Application of GIS in the Hydraulic Analysis of Water Distribution System

By Juned Laiq Syed
St.ID: 210239

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Instructor: Dr. Baqer M. Al-Ramadan

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Abstract

Many powerful computer application packages have been developed for the analysis and design of water distribution systems. They can model large water distribution system networks consisting of hundreds of pipes. They are capable of analyzing the out put data that is mainly the pressures and flow demands at the junctions of pipe network. It is observed that most of the commercial computer application packages used to model the water distribution network present the output data in the form of tables that is not conducive to visualize. To aid in analyzing output data produced by the modeling of water distribution system, use of Geographic Information System (GIS) is used in this study to present data in the tabular and graphical form. A water distribution system is modeled using WaterCAD and GIS is applied in this case by using ArcView GIS 3.2a.

APPENDIX A
Hydraulic Analysis by WaterCAD

APPENDIX B

AutoCAD drawing of water distribution system

APPENDIX C
Layout by ArcView GIS

1. Introduction:

Water-distribution design is a multifarious task involving numerous interrelated factors requiring careful consideration in the design process. Municipal water-distribution networks consist of multiple loops with pipe flows governed by non-linear equations, and hydraulic devices such as pumps, pressure reducing valves, and storage tanks with complex design characteristics. Important design parameters include water usage and demand, minimum pressure requirements, topography, system reliability, economics, piping, pumping, and energy use. All of these factors require an extensive database that must be stored and managed efficiently.

Optimal design of water -distribution system is challenging due to the need for joint consideration of cost-effectiveness and reliability. Extensive systems are needed to deliver water to individual consumers in adequate flow quantities and pressures under low risk of failure.

The complexity of the optimal layout and design problem is underscored by different factors such as the discrete characteristics of the decision variables (i.e., commercially available pipe sizes); complex, discrete cost functions involving material, labor and geographically based costs related to layout and excavation; the need for multiple demand loading patterns to be considered in the design; and requirement for a priori knowledge of both pipe flows and pressures for calculation of energy costs in systems requiring pumping (Gessler 1982).

In the analysis and design of water distribution system, water demands at different locations of the water distribution system are determined on the actual water demand needs of that location, which usually vary according to the area requirement. There are several commercial softwares that are available in the market for the "hydraulic analysis" of water distribution system like EPANET[1] , WaterCAD[2] etc. These sofwares model water distribution system and on the basis of water demands, pipe characteristics, demand patterns they determine the pressures at the nodes and flows in the pipes, and water levels in tanks and reservoirs. In short, we can say that they determine the hydraulic characteristics of the water distribution system.

The analysis of data generated by performing the "hydraulic analysis" of water distribution system can be used to analyze whether the water demands are met at all the junction locations of the area under consideration. It can be used to check the minimum pressure demands at the junctions, and also to check the flows in the pipes.

Hydraulic analysis of the water distribution system is mostly performed for twenty four (24) hours duration with an interval of one (1) hour. This means that a hydraulic analysis software like WaterCAD generates results of hydraulic analysis for twenty four (24) hours with an interval of one (1) hour. Therefore, enormous and huge data is generated after performing the hydraulic analysis of water distribution system for 24 hours, which is the standard duration. Although, hydraulic simulation softwares have some options for manipulating the huge generated data but it is difficult to manipulate them when the water distribution network is very large.

A package such as WaterCAD has an option for exporting the graphics and data files to a GIS package such as ArcView so that Geographic Information System (GIS) tools can be applied to the modeled water distribution system. WaterCAD is presently the only available software that has compatibility with GIS packages such as ArcView[3] GIS.

Geographic Information System (GIS) are general-purpose systems to manage spatial information. They are similar to commercial database management systems except for their strong spatial context. Due to this fact, Geographic Information System (GIS) are presently employed everywhere in the world in almost all fields of engineering e.g. electrical engineering, civil engineering, urban engineering etc. In civil engineering, it is widely used in transportation planning and management, and water resources planning and management, which mainly include watershed management.

[1] Product of National Risk Management Research, U.S. Environmental Protection Agency (USEPA) (website: www.epa.gov)
[2] Student Edition, Product of Haestad Methods, Inc USA (website: www.haestad.com)
[3] Version 3.2A, Product of Environmental Systems Research Institute , Inc (ESRI), USA (www.esri.com)

2. Problem Statement and Objectives

The output data produced by the hydraulic analysis and design of water distribution system is huge and enormous. Most of the modeling packages such as WaterCAD and EPANET produce output data in the form of tables. These packages have some tools to present the data graphically but it becomes very cumbersome and difficult when the water distribution system is very large such as the water distribution system of a city.

Geographic Information Systems (GIS) are very effective tools in manipulating the huge spatial and attributes data. Such systems are needed to aid WaterCAD for improved spatial and attributes representation and WaterCAD results.

The results of modeling performed by the commercial packages available for hydraulic analysis such as EPANET and WaterCAD produce output data in tabular form. This data must be presented both in graphical and tabular form otherwise it is very difficult to visualize the data.

4. Review of Literature

In order to analyze and design of water distribution a wide variety of techniques have been proposed since the mid 1970s. Walski (1985), Walter (1988), and Goulter (1982) have provided extended reviews of the most relevant and promising techniques for the optimal design of water distribution system. Alperovits and Shamir (1977) suggested the linear programming gradient (LPG) method, which performs a hierarchical decomposition on the optimization problems. Lansey and Mays (1989) coupled the generalized reduced gradient algorithm with an existing water distribution simulation model to optimally size the pipe network, pump stations and tanks.

Morgan and Goulter (1985) linked a Hardy-Cross network solver with linear programming to optimize both layout and design of new systems and expansion of existing systems.

Rosser and McBrien (1994) performed hydraulics analysis of water-distribution system of district Vail, Colorado, USA and emphasized on friction factors of pipes, losses, and control valve characteristics.

Taher and Labadie (1996) proposed that the desirable simulation and optimization techniques needed for optimum pipe network design should be incorporated within the framework of a decision support system (DSS). Effective pipe network design requires the availability of user- friendly decision support systems that are reasonably flexible in handling the large amount of design data needed, including constraints the design engineer would like to impose; and that utilize optimization techniques that allow incorporation of as much problem realism as possible.

These requirements suggest the need for an efficient data management and analysis tool such as Geographic Information System (GIS). Without GIS, required system parameters are often generalized to typical values prior to use. Spatial details on pipe connections, such as installation cost, are often reduced to a single value expressing average tendency over a group of connections, which may introduce significant error. GIS provides functions for development and preparation of accurate spatial information for input to network design optimization models. It also facilitates postoptimization spatial analysis and graphical output display for evaluating results. Given the time and spatial variability of parameters such as water-distribution network layout, street layout, pipe characteristics and cost, pressure requirements, and demand patterns, the GIS can perform cost analysis, network routing, and allocation, and provide effective color graphic display of results.

Zick (1991) linked Geo/SQL GIS and AutoCAD with the water -distribution system analyzer WADISO (Walski et al. 1990) to provide users immediate feedback on impacts of proposed changes on water –distribution networks. Moutal et al. (1992) report on an extensive water main mapping project for New York City involving 9,600 KM of pipes, 180,000 valves, and 99,000 fire hydrants entered into a GIS database. The GIS is designed to assist in water-distribution network planning, design, maintenance and management.

Shamsi (2002) proposed different GIS tools for water, wastewater, and stormwater systems. Bryant, Carper, and Nicholson (2001) proposed different GIS tools for proactive urban watershed management. Martinez and Garcia (1999) presented simplification of detailed models of water distribution systems obtained from GIS systems. Jacobs and Goulter (1993) developed an approach for calculating the reliability analysis of the water-distribution system of the city of Winnipeg, Canada. They used a digitized street map in combination with the computerized base derived from records of pipe leaks that occurred in the period 1975-89.Karamouz (1991) proposed application of GIS in monitoring and trouble shooting of water distribution systems. Moutal and Bowen (1991) applied GIS in updating New York City’s sewer and water main distribution systems.

Xu (2001) presented the integration of a physically- based distributed model with a geographic information system (GIS) in water-shed based water resources management. He first processed data by GIS and then simulated important hydrological processes including evapotranspiration, snowmelt, infiltration, aquifer recharge, ground water flow, and overland and channel runoff. Finally, he displayed modeled result using GIS.

Denes and Hanson (1997) used GIS to perform benefit/cost analyses for water resources projects. Leipnik and Kemp (1993) proposed that GIS process starts with the initial decision to use GIS; proceeds through system selection, installation and training; and upto data-base development and product generation. They focused on different aspects of GIS pertinent to water-resources planning and management.

Weghorst and Cavender (1992) emphasized on information management in water resources i.e database and GIS integration.Mercado (1991) proposed GIS and remote sensing as a guide for parameter development in water resources and environmental modeling. Stafford (1991) proposed different civil engineering applications of remote sensing and GIS. Kruzich (1991) used GIS for better management of water resources in Texas, USA.

Klesch and McKim (1989) applied GIS to the water resources development program of the U.S Army Corps of Engineers. Wright (1989) explained the role of Raster-based GIS technology in water resources planning and research. Berich (1985) developed a micro-computer GIS for water resources planning.

5. Study Area

The modeling is performed on the water distribution system of hypothetical area. This water distribution system model area has been taken from sample example of the hydraulic modeling software WaterCAD. This is a hypothetical area whose details are not provided but it belongs to a small town of Unites States of America (USA) with a lake. The AutoCAD 2000 drawing of the modeled hypothetical area is attached (Appendix B).

6. Data

The map/drawing is obtained from the sample example of the hydraulic simulation software WaterCAD, which is transferred to AutoCAD 2000[4] to see the details of the drawing such as layers which give some details of the hypothetical area.

The water distribution system of the modeled hypothetical area consist of nine pipes, seven junctions, one reservoir and one pump. The input parameters needed by WaterCAD for performing hydraulic simulation are pipe characteristics, pipe lengths, junction water demands, junction and reservoir elevations and pump characteristics. The default input data is used to perform the hydraulic simulation in WaterCAD.

After performing the hydraulic simulation for a particular time period such as twenty four hours (one day), WaterCAD produce output data (results) such as pipe water flows , junction water pressures, changes in reservoir elevations during the twenty four hours with an interval of one hour. The full details of analysis performed by WaterCAD is attached (Appendix A).

[4] Product of Autodesk, Inc. USA

7. Tools of Study

The following tools are used for applying GIS in the hydraulic analysis of water distribution system.

1 AutoCAD 2000 is used to see the details of the drawing that is imported in AutoCAD 2000 from WaterCAD. It is widely used commercial software for drawing the maps. The layers concept is also applied in AutoCAD 2000, which is similar to that of ArcView GIS 3.2a.

2 WaterCAD is used for the hydraulic analysis of the water distribution system. WaterCAD was designed, developed and programmed by Haestad Methods Inc. (USA) staff of Software Engineers and Civil Engineers. This program is intended to represent the state of-the-art for stand alone, Windows based, Water Distribution Analysis and Design. WaterCAD has an option of converting the WaterCAD files (extension .wcd files) into shape files, which can de imported into ArcView GIS 3.2a to make themes. There are also several other commercial computer packages for hydraulic simulation such as EPANET , but they are not compatible with GIS packages.

3 Microsoft Excel 2000, a product of Microsoft Corporation, is used to convert datafiles exported from WaterCAD into database files. There are different options of converting MS Excel files into different file formats such as database files, text files (tab delimited), which are acceptable to ArcView GIS 3.2a.

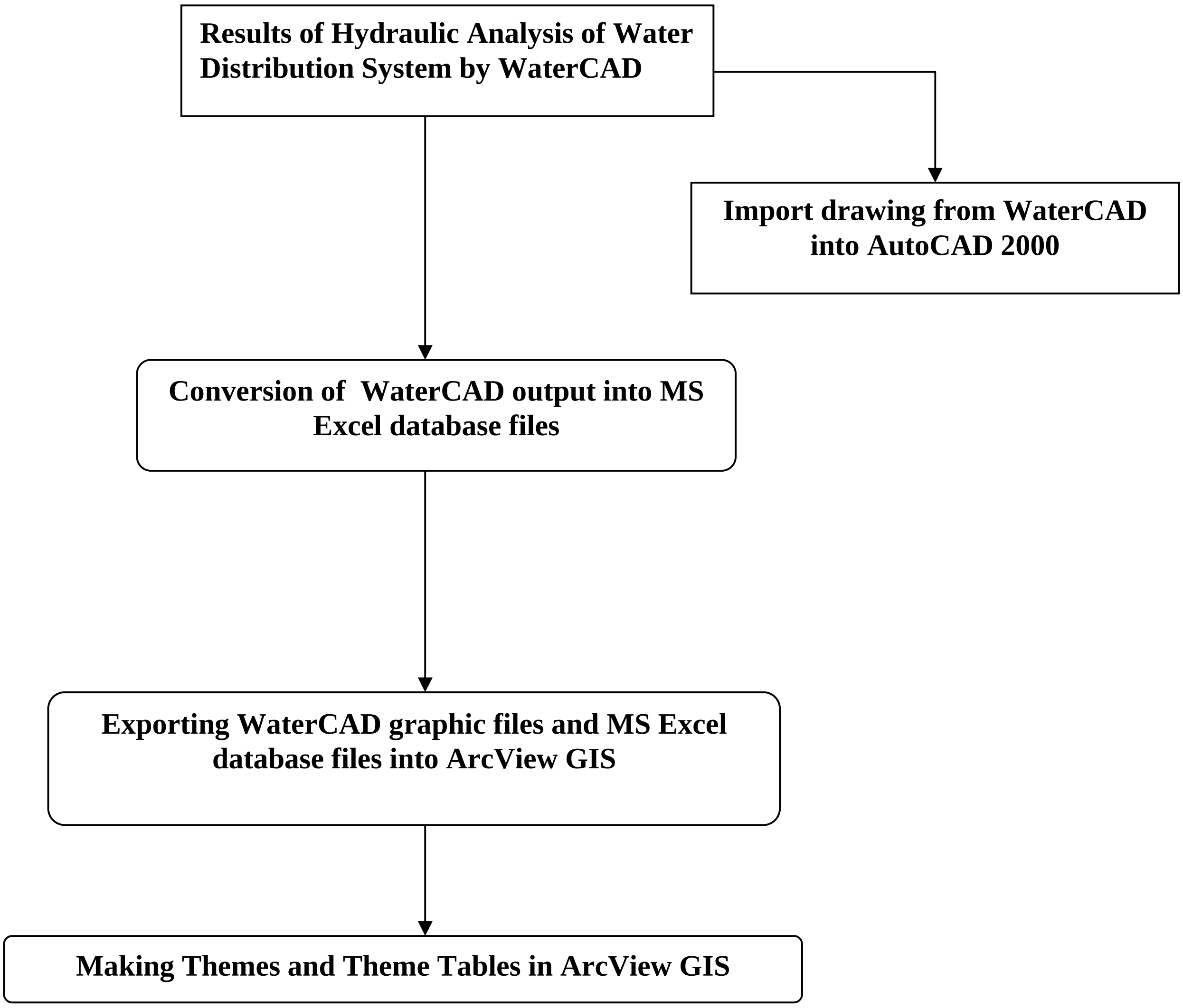
4 ArcView GIS 3.2a, a product of ESRI (USA) is used to manipulate huge data generated after performing the hydraulic analysis of water distribution system. It is compatible with WaterCAD and shape files from WaterCAD can be imported into it.

8. Methodology of Study

The extended period hydraulic analysis of hypothetical water distribution system is performed for the standard duration of twenty-four hours by using WaterCAD. WaterCAD drawing of the hypothetical water distribution system is exported to AutoCAD 2000 to see the details of the drawing. The results of the hydraulic analysis produced by WaterCAD such as pressures at the junctions, water flows in the pipes, reservoir water levels are exported and converted into database files using MS Excel 2000. Graphics (dxf) files and database files are exported from WaterCAD and MS Excel 2000 into software ArcView GIS 3.2a. Different themes are made in ArcView GIS (Appendix C) and the detailed results of the hydraulic analysis are presented both in tabular and graphical forms (see flowchart).

The output data of modeling is converted into tabular and graphical form by using GIS package ArcView GIS so that available tools of ArcView GIS can be applied for analyzing the output data obtained by modeling the water distribution system.

The results of modeling performed by package WaterCAD are viewed and analyzed using available GIS package ArcView so that the time of analysis can be reduced and more accuracy can be achieved .



Flow Chart of Methodolgy

9. Conclusions and Recommendations

By performing this study, it is concluded that ArcView GIS can effectively be used to graph and tabulate huge data generated by performing the hydraulic analysis of water distribution system. Presently, hydraulic simulation software WaterCAD is the only commercially available software which can be incorporated with ArcView GIS, therefore if the model distribution network is very large then WaterCAD results can be easily handled and managed using ArcView GIS.

It is recommended that ArcView GIS be used to analyze and graphically present the large water distribution networks as otherwise it will be very difficult and cumbersome to handle such huge data. It is recommended to carry out more modifications in WaterCAD regarding the export of data from WaterCAD into ArcView GIS as it is observed that ArcView GIS was unable to import generated data directly from WaterCAD, but it has to be first transferred to MS Excel for converting data into database files and then exported to ArcView GIS.

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