5

GISRed 1.0, a GIS-based Tool for Water Distribution Models for Master Plans

Fernando Martínez and Hugo Bartolín

GISRed is a customized extension to ArcView® GIS3.2, oriented to modeling and calibration of water distribution networks, and which integrates all capabilities of the widely-used hydraulic modeling software EPANET 2.0. It basically includes a large set of hydraulic modeling tools, connections to the EPANET solver, and a hydraulic calibration module based on genetic algorithms.

Additionally, more advanced modules to carry out complex tasks such as topological analysis, demand allocation and elevation interpolation tools, have been developed to enhance the features offered by the EPANET 2.0 interface and the inner capabilities of the supporting GIS platform.

One of the most useful issues GISRed can help with, is in master planning. GISRed can simultaneously manage topological and structured data concerning the network elements and its properties, shape files containing auxiliary information and background layers. Information from the shape files and background can be imported to become part of the network; and, on the other hand, network information such as data or results can be queried to create new layers which can be symbolized to produce meaningful maps. In addition, results can be post-treated to create new information by using the spatial and geo-processing tools of the GIS platform. Finally GISRed can manage diverse scenarios in the same session to allow contrasting different results. This chapter focuses on the general procedure to be followed in order to develop a master plan based upon the authors' experience using the GISRed Extension.

Martínez Alzamora, F. and H. Bartolín. 2005. "GISRed 1.0, a GIS-based Tool for Water Distribution Models for Master Plans." *Journal of Water Management Modeling* R223-05. doi: 10.14796/JWMM.R223-05.
© CHI 2005 www.chijournal.org ISSN: 2292-6062 (Formerly in Effective Modeling of Urban Water Systems.
ISBN: 0-9736716-0-2)

5.1 About GISRed 1.0

GISRed 1.0 is essentially a tool to assist technicians in the task of modeling water distribution networks and supporting decision-making for planning tasks, all within a GIS environment.

GISRed has been developed as an extension to ESRI's ArcView GIS3.2 software that integrates the widely-used hydraulic modeling software EPANET2.0 along with all the original GIS functions of ArcView. This 'built-in' application was originally conceived to fulfill the drawbacks of the EPANET2.0 GUI in treating different sources of data such as CAD or shape files, in assigning some properties to the model components such as demands and elevations, in calibrating the network parameters to match the results with the field measurements, and in contrasting the results of different scenarios between them or against the background information. But instead of developing only assistance to carry out these features, the approach followed in developing GISRed has been first to reproduce the current features of the EPANET GUI under the ArcView environment, and then to add new capabilities.

Many problems had to be solved during the first stages of the GISRed development to emulate the capabilities of the EPANET GUI, because ArcView was conceived only as a GIS viewer. But using the Avenue language, tasks such as creating, and permanently updating, the topology of the network elements, or maintaining an inner Relational Database (RDB) to allocate all data of the model, have been successfully addressed. Describing the procedures implemented in GISRed is beyond the scope of this chapter, but some details can be found in Bartolín and Martínez (2001, 2003).

Currently in GISRed 1.0, some similar capabilities of the EPANET GUI have been improved e.g. editing tools offered to build the network layout or to manage patterns, however EPANET is still more powerful in browsing certain results.

This application has been developed at a University essentially using public funds, and intended to be used as freeware. This explains why the lower cost GIS, ArcView 3.2, was chosen as the only base software needed to run the extension

5.2 Model Building Process

The first step prior to developing a master plan is to build a network model. Typical steps for a modeler when using the GISRed Extension to build a water distribution model are:

1. Create the layout of the distribution network system either using the editing tools or importing spatial data from a CAD file, a shapefile or Epanet input file.
2. Check import errors (if necessary).
3. Edit the network properties.
4. Interpolate elevations.
5. Allocate demands.
6. Describe the system operation by means of demand patterns, pump curves, control rules, etc.
7. Select the analysis options.
8. Run a hydraulic/water quality analysis and view the results of the analysis.
9. Adjust some parameters of the network manually as a first approach, to match results with expected values.

Alternatively:

10. Calibrate the network automatically by defining a calibration configuration and using the GA calibration module.
11. Send the calibration results back to the model.
12. Perform a new simulation and analyze the results again.
13. If the results are good enough, stop the process, otherwise, proceed with the calibration.

5.3 Analysing Information and Importing the Network

Before developing a network model to proceed with the master plan, the technician has to analyze all the available information (spatial and alphanumeric data). In most cases, the typical format of the information source is a CAD file (dwg, dxf, dgn,...). The Extension allows importing a CAD drawing, which implies a specific interpretation of the information in its origin. The user must previously identify the CAD layer in which the network was drawn as shown in Figure 5.1.

When importing, the data are read, filtered, treated if necessary and stored in a relational database, configuring a new simulation scenario. During the process, the most remarkable point lies in simultaneously creating a link and a node theme, and generating a coherent topology for the network assuring the connectivity between pipes and nodes.

Figure 5.2 shows the result of capturing a network from CAD, keeping the blocks in the background. Nodes have been created automatically during the import and at the same time the inner topology is established.

Figure 5.1 Separation of the different layers before being imported by GISRed (from top to bottom: pipe network, mass elevation points, background and auxiliary features).

5.4 Editing the Network Layout and Properties

A series of advanced editing tools were developed, grouped in different tool bars that are directly dependent upon the current active Theme. These tools allow one to model network elements and make changes on the network layout when detecting errors or inconsistencies. One of the most valuable tools after importing spatial data is the connectivity validation tool, which detects unconnected parts of the network generated as a consequence of importing a CAD drawing inaccurately digitized as shown in Figure 5.3.

Among the layout editing tools, the link tool bar allows one to add/remove pipes to/from the model, edit and modify vertices and draw pipes by coordinates, while the node tool bar allows one to add junctions, pumps, valves, reservoirs and tanks, move nodes (and consequently all those pipes connected to the node), connect pipes to a node, make 'T' connections and delete nodes (merging the corresponding two pipes into one if possible). All these operations are done while maintaining the topology and connectivity of the network. There are also tools to edit auxiliary pipe/device Themes (non modeling oriented), which work in a similar way, but without considering the

topology, as well as tools to work with catalog images and to generate street address Themes.

Figure 5.2 A water distribution network model captured from CAD.

Figure 5.3 The magnifying window browses for the detected connectivity errors after the capture, saved in an Error Theme.

Even though most network properties are imported, others are set by default through a specific defaults dialog. It is likely that some features may be missing or undefined at the time of the import process, so a series of dialogs enable one to enter the hydraulic/quality properties of all the elements present in the model. There is a specific dialog for each kind of network element and also a dialog to assign properties by groups. Other dialogs for the non-physical elements comprise curve and pattern editors, control rules dialogs, analysis options, etc as shown in Figure 5.4.

5.5 Loading Demands and Assigning Elevations

Demand allocation is usually one of the most important and critical tasks when modeling a network, to such an extent that a reliable allocation can make a big difference in terms of hydraulic behavior.

For most projects, the model loading is based on the water company's billing records grouped by streets or blocks, which is normally the information that water utilities provide. Thus one of the approaches is to equally distribute the total consumption of each street to the closest nodes. The unaccounted-for-water is next added proportionally to demands as shown in Figure 5.5. Other demand allocation methods for point or district demands based on spatial queries have been also foreseen.

On the other hand, the elevation of a junction is always a required property for a hydraulic model. Even though node elevations do not have any influence in the flow distribution, they are used to compute pressure at the junction, and are a basic parameter for reliable results.

Node elevations can be assigned manually or interpolated using an implemented IDW method. If Spatial Analyst extension is available, the alternative is to use a GRID generated from a theme of scattered points as shown in Figure 5.6.

5.6 Running a Hydraulic and Quality Simulation

Once all data model are defined, they can be exported as an INPUT file of EPANET to be run. All data models considered by EPANET, including those concerning quality models, can be declared from the GISRed interface. Alternatively, another benefit of the total integration is the possibility of running the final network model by clicking a button. Again, GISRed offers some capabilities to analyze and view the results as shown in Figure 5.7.

These can be matched against the background themes such as streets and building blocks to evaluate the impact on the quality of service for the final customer. Also results can be exported to other Views in order to be post-treated like creating contour maps.

Figure 5.4 GISRed property dialogs for the non-physical elements.

Figure 5.5 The GISRed demand manager. On back, allocation of the street demands to the closest nodes.

Figure 5.6 Using a GRID theme to interpolate the node elevations.

5.7 Calibrating the Model

A water distribution model, in order to be reliable, must be calibrated, i.e. the model must be capable of accurately predicting flow and pressure conditions within any point of the system. Determining the physical and operational characteristics of an existing system is not easy. Usually, because few field measurements are available, a trial and error process has to be performed to adjust different parameters (pipe roughness, valve settings, node elevations, base demands, etc.) until a reasonable match between measured and computed pressures and flows in the model is achieved.

Figure 5.7 Analyzing the results of Net3 from the EPANET interface or from the GISRed interface.

GISRed offers a module to fine-tune some of the network parameters using an advanced search technique as shown in Figure 5.8. This module is based on a Genetic Algorithm developed by the Centre for Water Systems of the University of Exeter.

Figure 5.8 Definition of the GIS parameters for the Automatic Calibration of the strategic model of Valencia (5.000 nodes).

5.8 Proposing New Scenarios

Based upon the performance of the model, GISRed offer facilities to build new scenarios proposed for short and long term, taking into account the future variation of the population and the new expanding areas. The new demand conditions can lead to the installation of new, or the replacement of old, pipes and the creation of new loops on the original network to satisfy future situations. Every alternative must be planned and simulated to check the feasibility of the approach and support the action strategies as shown in Figure 5.9. With this aim a project can be cloned before introducing the changes to build the new scenario, by managing different scenarios in the same ArcView session

pressure, according to local regulations or standards. If this is not accomplished, new diameters should be tested until the demand and pressure requirements are met as shown in Figure 5.10.

Figure 5.10 Critical area in terms of pressure in case of fire.

5.10 Additional Proposals

Sometimes, in some projects the engineer must deal with particular issues such as the evaluation of leakage throughout the network, the consumption within an area, the reliability of the system or the quality standard compliance for certain regions or critical zones. In such cases, a network sectoring appears to be the best option to put into practice. This is based upon the division of the main network in smaller subsystems in which the inflows/outflows are perfectly identified, so that the analysis and assessment of the whole system turns out to be more effective.

GISRed allows the user to undertake a sectoring plan using overlapping a polygon theme of sectors in conjunction with a point theme of shutoff valves. Once the sectors are defined, the strategy to tackle is the expert's decision as shown in Figure 5.11.

Figure 5.11 Sectoring a network to control water losses.

Taking advantage of all the capabilities offered by the extension, such as importing other geo-referenced networks, it is possible to simulate for instance a connection between two real independent water networks, so as to pass on higher quality water from one network to another. That proposal arose in a real case, and the question was to check the pumped flow and the impact in terms of pressure on both networks. After setting a new simulation scenario with the two networks connected by a new water main, it was confirmed that the solution was infeasible due to the characteristics of the current pumping station.

5.11 Conclusions

The capabilities of a GIS can be extended beyond that of maintaining utility records into the area of planning and managing.

Since computer models are in common use to simulate the reality before decision taking, the use of ArcView® GIS 3.2 along with the additional functionality given by a customized extension GISRed 1.0 oriented to water

distribution network modeling, supposes a major advance in terms of analysis, assessment and maintenance of the main assets of a water utility company.

GISRed integrates tools which assist on the evaluation of the system's performance. In fact, the extension has been applied in many master plan projects, from large cities such as Valencia (up to 26,000 nodes) to medium-sized urban areas, to diagnose the state and performance of water network systems, so that many alternatives could be studied before taking any real action on the system.

5.12 Downloads

A ready-to-use reduced version of GISRed 1.0 can be downloaded from www.redhisp.upv.es/software/gisred, along with a full manual, some tutorials and several examples, all in both English and Spanish.

This version is public domain and allows the user to use most of the tools described in this chapter to build a water network model and analyze further scenarios, without limits of the network size. But some advanced tools such as the error checker, the navigator to repair errors after importing data, the demand manager and the demand allocation or the automatic GA calibrator are not available for public use yet. We hope to offer soon - free - all the capabilities of this powerful extension

Acknowledgments

GISRed has been mainly financially supported by the CICYT Commission of the Spanish Ministry of Science and Education, project CALNET REN2000-0380-P4-03, and by the Polytechnic University of Valencia through a research grant from the second author. We also want to thank the initiative and contribution of Aguas de Valencia Water Company for the project.

References

- Bartolín, H., Martínez, F. (2003). "GISRed v1.0. Water Distribution Model Builder Extension. User's Manual". Distributed on the internet.
http://www.redhisp.upv.es/software/descargas/gisred/GISRed_UsersManual.pdf
- Bartolín, H., Martínez, F. (2003). "Modeling and Calibration of WDS. A New GIS Approach". 23rd Annual ESRI Int. User Conference. San Diego (USA).
<http://gis.esri.com/library/userconf/proc03/p0126.pdf>

- Bartolín, H., Martínez, F., Monterde, N. (2001). "Connecting ArcView 3.2 to EPANET 2. A full environment to manage WDS using models". CCWI 2001. De Montfort Univ., Leicester, UK.
- Macke, S. (2001-2004). "DC Water Design Extension". Dorsch Consult. .
<http://dcwaterdesign.sourceforge.net>
- Ramirez, A. (1997). "Interfacing potable water hydraulic models with ArcInfo and ArcView data sets: From start to finish". 27th ESRI Int. User Conference. San Diego (USA) <http://gis.esri.com/library/userconf/proc97/proc97/abstract/a454.htm>
- Rossman, L. (2000), "Epanet 2 User's Manual". USEPA. Cincinnati, USA.
- Environmental Systems Research Institute, Inc. (ESRI, 1996). "Using ArcView GIS" "Using Avenue", "ArcView Spatial Analyst". Redlands, (USA)
- Tabesh, M., Delavar, M.R. (2003). "Application of integrated GIS and hydraulic models for unaccounted for water studies in water distribution systems". Advances in Water supply Management. London (UK)