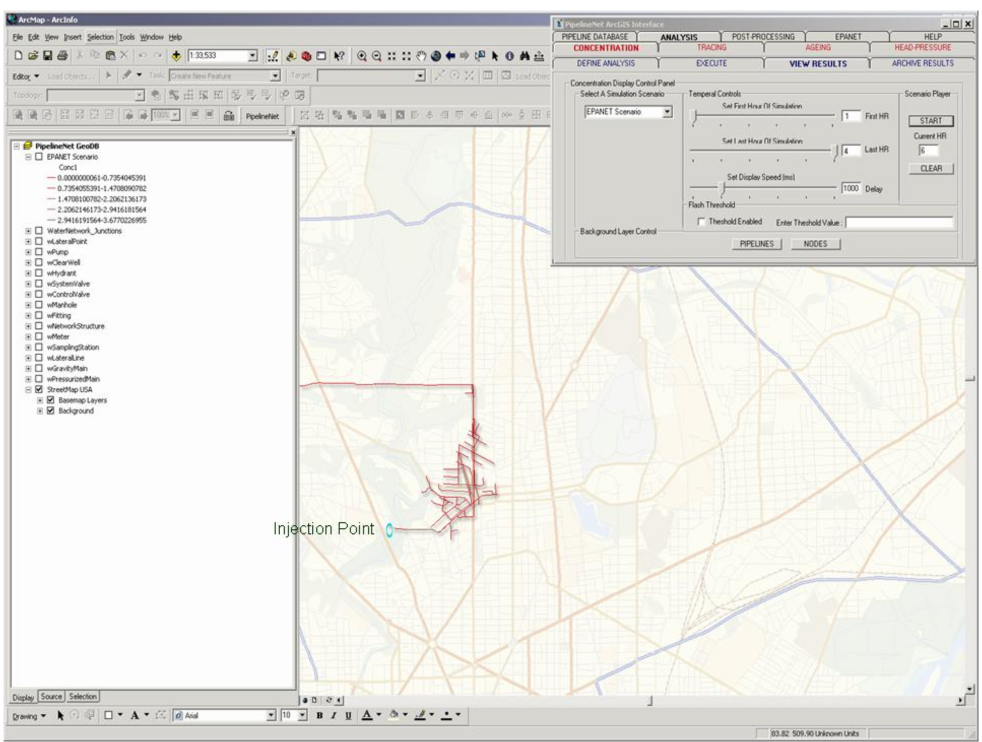

Figure 6. Example water quality simulation in PipelineNet.

Consequence assessment can be performed after running a water quality simulation to estimate the population and critical facilities (hospitals and schools) at risk (see figure 7). Additional layers and map background such as aerial photos and satellite images can be added to the view to enhance the output display.

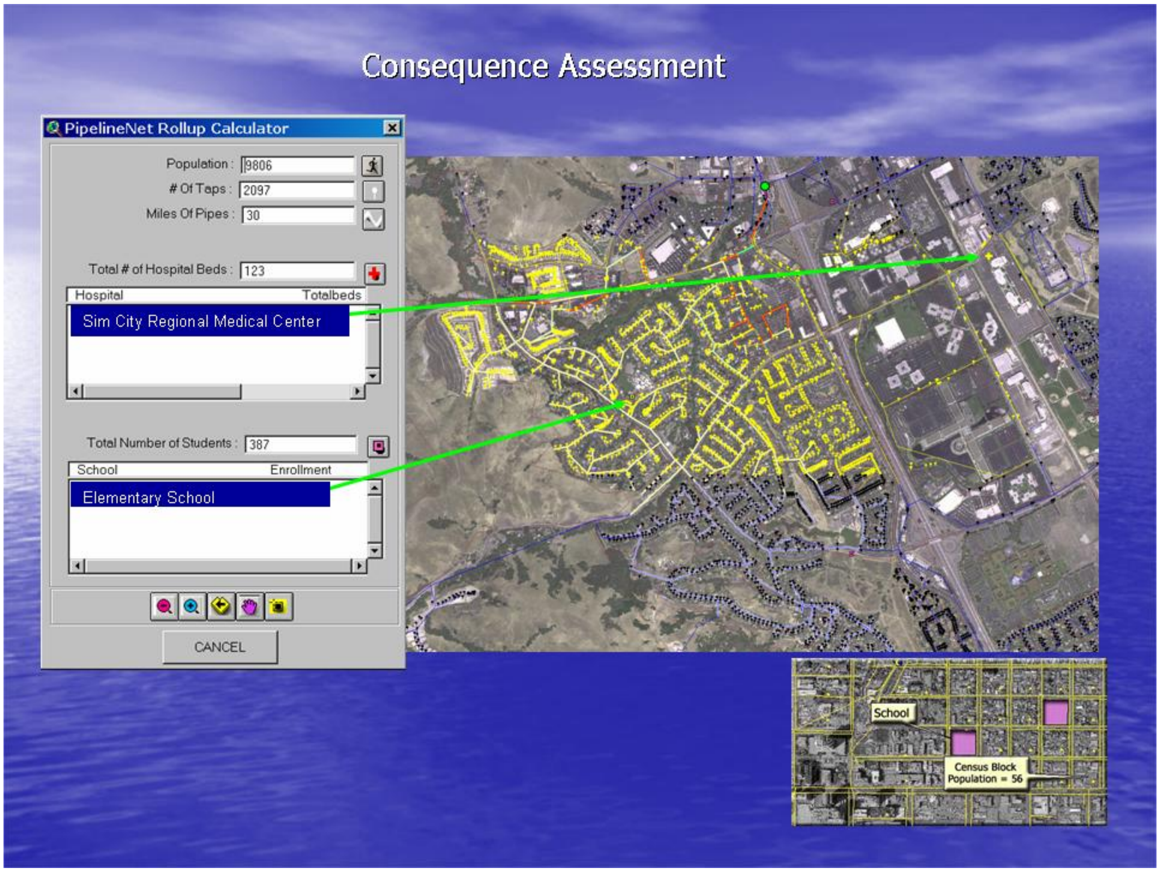

Figure 7. Consequence Assessment using PipelineNet.

Summary and Conclusion

As a result of this project, PipelineNet is an ARCGIS based system, which integrates hydraulic and water quality models with existing databases. PipelineNet integrates EPANET and ARCGIS to give emergency managers real time information estimating the risks to public water supplies. This integration gives PipelineNet all the computational (hydraulics and water quality) capabilities of EPANET and all the functionality of ARCGIS. The integrated system calculates, locates, and maps the population at risk from the introduction of contaminants to the public water supply. The model performs the following functions:

- Simulates the flow and concentration of biological or chemical contaminants in a city or municipality's water distribution system from single and multiple sources
- Simulates water tracing and water ageing
- Assesses the effects of water treatment on the contaminant.
- Helps planners with present and future predictions.

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References

Bahadur, R., Pickus, J., Amstutz, D, and Samuels, W., 2001. A GIS-based Water Distribution System for Salt Lake City, UT., Proceedings 21st Annual ESRI User Conference, July 9-13, 2001, San Diego, CA.

Bahadur, R., Samuels, W.B. and Grayman, W., 2001. EPANET-Arcview Integration for Emergency Response, Proceedings World Water and Environmental Resources Congress, ASCE, Orlando, FL, May 20-24, 2001

Bahadur, R., Samuels, W.B., Grayman, W., Amstutz, D. and Pickus, J., 2003, PipelineNet: A Model for Monitoring Introduced Contaminants in a Distribution System, Proceedings, World Water and Environmental Resources Congress, June 23-26, 2003, Philadelphia, PA

Rossman, L. A., 2000. EPANET 2 User's Manual. National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, OH 200p.

SAIC, 2004. PipelineNet Migration to ArcGIS, Software Requirements Specification, submitted to Technical Support Working Group (TSWG) by Science Applications International Corporation (SAIC) McLean, VA., 45p.

Samuels, W.B., Bahadur, R., Amstutz, D., and Pickus, J., 2003, PipelineNet: An Extended Period Simulation Hydraulic Model for Distribution System Emergency Response, Proceedings AWWA DSS: The Distribution & Plant Operations Conference and Exposition, September 28 – October 1, 2003, Portland, OR

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