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GEOGRAPHIC INFORMATION SYSTEMS APPLICATIONS IN WATER NETWORKS - ALEXANDRIA NETWORK CASE STUDY

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الملخص:

تعتبر نظم المعلومات الجغرافية (GIS) انها إحدي أقوى تقنيات المعلومات و ذلك لانها تعتمد على دمج المعرفة من مصادر متعددة و خلق بيئةشاملة للتعاون .نظم المعلومات الجغرافية هي نظام لإدارة وتحليل وعرض المعرفة الجغرافية ، ويتم تمثيلها باستخدام سلسلة من مجموعات المعلومات. و يهدف هذا البحث الي استخدام نظم المعلومات في تصميم شبكات توزيع المياه و إدارتها ،بالاضافة الى شرح بعض التطبيقات المستحدثه لادارة الشبكه ؛ مثل تحديد المحابس المراد إغلاقها في حالة وجود كسر بالشبكه، و تحديد مناطق خدمة محطات تنقية مياه الشرب ، و اعادة هيكله شبكات المياه فى التخليل الهيدروليكي و ذلك بالاضافه الي استخدام نظم المعلومات الجغرافية لتوفير عرض رسومي للنتائج التي تم الحصول عليها من نماذج المحاكاة الهيدروليكية و ربط النتائج المستخرجة من النمذجه الهيدروليكيه بالمواقع وقد أظهرت التطبيقات كفاءه فى الاستخدام مقارنه بالوضع فى الطبيعه عند المقارنه.

كلمات مفتاحية: نظم المعلومات الجغرافيه، الشبكة الهندسيه، شبكات توزيع المياه

Abstract:

Subsurface Many have characterized Geographic Information Systems (GIS) as one of the most powerful of all information technologies because it focuses on integrating knowledge from multiple sources and creates a crosscutting environment for collaboration. GIS is a system for the management, analysis, and display of geographic knowledge, and represented using a series of information sets.

In the present paper, GIS will be used to organize the data for usage in water distribution networks design, and analysis. In addition, GIS as a tool for number of created applications for network management; such as identifying valves to be closed in case of pipe break, service area for treatment plants, and network skeletonization. Finally, GIS is used to provide graphical display of results obtained from both hydraulic simulation, and

optimization models; linking tabular data with geographic locations, and graphical drawing. Indeed, these applications shown efficiency while implementation in real life.

1. Introduction

One of the main challenges facing its sustainable development in Egypt is the need for better development and management of its limited fresh water resources as per the National Water resources Plan of Egypt 2017(Allam & Allam, 2007). Innovative technologies, as remote sensing (RS) and Geographic Information Systems (GIS), have an immense role to play (Jha MK & Chowdary, 2007). Geospatial technology has enabled us to create and use high-resolution ortho-rectified images in conjunction with (GIS) for spatial problems such as watershed characterization and sustainability, digital elevation models and natural and urban information systems (Khadri & Pande, 2014). The GIS and remote sensing together with pipe hydraulic models are used for design and evaluation of water distribution networks. Developing countries face drawbacks of intermittent water supply system and are unable to shift to continuous supply mode (Mohapatra, Sargaonkar, & Labhasetwar, 2014).

This paper attempts to study the water distribution system of potable water using geospatial tools in near-real time scenario. The water distribution systems typically have two important aspects: (1) to serve the water demand for the community and (2) to provide sufficient water for firefighting (Farina, Creaco, & Franchini, 2014). GIS is used as a long term planning and management tool as it can be easily updated as development occurs. The hydraulic simulation models like EPANET 2.0, WaterGems, KY Pipe etc. are key tools for design, analysis, operation and maintenance of the water distribution systems (Berardi, Laucelli, Ridolfi, & Giustolisi, 2014; Kanakoudis & Gonelas, 2014; Koor, Puust, & Vassiljev, 2014). These models are capable of tracking flows in each pipe, pressure at each node and concentration of chemicals throughout the pipe network during a simulation period (Rajeswaran, Narasimhan, & Narasimhan, 2018). In this paper, some custom applications for water distribution networks management using ArcGIS 10.2 created to solve some burning issues at network management on a daily operational level; such as; isolating valves in case of pipeline break, adjusting GIS layers to equivalent hydraulic analysis layers, service area allocator for water distribution plants, and demand aggregation for junctions in skeletonized networks.

2. ArcGIS standard Water Distribution Network Geospatial Data Model

ArcGIS is used here to create an integrated model for water distribution networks. The system contains six main procedures. Creation of digital vector maps; followed by geodatabase creation to store network data. Then, building geometric networks is needed to ensure accurate network drawing, followed by topology rules creation to ensure accurate spatial relationships. Finally, relationship classes are applied to link external models data with GIS database.

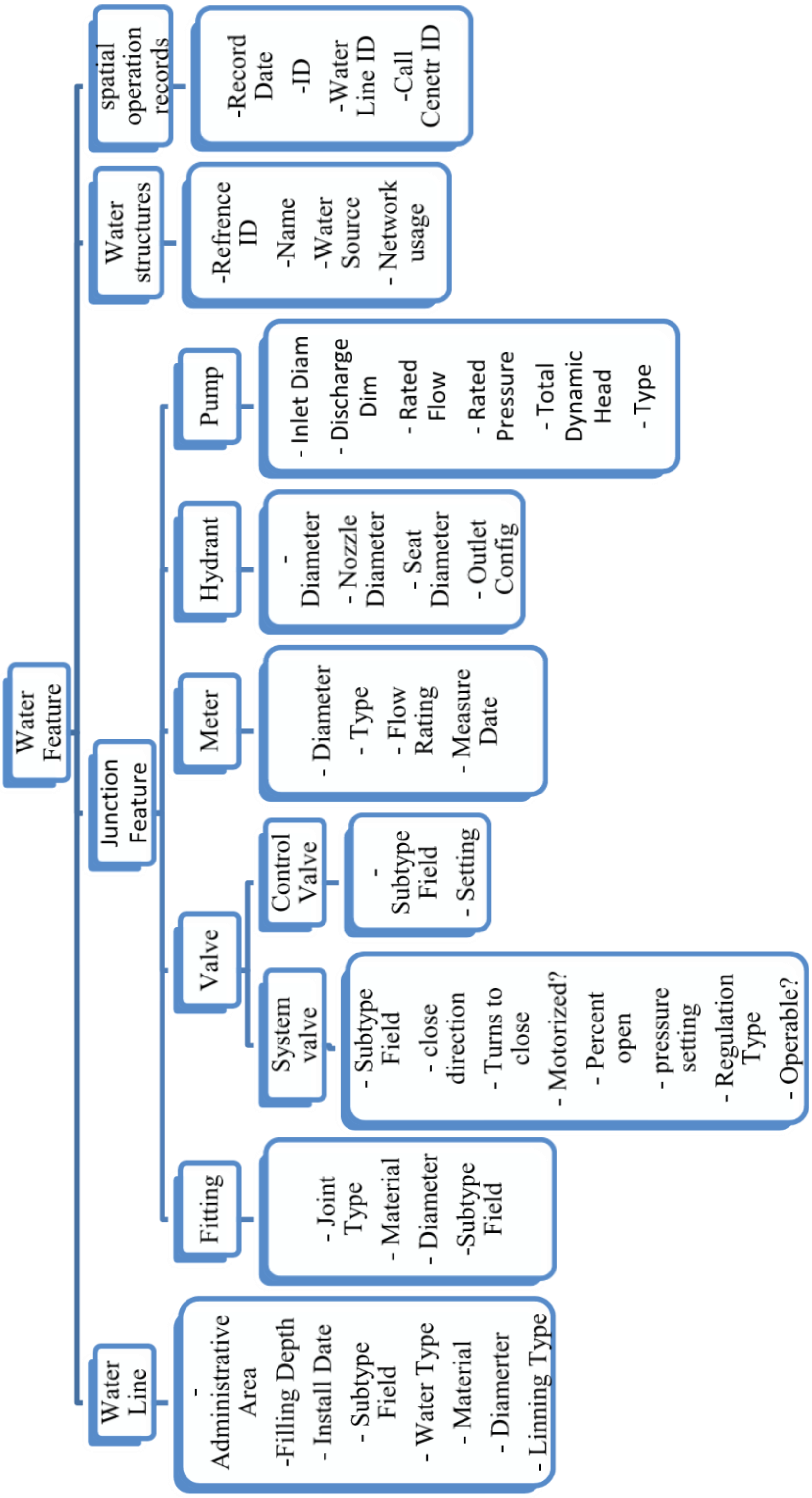


Figure 1 **Detailed GIS water distribution model data representation**

2.1.Building Geometric Networks

Geometric networks offer a way to model common networks and infrastructures found in the real world. Water distribution, electrical lines, gas pipelines, telephone services, and water flow in a water pipe networks are all examples of resource flows that could be modeled and analyzed using geometric network.

In the present paper, geometric network is created from the set of feature class layers presented earlier, along with connectivity rules that are used to represent and model the behavior of a common network infrastructure in the real world. We define the roles that various features will play in the geometric network and rules for how resources flow through the geometric network.

Geometric network consisted of two main elements: Edges and Junctions

(i) Junctions are the features that allow two or more edges to connect and facilitate the transfer of flow between edges. Junctions are created from point feature classes in a feature dataset and correspond to junction elements in the logical network. Examples of junctions are valves, hydrants, fittings, and meters.
(ii) Edges are features, which have a length through which some commodity flows. Edges are created from line feature classes in a feature dataset and correspond to edge elements in a logical network. Examples of edges are water lines, hydrant line layer, and house connection layer.

There are two types of edges in a geometric network. The first is Simple edges, which are always connected to exactly two junctions, one at each end, and Complex edges are always connected to at least two junctions at their endpoints but can be connected to additional junctions along their length.

Table 1 water distribution network model edge type.

Edge layer	Type of edge
Water pipes feature class	Complex edge
Hydrants pipe feature class	Simple edge
Streets feature class	Complex edge
House connection feature class	Simple

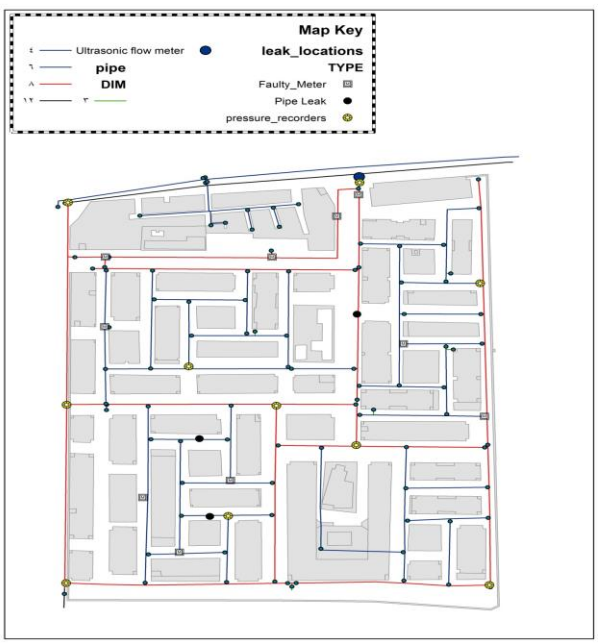
The present paper sets water pipeline networks as complex edge feature to save the time required for hydraulic analysis, as single water pipe network is connected to many meters through house connections. That will be later simplified for hydraulic simulation to only two junctions at the start and end of each pipe; Accumulating the demand to either downstream junction, or splitting the demand in half between the two ends junctions using custom made applications presented by the current paper.

3. Methodology and applications

In this section, a newly created GIS based applications are introduced in to identify isolating valves in case of pipeline break, adjusting GIS layers to equivalent hydraulic analysis layers, service area allocator for water distribution plants, and demand aggregation for junctions in skeletonized networks.

3.1.Study Area

Faisal City Block consists of 86 building, each one contains 13 floors, Mosque and two schools and a number of commercial stores and also governmental offices, 9 gardens, 5 hydrants, and 159 master meters installed in the block. The total pipe length of the water distribution network is 6.7 km and, the block area is 0.252 square km. The average pressure is between 1.6-1.8 bars, and population count is 15000 capita. The area is feed from 3 sources, two of them were closed and an ultrasonic flow meter was installed on main entrance (8" inch pipe) and 10 pressure recorders where distributed around. Fig.2 shows the layout of the pilot area indicating the



Faisal Area Layout2 **Figure**

locations of both pressure recorders and leak noise loggers using ArcGIS.

3.2.Transfer Attributes Application

This application is intended for use in case of adjusting GIS layers to be used in hydraulic analysis models (e.g., EPAnet). It copies attribute data from point features (e.g., pumps) to adjacent line layer (e.g., Water line layer). As it worth mentioning that in hydraulic analysis procedures pumps and valves (e.g., PRV , FCV PSV …etc) are modeled as pipe with zero length the model is used to transfer pump & valves nodal data in GIS environment into adjacent Lines(edges) to be ready for EPAnet model model . Figures (3,4) explain the difference between GIS network representation, and hydraulic analysis models representation.

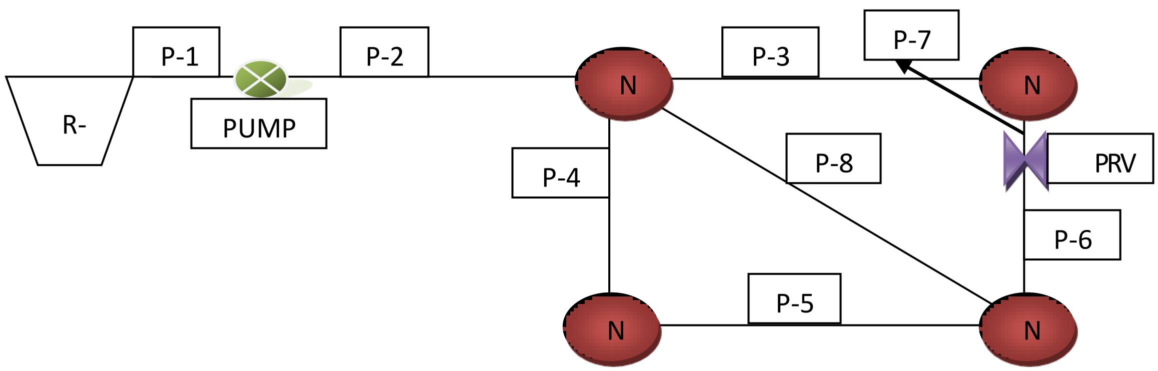


Figure 3 Schematic ArcGIS WDN graphical representation

In the above figure, we can notice that both pump and Pressure reducing valves are considered nodes; as the real representation to these network components considered as nodes along with other fittings (N1, N2, N3, and N4).
While for hydraulic simulation models, the same network representation will be in the following form as explained in figure 4

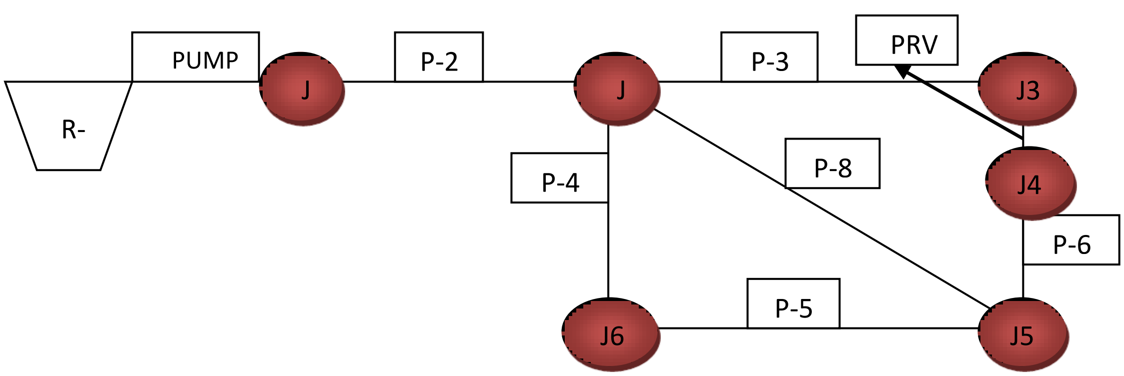
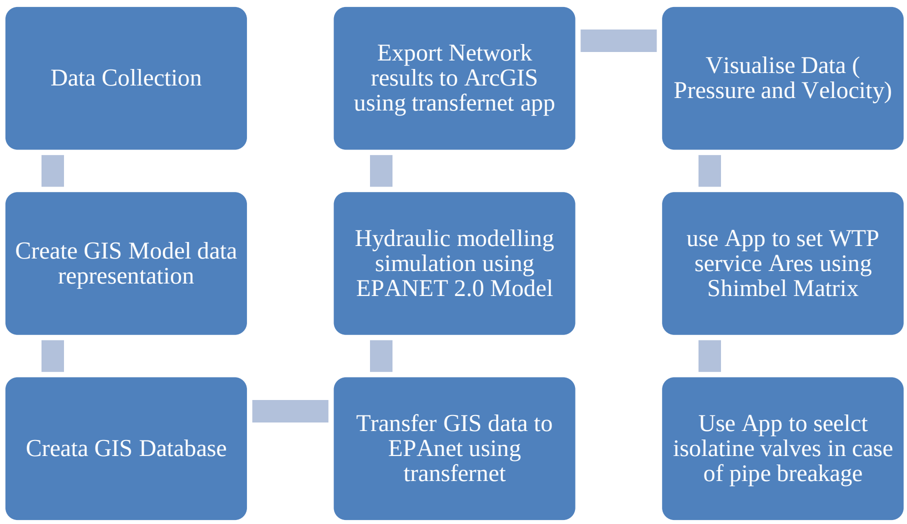


Figure 4 Schematic hydraulic model graphical representation

The application (Named Transfernet app) using Python Language (Ayad , 2010) transfers the selected nodal layers (e.g., pump, and valves) data to the adjacent pipeline layer; thus transferring the GIS geometric network into an equivalent accepted hydraulic model ready for analysis. The application created prepares the data in suitable form for hydraulic analysis model to be used as input files. That allows the link between hydraulic model (EPAnet) and ArcGIS to be well established; also through relationship class, results can be linked to GIS. **Figure 5 Summarize the methodology implemented for data import and export**.

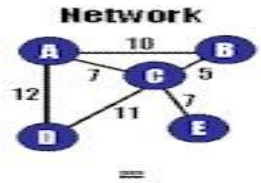


Methodology Flowchart5 Figure

3.3.Service Area Allocator Application

The service area allocator application created uses the idea of shortest path to identify the service area per service station. It works on the basic principle of Origin-Destination matrix (OD-matrix). OD cost matrix is a table that contains the total impedance from each origin (e.g., water structure layer) to each destination (junction layer). The shortest distance is based on network weight assigned by the geometric network, in current paper the network weight is chosen to be; pipe head loss across pipes obtained from EPAnet (Farina & Franchini 2014). The values of travelling cost are set in a matrix where each column represents the cost of travelling (minimum pipe head loss summation) between each junction and source nodes. Then, the application selects the least travelling cost (least cell value per column) and identifies the corresponding source node.

Figure 6 shows a simple explanation for the OD cost matrix creation.



	A	B	C	D	E	Σ
A	0	10	7	12	14	43
B	10	0	5	16	12	43
C	7	5	0	11	7	30
D	12	16	11	0	18	57
E	14	12	7	18	0	51
Σ	43	43	30	57	51	194

Figure 6 OD cost matrix

From above figure, it can be noticed that by calculating OD-matrix and calculating the index for the minimum for each column the source point for each destination point is identified. The current application creates the matrix between junction layer and water structure layer, and then each junction the corresponding source is identified. After which, the service area per source could be identified. Calculation of service area for each source is based on cost of travelling (hydraulic losses through pipelines) and flow direction. Figure 7 shows the output obtained from application for simplified network for Alexandria, where main water treatment plants where introduces as main source points, and simplified water network analysis was obtained by use of EPAnet to calculate friction losses per pipe and flow direction (Ramana,G et al 2018). The application colors each junction with a coloring symbol that matches the symbol taken for the feeding source.

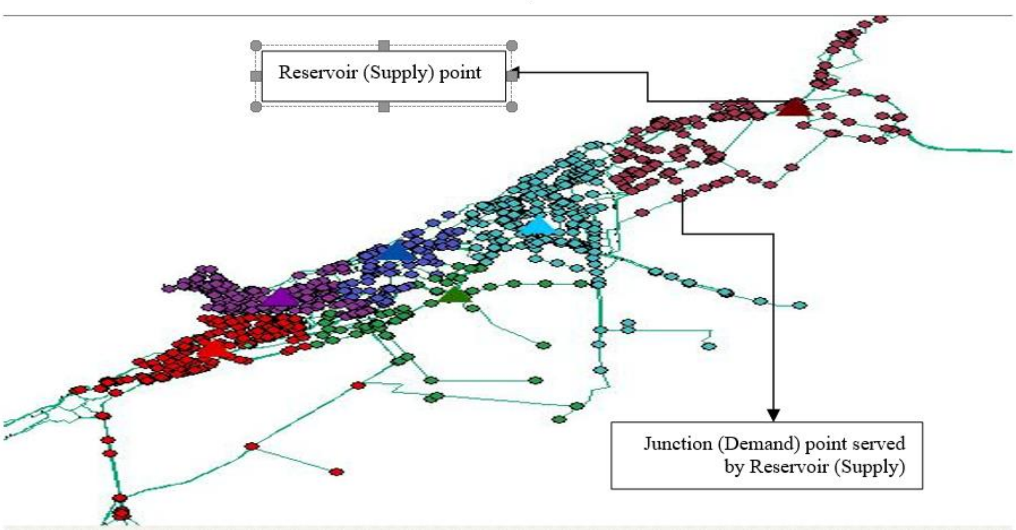


Figure 7 service area allocator application for Alexandria water pipe network

3.4.Custom Valve Isolation Application

The application performs a valve isolation trace based on selected pipes and display results. By using the features of geometric network; a network analysis, based on the upstream and downstream connectivity for the water pipeline feature to identify the valves that isolate selected pipe. Then, all valves are highlighted and summary report for data is being exported in suitable format. The application is used in the preliminary stage of design to ensure that every region for pipeline network could be easily isolated in case of pipeline break without affecting other regions. Also, used in post optimization, post design stage to identify the key valves that control the network and to ensure proper isolation in case of pipeline breakage. Figure 8 shows an example applied to Faisal City network in Alexandria .

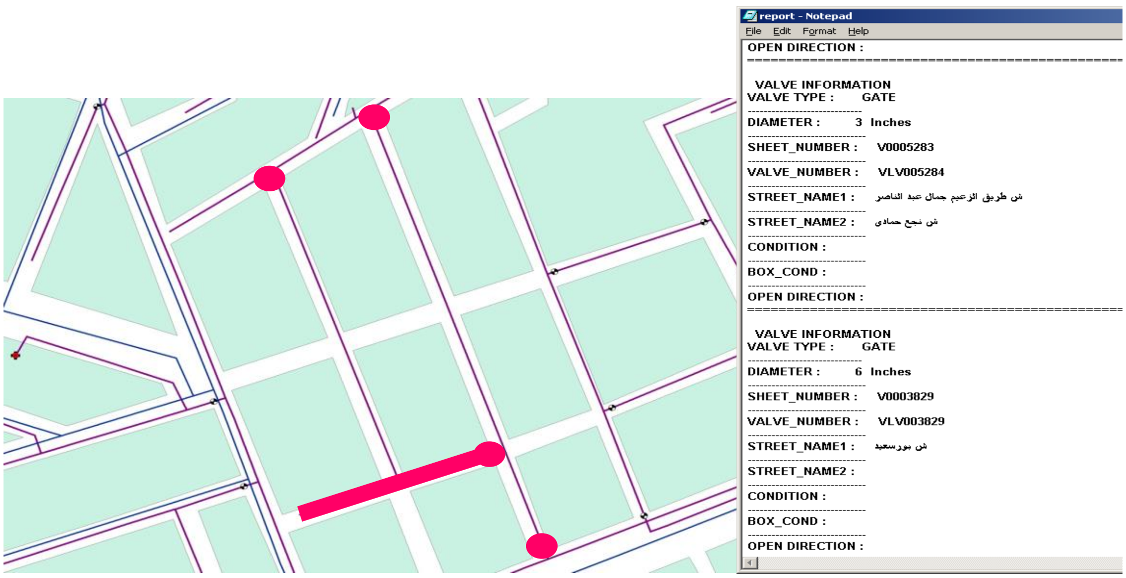


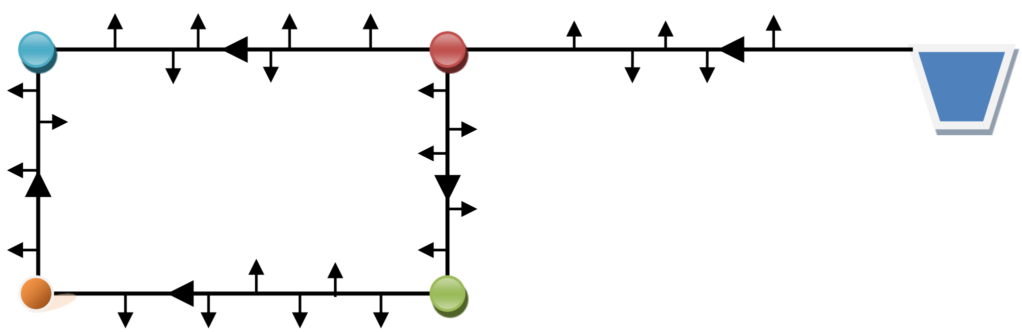
Figure 8 Custom valve isolation application example

3.5. Custom Application for Network Skeletonization

When building a network model, which pipes to include in the model must be decided. The process of representing only selected pipes within a model is called skeletonization. Water demands, or consumption rates, for a distribution system are equivalent to the loads placed on a structure. Both play a key role in determining the behavior of their relevant systems. Average demands can be estimated and assigned to network junctions in several ways. The current paper presents three applications for assigning demands to junctions and the applications created for such purpose. ArcGIS application is created to calculate the junction layer demands from actual meters reading (meter layer) with two methods of calculating nodal pressure. Finally a comparison is made between the results (Pressure difference at key junctions) obtained from the two modalities vs actual pressure to identify the best method.

Upstream Flow Accumulator Application

This method is used for adjusting demands for junctions in case of network skeletonization. Where it selects all the demand junctions (meter layer) on the upstream of each junction layer based, then it sum the demands of all junction and assign it to the downstream junction. The upstream direction is based on the flow direction obtained from either field measurements, or hydraulic analysis simulation (EPAnet).



Schematic water distribution network9 Figure

In the above figure, a schematic figure for a simple network is created. The small arrows represent house connection meters, the thick arrows represent digitized flow direction, while the dots represents' the hydraulic network junction, and the trapezoidal shape represent the water source.

The first method allocate all the meters at the upstream of each junction till it reach the next junction, and do this for all network junction of specified junctions. The summation of meter readings field is being added at the demand field of each junction. And the service area for each junction is being specified. Figure 10 explains the output of the application where each junction obtains the summation of same colored master meters (arrows). It worth mentioning that calculating upstream direction can be obtained by either actual flow reading or by pipe digitizing direction.

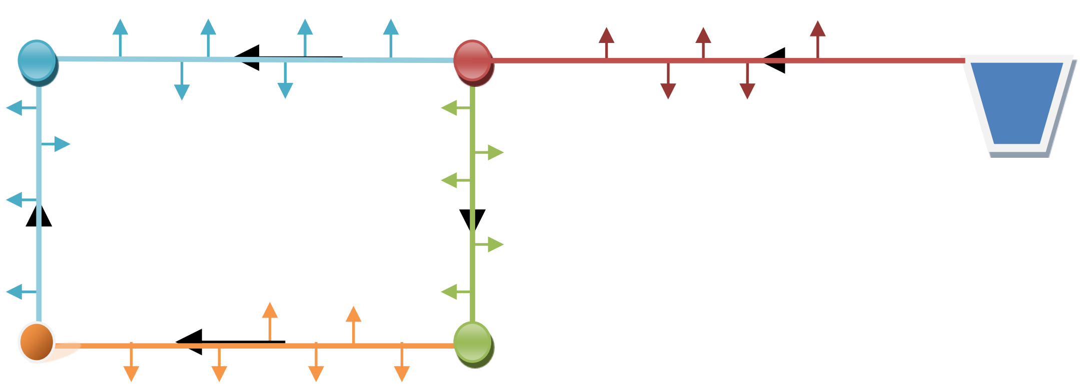


Figure 10 Upstream flow accumulation tool for network skeletonization

Voronoi Polygons

Voronoi maps are constructed from a series of polygons formed around the location of a sample point (Ayad. 2010). Voronoi polygons are created so that every location within a polygon is closer to the junction point in that polygon than any other junction point. Voronoi Polygons create a relationship between junction node layer and meter layer in case of a network skeletonization occur, where the approximate equivalent service area for each junction is determined and summation of meter reading field is calculated; thus creating a simplified water network with demand allocated.

Figure 11 Voronoi polygons demand aggregation application in Faisal Pipe Network

Table 2 shows the observed and calculated nodal heads at pressure recorders locations. It is clearly shown while comparing both difference and variance; the upstream Accumulation yields closer results. Yet, the Upstream Accumulation requires adequate measurement on flow directions; as for voronoi polygons; flow direction accuracy is irrelevant. Therefore, in some occasions, where flow direction is unknown, Voronoi Polygons might be useful.

Table 2 Observed and Calculated pressure head for Faisal City Block Network

Junction ID	Observed pressure	Voronoi Polygon	Upstream Accumulation
177	**17.132**	21.47	14.206
167	**17.448**	24.16	19.061
161	**16.53**	15.956	19.748
145	**17.556**	19.346	15.301
126	**16.339**	14.594	14.95
120	**18.648**	24.942	17.374
92	**16.925**	20.993	16.236
66	**17.134**	18.675	18.049
31	**16.255**	16.552	19.959
18	**17.041**	22.257	19.638
Difference (%)	--------	16.33666261	2.054874626
Variance		7.645647227	2.35928455

4. CONCLUSIONS

A methodology for using GIS in water distribution networks to reduce the time needed to collect and store data in the distribution networks. Transferring data between the GIS system and hydraulic analysis models helped optimize the engineering design and analyses. Results of the hydraulic analyses (e.g. pressure, flow.. etc) and those of Optimization model (e.g. Pipe diameter) can be displayed in the GIS, and in combination with other layers such as the topographic layer of the city, greatly assist in the understanding of the network behavior and identifying the critical zones in network. Using GIS has enabled prompt action to identify problems (e.g., in case of pipe breakage, service areas) in the system followed by quick solutions to optimize network maintenance work, and provide a framework for continuous improvement. The simulation can be further corrected by incorporating details of water tanks on each building, which will make us analyse intermittent supply of water.

This paper proves that geospatial technology is an efficient, time and cost saving alternative to the traditional methods of design and evaluation of potable water distribution networks. GIS technology is need of the hour for designing and evaluation of complex water distribution systems. This can help in decision making and planning of the networks, which are future ready, efficient and cost effective. EPANET 2.0 is a very handy tool that can be used by the engineers and planners to plan and check their existing and proposed water distribution network designs. Any problem in the design can be found beforehand and can be corrected by any number of iterations.

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