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Leakage management for water distribution system in GIS environment

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Abstract

Leakage control is one of the most important issues in water networks. This paper presents leakage management and how to organize and analyze a water distribution system for leakage purposes. Also various aspects of management of water supply networks are depicted in order to provide integrated hydraulic model in (Geographical Information System) GIS. These consist on determination of required data structures and, how to supply and reintegrate the information in GIS. The specification and applicability of the hydraulic model, in GIS for leakage management in urban water system, is studied with practical project in Saveh city of Iran. These are accomplished using Arcview as GIS base and EPANET software for hydraulic modeling and link between the above programs is DC water extension. Based on the analyses carried out and using the relationship between hydraulic and physical characteristics of distribution system, leakage indices have been calculated. The results can provide valuable management guidelines to identify leakage location in the system. Also a flowchart of data management and analyzing hydraulic systems in GIS environment has been obtained that can be useful in any other process of such analysis.

Keywords: hydraulic modeling, leakage management, GIS

Introduction

Recently, many countries have paid attentions to the reduction of water leakage considering the limited water resources, and so they have obtained considerable progresses by using various tools and technology (Macke, 2001b). This has been considered since 1993 In Iran. Based on the investigations and experiments obtained in Iran, it has been shown that the unaccounted for water is much higher than others especially in developed countries.

Corresponding to the new experiences in recent years, it has been shown that performance of research and exact analysis is required with the new tools and technology such as new hydraulic models and GIS. Linking between various technologies is very important approach to obtain the higher degree of accuracy. In this paper, it has been demonstrated the capabilities of linkage between GIS and hydraulic model in a case study in the field of non-revenue water and leakage management. The operator can save a lot of time in constructing a network model making use of all the potential that the GIS offers when it comes to data management, manipulation and analysis.

Also in order to make network simulation models useful, it is necessary to calibrate them before being used. So the model calibration process, which consists of adjusting a set of physical and operational parameters, is achieved for the purpose of a reasonable match between measured and computed pressures and flows in the network. GIS can be used in calibration process in estimating parameter more accurately. In this case, GIS technology can provide the linkage between customer's billing records with network model components. So better initial estimations of nodal demand, which is an important parameter in calibration approach, are achieved.

Application of in GIS Hydraulic Modeling

In recent years geographical information systems are as invaluable tools in water distribution system modelling, because the required information is descriptive and spatial. The general advantages of water distribution system (WDS) in GIS are: review of models results in GIS, Transferring of information from GIS to model and visa versa, estimation of water demands and quality control parameters, and the calculation of flow in GIS environment can be performed with spatial information such as land use, population distribution, connecting points of different types of consumers with network and etc. Finally, information will be updated while entering new inputs in each case. (Saraye, 2002), (Feinberg et al., 1997)

In spite of many capabilities of GIS in establishment of optimum management of WDS, the following cases are as the constraints of application of GIS in modelling:

1- The difference between the format of input information in GIS and most hydraulic models, needs linkage program.
2- Showing the results is often different in models than in GIS
3- Most models make temporary information that is not applicable in GIS such as EPS
4- The plan resulted from network is different from the plan resulted from GIS. In other word, correspondence of network plan from model with plan from GIS has some differences.
5- In most cases, models do not show the entire network of pipes and equipments, but in GIS all pipes can often be viewed.

Case study

In this research, an area with ten thousand households (equal to forty percent of the current tributaries in Saveh city) is investigated. First, population of this city and increasing rate of population corresponding with estimation of population in future years has been investigated. Then the climatic conditions of Saveh city were studied.

Based on these studies, the water requirement is supplied from 15 wells. Within the city, the water obtained from these wells goes into two reservoirs with capacity of 5000 and 10000 m^3. The pipe materials in the network are asbestos cement, ductile, cast iron, and polyethylene. (Sabour, 2002)

Data gathering for Hydraulic model

Required information of WDS can be divided into two qualitative and quantitative categories. Investigation of quality model is not considered in this research. Generally, required information in WDS is assigned to the following statements.

1-information associated with the network
2-information associated with the operation
3- Information associated with the water consumption

Methodology

After preparing the required data, it is necessary to create model in both hydraulic and GIS model, and then integrating them together. The typical process is as follow:

1- Create Geographical information system data
   1.1- Draw a network representation of the distribution system using the editing tools or import it from a CAD file, a shape file or EPANET input file
   1.2- Check and correct import errors (if required).
   1.3- Edit the network properties
   1.4- Describe how the system is operated by means of demand patterns, pump curves, control rules, etc.
   1.5- Select the analysis options
2- Create hydraulic model via linking software from GIS environment to hydraulic modelling environment
3- Edit errors in hydraulic modelling
4- Calibrate the network manually as a rough estimate
5. Send the calibration parameters back to the model for result with respect to leakage control

The brief review of this algorithm is shown in figure 1. In this figure the flowchart of data preparation and processing required for analysis of an integrated hydraulic modelling in GIS environment is identified. Detailed descriptions of the flowchart are illustrated in the following sections.

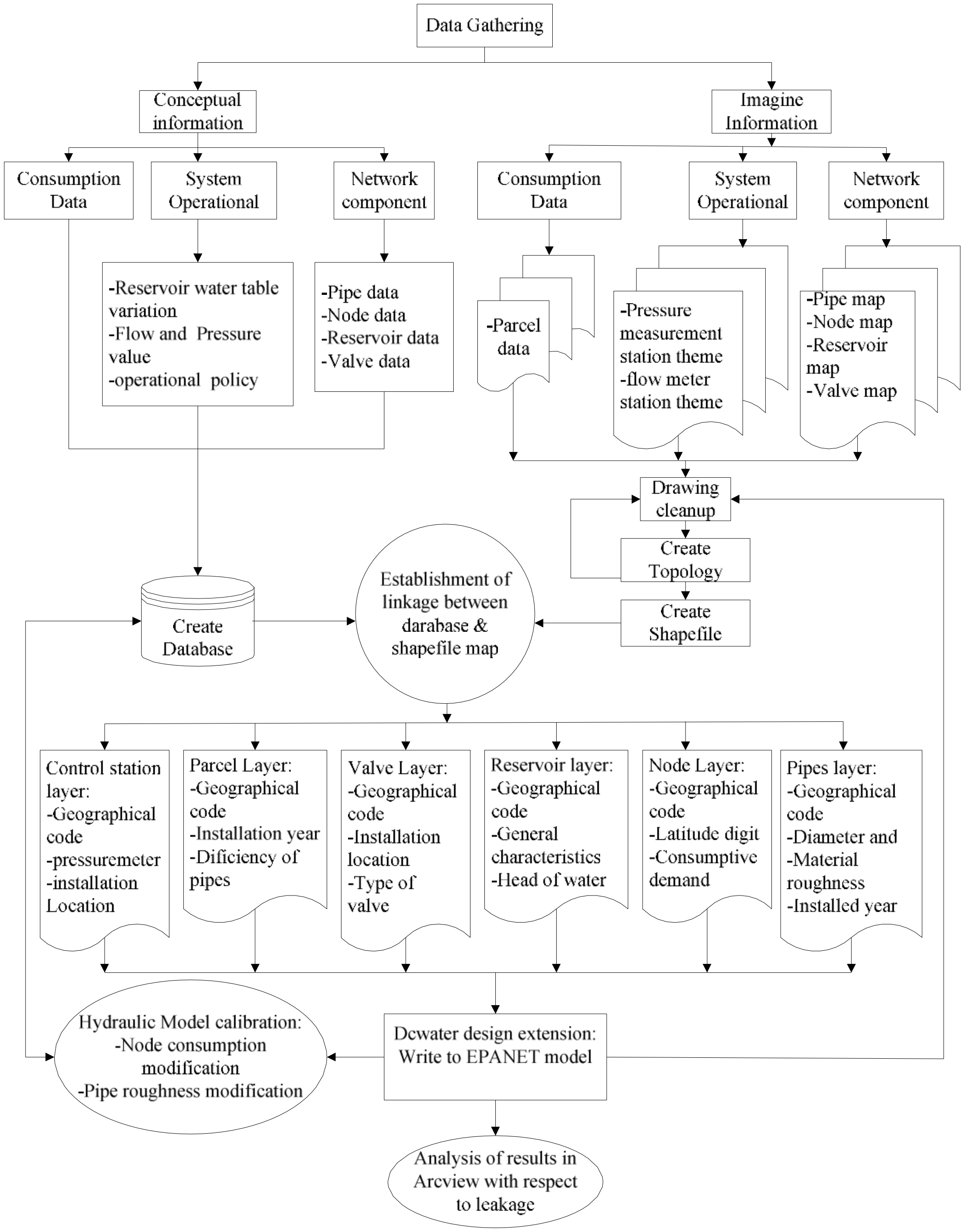


Figure1 Flowchart of data preparation and processing of water supply networks

Geographical Information Systems (GIS)

In order to create GIS network, it is necessary to perform connection between spatial topologies and conversion map topology and database to GIS format. To create this connection, the topology model is created, which is widely used in this field.

Construction of applied topology model

The software used for creating topology and providing information layers for water distribution system (WDS) case study is AUTOCAD map. After constructing topology of WDS, the file is prepared in shape format that is identifiable for ARCView software.
Topology is defined as how to create the relationship between objects and conceptual data. To demonstrate objects, the following three topologies are used:
1-Network topology
2-Node topology
3-Polygon topology

It is necessary to mention that the process of building topology will be successful if the entire errors of map (corresponding to spatial connection) are removed. The creation of topology has been shown in figure 2.

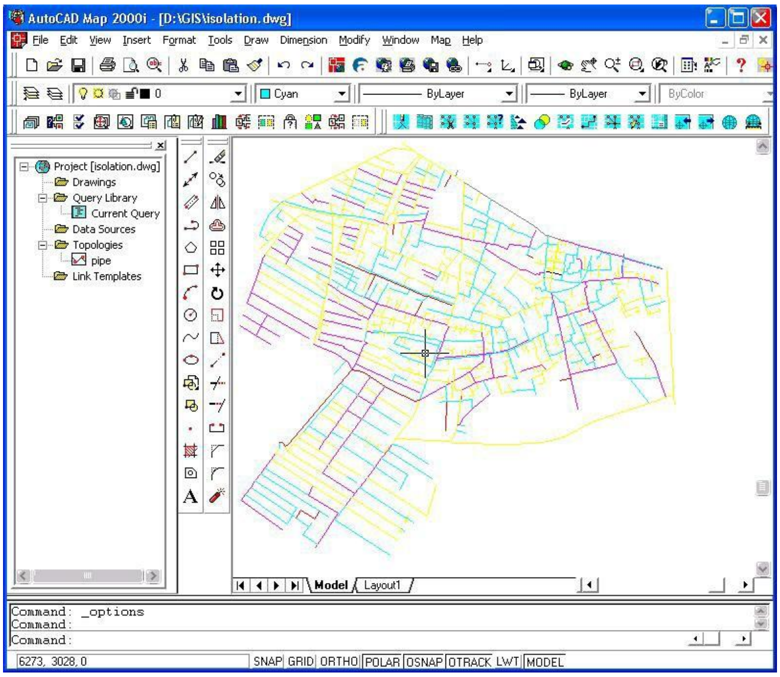


Figure 2 Topology of pipes in AUTOCAD map environment

Preparation of Information Layer in ARCView

Following topology creation of each WDS objects, these informations are prepared in ArcView, to be applied in hydraulic model. This purpose is accomplished by means of creating a project file and opening a view and finally related layers are shown below. A sample of this process has been shown in figure 3 including network layers of system.

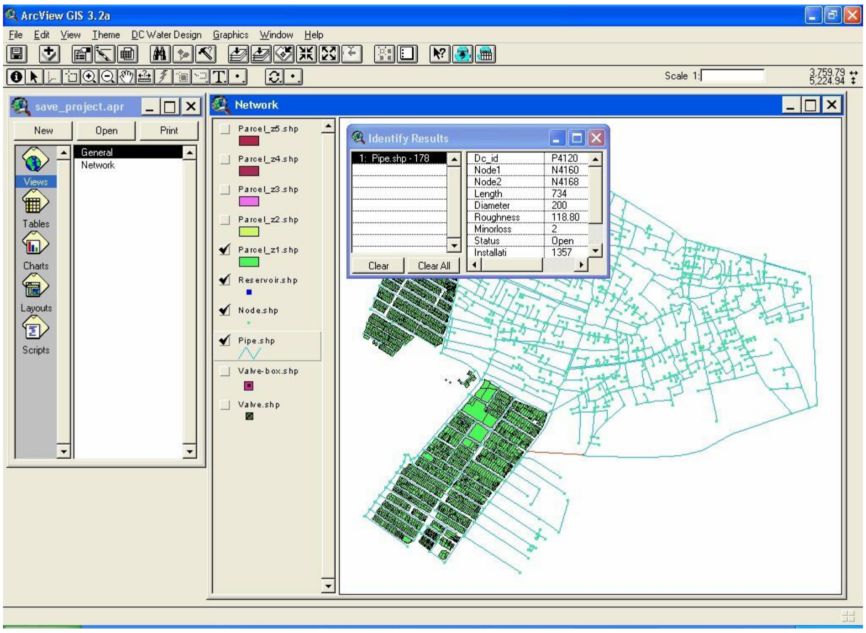


Figure 3 ArcView project environment accompanied with WDS data layers

Linkage between hydraulic model and GIS

The link between the two software, hydraulic model (EPANET software (Rossman, 1994)) and GIS (ArcView software), DC Water Design Extension was accomplished (Macke, 2001a). Accepted format and structure of information was necessary form DC water design extension for the hydraulic model. This extension is an extension of GIS that uses current data in layers and conceptual data in tables to create input file required for EPANET software.

Creating hydraulic model

It could be possible to create hydraulic model in ArcView environment via DC water design extension. There are two

Methods for this purpose as follow:

1-Build an input file of EPANET in ArcView

2-Call the EPANET software in ArcView and run the model and return results to ArcView automatically

In order to create the model, the first approach was using the method one, and then the model was run in ARCView. The second method was used for leakage purposes. A sample of building the model in EPANET is shown in figure 4.

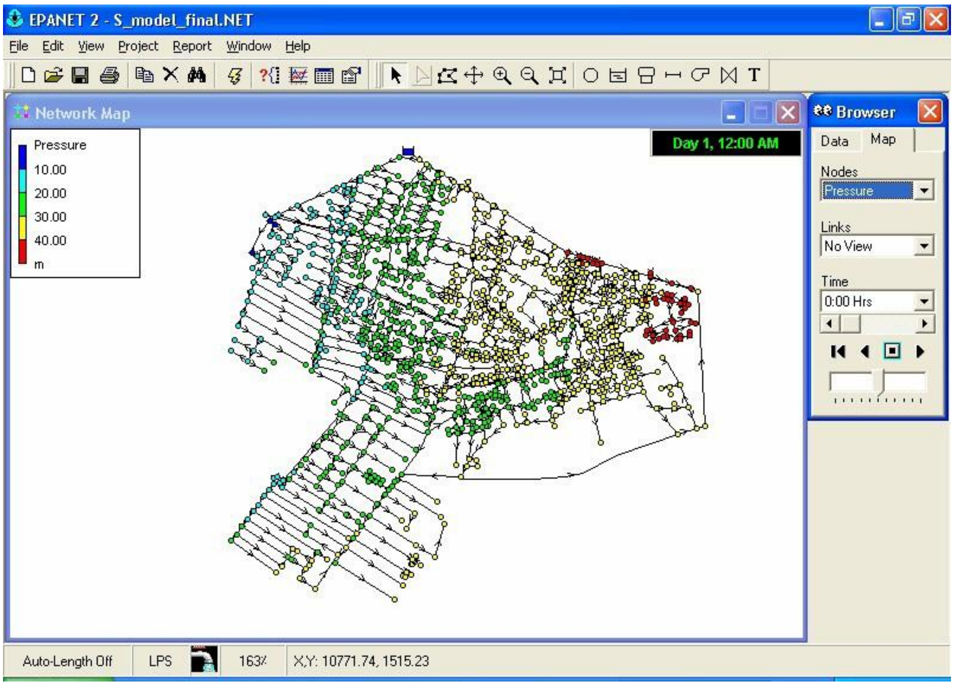


Figure 4 Creation of hydraulic model in EPANET environment

Model calibration

Along with preparation, the final hydraulic model should be calibrated for verification of the results. It means the model must perform in such a way that the predicting flow and pressure is as closely representative as the observed flow and pressure at any point in the system. According to Shamir and Howard (1968), calibration of pipe network systems consists of determining the physical and operational characteristics of an existing system. This is obtained by determining various parameters that, when put into a hydraulic simulation model, it will yield a reasonable match between observed and predicted pressures and flows in the network.

There are various algorithms to calibrate the model. One of the methods is based on optimization techniques (Kapelan, et al. 2003). The second method is based on trial and error. These methods are based on proper experience for researcher to conduct the process to a high degree of accuracy in a short time. In this research, the second technique was used and with respect to variation in consumption demand at nodes and roughness coefficient of pipes. The model was calibrated. The results of calibration process is shown in figure 5

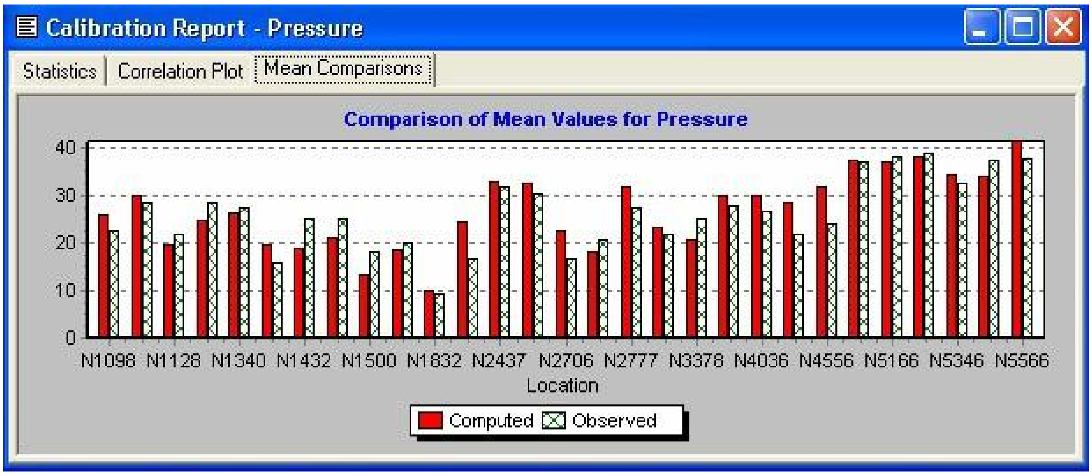


Figure 5 Calibration chart of WDS in EPANET environment

Leakage Analysis

After calibration process and editing some nodal demands and pipe roughness coefficients, the model in Arcview was ready for hydraulic simulation in each arbitrary part of the model. In order to do leakage analysis, it was required to state the type of leakage relationship and specified indices.

Pelletier et al. (2003) developed a modelling strategy using the annual number of water pipe breaks as an indicator of the structural state of a network and applied that to three municipalities, characterized by their brief recorded pipe break histories. They stated a descriptive analysis of the pipe and breakage data, and the application of the modelling strategy for these municipalities. Different replacement scenarios were also simulated to assess their impact on the evolution of the annual number of pipe breaks in the three municipalities.

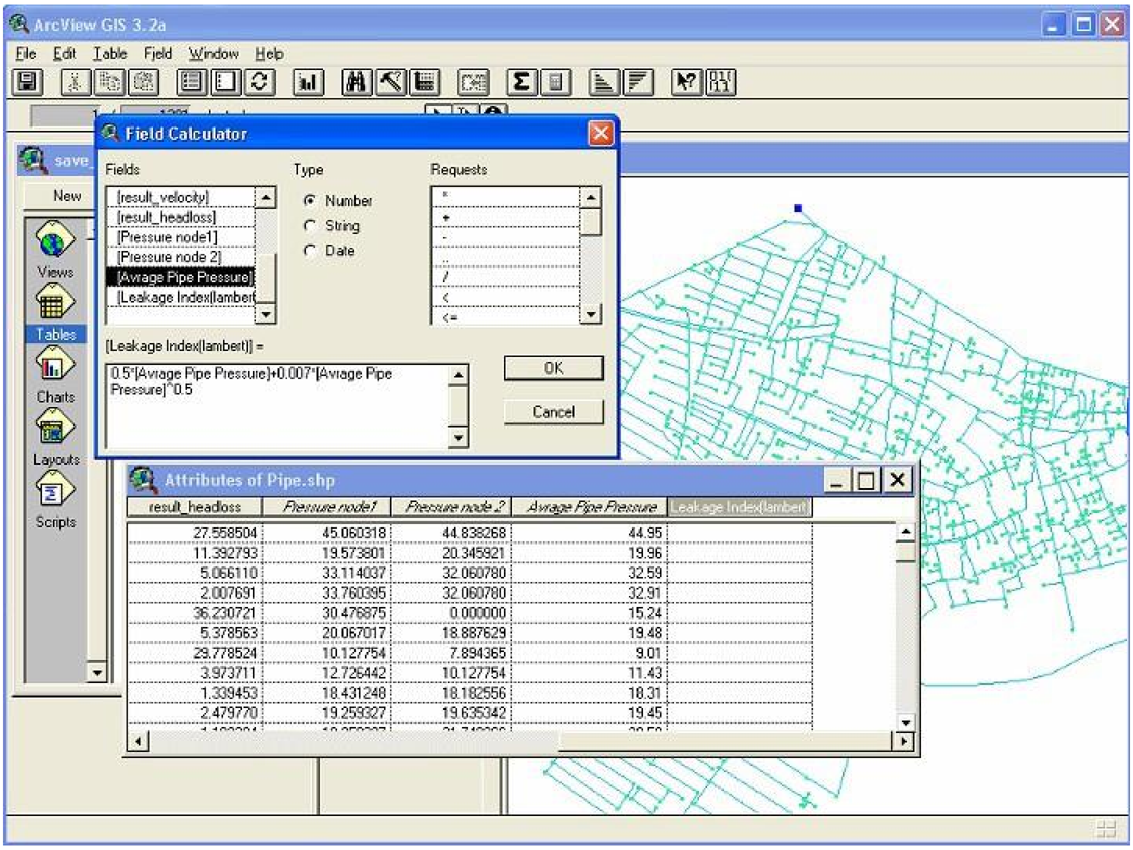
Generally the most important cause of leakage in WDS pipes is lack of balanced pressure in the system. To perform leakage calculations, two approaches are considered. The first one is Lambert index that states the leakage index is proportional to pressure as the following relationship:

$$Leakage\ Index = 0.5 \times p + 0.007 \times p^2 \qquad (1)$$

That p is pressure head of the pipe. The second approach is related to Germanopulos relationship that estimates the discharge of leakage for each pipe. It has been shown as follow:

$$Q_{ij} = C.L_{ij}.(P_{ij}^{av})^{1.18} \qquad (2)$$

That C is a constant that depends on the age, type of the pipe, L is the length of the pipe, P is the average pressure of the pipe in atmospheric unit, and Q is calculated in litre per second. A sample of leakage calculation is shown in figure 6.



result_headloss	Pressure node1	Pressure node 2	Avrage Pipe Pressure	Leakage Index(lambert)
27.558504	45.060318	44.838268	44.95	
11.392793	19.573801	20.345921	19.96	
5.066110	33.114037	32.060780	32.59	
2.007691	33.760395	32.060780	32.91	
36.230721	30.476875	0.000000	15.24	
5.378563	20.067017	18.887629	19.48	
29.778524	10.127754	7.894365	9.01	
3.973711	12.726442	10.127754	11.43	
1.339453	18.431248	18.182556	18.31	
2.479770	19.259327	19.635342	19.45	

Figure 6 Calculation of leakage index in ArcView project environment

Conclusion

The use of ArcView GIS along with the additional extension in water distribution network modelling may provide a major advance in terms of analysis, assessment and maintenance of a water distribution system. The integration of a hydraulic simulator within a GIS, offers a series of advantages in various aspect of hydraulic models such as leakage control and disaster management in the network. Also it can be useful in other events, such as, planning, design, management and decision-making issues.

By means of an ArcView GIS extension entitled DC water design, these objectives have been fulfilled. Finally, it can be visualized the zones of high pressure that have more probability of leakage so that it can offer the pipes that must be changed and so the manager can control the area studied and take into account alternative actions before any major breakdown of the system.

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