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AGIS based Decision Support System For Management of Water Distribution Networks- Nablus City Case Study

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Declaration

I hereby declare that this master thesis has been written only by myself without any assistant of any third party and describe my own work unless otherwise acknowledge in the text of the thesis.

All reference, verbatim extracts and information source are quoted and cited properly. Thus, I con firm that no source have been used in this thesis other than those indicated in the thesis itself.

This Master thesis has not been accepted in any other previous application, in whole or in part for any degree.

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Abstract

Water is very important for every living creature. Palestinians face many challenges of access to safe and sufficient drinking water under the existing circumstances because of restricted water allocations.

Water data are available at many municipalities but they are not ordered in suitable way that can facilitate decision making and problem detection so all water data must be collected, edited and managed more professionally in order to analyze it and be able to get informed.

Water resource management is an integrated process of planning, developing, distributing and managing the optimum use of water resources**.** The use of GIS provides better awareness tools for water distribution network. Based on GIS we can detect and localize pipe breaks very fast after they occur using water network analysis.

The proposed model provides a template framework used in all countries that have an intermittent water supply system. Intermittent water supply system is not continuous supply, so municipalities need to use pump water cycles to provide a specific zone with enough water. This research aims at enhancing water system to have the ability for monitoring and analyzing water distribution system in Nablus.

Geographic information system GIS was integrated with the hydraulic simulation model (WaterGEMS) software [1] to build water network that supports the intermittent water supply system. WaterGEMS is hydraulic modeling software that can be used to simulate water network with its entire component. I chose WaterGEMS rather than EPANET software because WaterGEMS has the ability to deal with shape-files as the

output files in the results of connected geometric network prepared using ArcGIS software which has the ability of adding control information in WaterGEMS to manage intermittent water supply system. GIS were used to build the geometric network, check the connectivity between network components, perform Network Analysis, improve data access and querying process, find loops and different problems such as finding connected or disconnected parts in water supply system, and discover how to reconnect it.

Finding losses in the network based on two approaches; the hydraulic analysis leak detection approach which compares the model flow and pressure values to the SCADA flow and pressure values at specific time within a specific zone to detect if there is a water loss in that zone. The other approach used is the Minimum Night Flow (MNF) which compares water network input to their output. Leak can be calculated by the difference between water flow entering the pipeline (supplied) and the output from the pipeline (consumed) by reading the customer meters as a consumed (output) value.

Losses can be classified into real losses and commercial losses. Detection of real losses was performed using the MNF approach. ArcObjects and VB programming under Visual Studio program were used to build an application that performs leak detection using the required data for the required zone. I have also created a desktop application that reads the shape-file data which fetches the required data for the required calculation for the required zone then the system takes all the modified data in the geometric network in addition to the hydraulic model results to show problems and leaks in the connected water network and so to calculate real losses. Bulk meters were used to detect commercial losses.

العنوان

استخدام نظم المعلومات الجغرافية القائمة على نظم دعم القرارات لادارة شبكات توزيع المياه – مدينة نابلس كمنطقة الدراسة

الملخص

يعد الماء العنصر الاساسي لبقاء الانسان والكائنات الحية كافة . يعاني الفلسطينيون من نقص كبير في مصادر المياه وتعاني بعض المدن الفلسطسنية كمدينة نابلس من مشكلة توزيع المياه الى المستهلكين . تعتبر شبكات توزيع المياه في فلسطين من شبكات التزويد المتقطع .في هذه الدراسة تم استخدام نظم المعلومات الجغرافية بالتكامل مع برنامج WaterGEMSالهايدوليكي لبناء وتحليل شبكة المياه وهو نظام يعتبر كأداة شاملة وسهلة الاستخدام لدعم اتخاذ القرار لشبكات توزيع المياه.

في أطروحتي، تم جمع البيانات من منطقة الدراسة مثل بيانات الأنابيب (الأنابيب الرئيسية،الانابيب الفرعية)، بيانات مصادر المياه ، بيانات صمامات المياه و عدادات العملاء . تم دمج نظام المعلومات الجغرافية مع نموذج المحاكاة الهيدروليكية (waterGEMS) لبناء شبكة هندسية للتحقق من الاتصال والترابط بين مكوناتها وإجراء تحليللهذه الشبكة وتحسين الوصول إلى البيانات كتسهيل اجراء الاستعلام ، ايجاد العناصر المتصلة وغير المتصلة في الشبكة و إعادة توصيلها . تم اتباع نهجين للتنبؤ بوجود تسرب : الأول هو نهج موازنة مجموع قراءات عدادات المشتركين مع مقدار كمية الماه التي تم ضخها للمنطقة في وقت محدد مع تدفق سكادا في ذلك الوقت للكشف عن الخسائر . النهج الثاني هو مقارنة نتائج النموذج المقترح مع قياسات الضغط والتفق في نظام (SCADA) للمساعدة في التنبؤ عن وجود تسرب في الشبكة. تم إجراء الكشف عن الخسائر الحقيقية باستخدام نهج تدفق الحد الأدنى ليلا(MNF) باستخدام البيانات المطلوبة للمنطقة المطلوبة.

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List of Abbreviations

1. GIS Geographic Information system
2. CAD Computer Aided Design
3. ESRI Environmental Systems Research Institute
4. WDN water distribution network
5. DMA District Meter Area
6. GN Geometric Network
7. DEM Digital Elevation Model
8. MNF Minimum Night Flow
9. SCADA Supervisory Control And Data Acquisition
10. WaterGEMS Water Distribution Analysis And Design Software
11. SDSS Spatial Decision Support System
12. DBMS Database Management System
13. SQL Structured Query Language
14. UML Unified Modeling Language

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Chapter One: Introduction to water system Using GIS

1.1 Introduction

All water departments need an appropriate system to manage all data and detect their problems. GIS is one of best tools for managing spatial data related to water systems. GIS is used as a too l for queries on large volumes of spatial data which becomes very important in many domains such as water department, communication networks, gas networks and transportation. All water departments need a system that manage all its data and detect its problems. Water systems have a spatial data, so GIS is one of the best tools for managing water distribution systems.

Generally network theory is the study of graph that represents relations between discrete objects. Several reasons motivate me to use GIS technology for hydraulic modeling to create connected water network. The geometric network I used in this research allowed me to model the behavior of water utility networks for Nablus municipality. Geometric network also uses network operator as a tool for inspecting the logical consistency of a network and verifying connectivity between two components in the network. Use of such network can find connected and disconnected parts of water network, and reconnect them. based on the geometric network many analysis can performed such as discover loops or short circuit and find out which valve in the network need to be closed when a burst location is defined

1.2 Motivation

Serious problems affected water systems in Palestine in the past 50 years due to bad infrastructure, Israeli restrictions, improper water use by the public, and bad water management practices in municipalities and water utilities.Water data in Nablus municipality have been stored randomly in such a way that complicates the possibility of using such data for decision making and so improving the existing water system and resolve their problems to reduce their leaks.

Water systems used in Palestine are intermittent water supply systems. where is water is supplied to the customer only in a specific period within the day or within the week not existed all the time and there are a tanks need to be fill with water to be the source of water for the customer at the time that the water supply period is finished . There is a need to build water system that simulates the existing water system to analyze the existing system. Using the proposed model the municipalities will be able to check the network connectivity and detect leaks because it can compare the model results with real values.

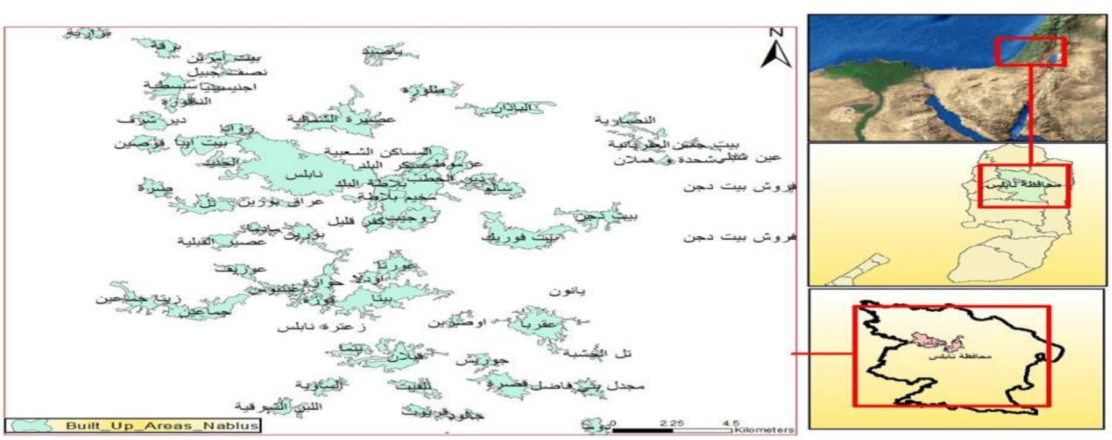


Figure 1: Nablus City.

1.3 Research problem

The existing data in municipalities or any organization such as electrical communication, and transportation companies need an intelligent system to make informed decisions. Water management is very important because the demand on water is increasing for various human and economic needs.

Data on water systems were prepared in different departments and came from different sources so therefore data is scattered and need to be compiled in one information system, so we can analyze or decision making. Thus the core issue in this research is to improve the existing water systems and resolve the existing problems such as the water leaks.

Water system is a network of nodes and edges and all its components must be connected to perform analysis of water systems. The Palestinian municipalities have no water network data that are professionally connected to be used for analysis.

Intermittent water supply systems have very low pressure not fully pressurized pipeline, pipeline like the continuous water supply systems that have a fully pressurized pipeline intermittent water supply systems have restricted water supply hours per day, roof tanks and roof tank connections. Spatial information about these component locations with the information about the hydraulic model simulation can and help in leak detection and leak location prediction. Restricted water supply hours per day, roof tanks and roof tank connections. There is no infrastructure or frameworks that combine spatial data and hydraulic rules.

1.4 Contribution

The main goal of this research is to support the intermittent supply in Palestine which is simply not supplying water all the time. Intermittent supply is common in Palestine and other countries due to inadequate water resources and insufficient infrastructure. The proposed model will prepare automatically all shape-files that represent the water network for any zone with intermittent supply, simulate water network during water cycle and calculate leaks in the network using an application programed by VB language under ArcGIS platform. feature in geometric network is used to model the component in the network such as lines or points and each group of features that share the same characteristics is gathered in the same feature class such as main pipes features in water network.

The geometric network consists of feature classes. Feature classes consist of sets of geographic features that have the same geometry species. All features in the same feature class have the same attributes in ArcGIS which enable us to inquire and select a specific field according to specific characteristic or according to a specific hydraulic model result under ArcGIS software. According to the analysis of the basic elements of the current data, we modify the existing shape-files, build the topology relations between water distribution network feature classes, improve data access within municipalities, and build an intelligent hydraulic model for intermittent water supply which operates for specific period of time. The model includes water tanks located at different elevations assigned to it using the contour line data. The hydraulic model is used to simulate the real water distribution network for different components water supply system.

1.5 Study Area

Nablus City is one of the Palestinian cities founded in 3600 BC and is the economic capital of Palestine. Its land area is 85 square kilometers. The city is located between two mountains; Eibal (940 m amsl) in the north and Gerizim (881 m amsl) in the south. It is called by several names such as Little Damascus, Mount of Fire, and Queen of Palestine. Nablus is one of the largest cities of Palestine in terms of population and the most important in terms of its geographical location. Its population is close to 321000 capita(2016). Nablus is located in the middle of the northern part of the West Bank. Nablus city and its boundaries are shown in figure 2 below

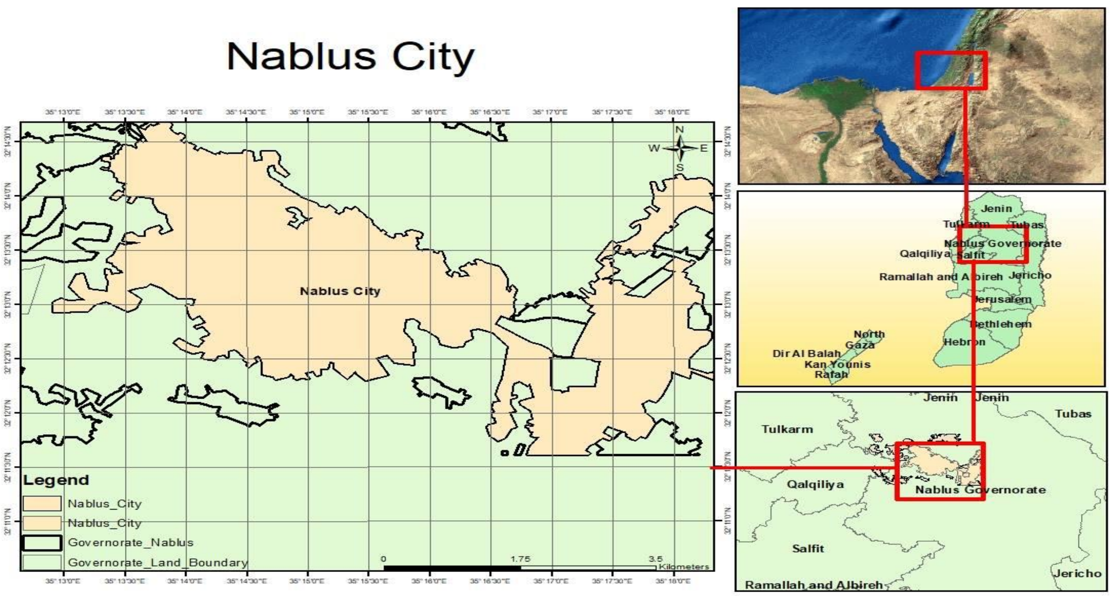


Figure 2: Nablus City and its boundaries.

Nablus has hot dry summers and moderate rainy winters. The maximum average temperature in Nablus city is 29.1 °C while the minimum average temperature is 6.2 °C.

[2] The main water sources of the City of Nablus is Odala well, Alfar’a well, AlBadan well, Alqaryoon, Deirsharaf well, EinBeit Elma, EinDefna, Ein Al-Asal, Sebastia well and Ras Al Ein. I have used a specific zone to perform my study. The zone is located in Ameria in Nablus the study area called by the municipality pressure zone W4. I have considered it as a District Metered Area (W4 Pressure Zone). The pressure zone W4 has a total area of 2580 Dunums. The water source for W4 pressure zone is Aljneed Tank which is supplied from Ayen Beet Alma station which is supplied from Deer Sharaf well and Sebastia Well.

1.6 Used Tools

I have used a computer with Intel® core (TM) i7-6500U CPU, the installed memory RAM is 8GB, and system type is 64-bit Operating System. ArcGIS 10.3 was used for data management, analysis, and build of the geometric network that is logically connecting all water distribution network components. ArcGIS 10.3 [3] which is Geographic information management software was linked to ArcObjects SDK as a middle ware. Visual Studio 2013 software, which is an integrated development environment to develop computer programs, web sites and mobile applications, was used as a tool for writing, coding, and performing the losses calculation. I have installed ArcObjects SDK, which is software that can be used r developing with ArcObjects in .NET to Link ArcGIS to Visual Studio. I have also used WaterGEMS V8i which is a Hydraulic Modeling Software that can be used to simulate water network and its features such as pressure, flow and headloss values.

1.7 Methodology

Decision Support Systems (DSS) use data, models and knowledge to help managers solve semi structured and unstructured problems. In the first phase of this research, I have defined the research problem, research approach, and research objectives. The main advantage of data analysis is detecting problems and finding solution to get ordered, understood and simplified data. On the other hand, data analysis show errors in data and show that some important data are missed. Nablus water department was taken as a case study. Initial data for Nablus water department were collected and transferred from AutoCAD to GIS that has lots of problems which needed to be fixed, modified and properly managed. It was difficult to modify the existing data errors and identify problems in various water network components in the study area, because the main problem was the lake of connectivity between network components because of the lack of service connection and build a service connection is required a lot of effort and a lot of time. To achieve the first goal of my thesis and build a connected water network and build DSS development, I need data on all water network components including main pipes, laterals pipes and house connection pipes, pumps, valves, and customer meters customer tanks. The house connections and customer tanks data were missed, so I have proposed an alternative solution instead of creating new house connections which require a lot of time, effort, and budget.

In the second phase, I used the geometric network which detects lots of problems. Geometric network detected two problems in the water data of the study area which is the lack of service connection and disconnections in many pipes especially at the network edges. In our proposed model we solved these two problems by preparing Substituting

Tanks (substituting tank is a tank for each groups of customer or roof tanks) and tanks connections using GIS and Excel software. Mathematically each substituting tank and substituting connection characteristics are explained in chapter three. There was a need to prepare a lot of shape-files for all line feature classes in line features category such as pipes and all point feature classes in point features category such as water tanks. Then data were analyzed to perform the research goal.

In the third phase, I built the hydraulic model using the WaterGEMS and linked its data to ArcGIS which was then used to rebuild the geometric network. Finally, the resulted geometric network was used to build a desktop application in GIS that can manipulate ArcGIS shape-files and perform losses calculations.

1.8 Document structure

In chapter one of this manuscript, I have discussed my contribution and motivation and explained the research problem and why I chose GIS tools and WaterGEMS hydraulic softwares to manage water system data in Palestine with Nablus city as a case study. In chapter two, I talked about the water supply system , explained the GIS as a tool for SDSS. In chapter three, I defined and built Water System Geodatabase and defined Water Geometric Network and its component. In chapter four, I defined the Hydraulic Model and performed the Hydraulic Model Analysis. In chapter five, I talked about definitions and kinds of Leaks in the Water Distribution Network in addition to performing Leak detection using different Approaches. The model was used to calculate losses. In chapter six, I defined the goals and objectives then I showed usage scenarios, class diagrams, and use case diagram. Finally, in chapter seven, I explained the System implementation and simulation using ArcObjects library.

2. Chapter two: State of Art

Water is very important as it is used in all life related fields such as agricultural, industrial and household. Water information is important to understand the way water and people interact.

2.1 Water supply system

Water supply system consists of engineered hydrologic components to provide water supply to the public. Several problems threaten the availability of water resources in Palestine, starting by losses, pollution, infrastructure, and the control of Israeli occupation over the existing water resources.

Water problems affect environmental and financial status in any country. In Palestine we are suffering from water losses especially in the major cities like Nablus city where the statistics of 2016 shows that 34% from the total supplied water were lost.

Water crisis is growing worldwide because of many factors such as, population growth and global climate changes that require the need for wise management of water resources. Water resources engineering is concerned with the design of better systems to manage water distribution, timing, and quality water. More quantities of water must be supplied to different zones in any city to provide enough water and avoiding water loss. All these factors must be considered in all regions because we may have too little or too much water, and may not be located where we need it. Water resources may be polluted or expensive so water resources information must be collected and archived to be used for water systems monitoring and management.

Many researches were performed for managing, monitoring water cycle and observing all factors that affect water availability, treatment and distribution. Lemos et al analyze urban water system using the Life Cycle Assessment (LCA) methodology. They consider all stages of processing such as water abstraction, treatment, water distribution, and water administration. Data used in this study have three levels according to its quality. They study each stage of water treatment to find what each stage affect. The results show that most electricity consumption was in water abstraction and treatment. [4]

GIS holds spatial data with all measurements of location and distance in addition to many other attributes of each feature. GIS used to generate maps which are a powerful communication medium. GIS provides attributes that help to generate reports and it is used as a mean to find relations between features. It is used to make decisions and find the best alternatives among them. There are many applications of GIS in water resources engineering starting from defining the watershed, representing location and spatial data and watershed characteristics such as, rainfall percentage and land-use change. GIS holds a series of maps layers that are geographically referenced. Each set of maps holds in a dataset considering a specific domain and registered to a common spatial reference. Each map is referred to as a layer. The layer is a slice that represents a specific component in particular area where all layer features have the same characteristics such as, political boundaries layer or roads layer. [5] Generally water system consists of water sources such as tanks which are containers that store water, distribution mains are sources for all end users that have drinkable or fresh water, fittings are used in water system to connect different pipe parts, system valves are devices that regulate and control the flow of water, pumps in water system are used to move water by mechanical action, laterals such as, house connection and service connection. Distribution main is the source for all running water in pipes of the water system. It is used to distribute the water to the end users in the water network. Each data type in the water system is represented in GIS software as a layer.

2.2 Related Work

Water leakage affects the water suppliers such as municipalities and customers worldwide. Many researchers give their attention to this point of research over the past years.

S. Adachi et al proposed a method to calculate leakage in a specific area by comparing the measured and the hydraulic simulation model results of pressure and flow considering the assist information. They prepared three leakage scenarios to minimize the leakage values, divide the area to three sub areas to calculate area leakage using, the assist information such as pipe length to calculate spatial factor of emitter coefficients. The drawbacks are the proposed method that cannot identify possible locations of leaks, on our system we take the results of the flow in the hydraulic model and compare it with the result of the SCADA data to predict the location of hotspots. On the other hand, the model does not show the results in GIS which can be used as a decision support system for a real water distribution network. [6]

EPEANT is a program that simulates the change of hydraulic pressure and water quality inside the pipe for long periods of time. Water networks consist of pipes and connections between them, pumps, valves and tanks as a source of water, other tanks are receiving water. EPEANT (hydraulic model) follows the flow of water in each tube, the pressure at each node, the height of the water in all tanks and the concentration of different types of chemicals in network during the simulation period and estimates the age of the water in the tank .Hydraulic model used to understand the function of the water in distribution network by diagnosing WDN problems such as, leakages and permutation of worn out pipes. Cherifa Abdelbaki et al used DXF2EPA software to convert all elements taken from DXF (AutoCAD format) to EPANET format since line and polyline layers convert to a set of fittings and pipes .Other elements in the water network are added to EPEANT manually such as tanks, valve and pumps. EPEANT does not take the GIS shape-file format which includes the feature class location and the database corresponding to that feature classes. Other softwares like water GEMS take the GIS file as a shape-file. The model results show that nodes with pressure less than 1 bar means it may have broken pipes . Nodes with pressure more than six bars mean that these nodes have serious leakage problems. Node with pressure between 1 and six bars is normal. [7]

Candelieri et al use the hydraulic simulation model EPANET based on a graph analysis for leak localization in urban water networks. They compare between traditional and spectral clustering approaches. Each leakage scenario is stored into a dataset with the pressure and flow values that are fetched from hydraulic simulation model with all other information related to the affected pipe. They build a graph that consists of edges and junctions. Each edge has a weight in term of flow and pressure to perform the graph clustering. They presented that the network can improve the leak localization. [8]

Alaeddinne Eljamassi et al studded the existing operation and maintenance system for Gaza strip. They combine GIS with WaterGEMS hydraulic modeling software to prepare a database for network component using a huge quantity of data. They use the hydraulic model results such as the pipes historical data to select which pipe lines to be replaced. On the other hand, they use GIS selection tools to find nodes pressure but they can't classify pipes or tanks according to its headloss, pressure or search about a specific pipe where they depend on selection of hydraulic results only on the existing selection tools in ArcGIS. They didn't perform any analysis on the hydraulic model such as checking the tanks percent of full or any other calculation. On other hand all their comparisons were based on normal shape-file not based on a geometric network. [9] Varade et al used GIS to minimize the water scarcity by identifying the best locations for water conservation. They use thematic maps and many other databases to get the best decision. The proposed model was useful in finding the best location for water saving but it will be more useful if they refine the model by using more interrelated layers and use a database that connects all layers which affected the site selection decision and considered all problems associated with it. [10]

The primary framework for Joao Coutinho-Rodrigues et al research is called MCPUIS (Multi criteria Planning of Urban Infrastructure Systems). MCPUIS consists of multi criteria decision analysis (MCDA) which is a set of methods used for decision aid by structuring and analyzing of data to obtain detailed comparative between alternatives in addition to the spatial analysis, relational DBMS (RDBMS), GIS for storing maps and visualization of the alternative on these maps and user-friendly computer interface. MCPUIS aim is to select the best water supply system to satisfy the new expanding demands. [11]

E. Karadirek et al build a hydraulic model using EPEANT hydraulic modeling software to simulate leakage, find optimum value and reduce pressure value to predict the amount of water saved. Water Distribution Network in Antalya, Turkey is used as study area. For better management of water losses they divided it into 18 district metered areas (DMAs). They reduce physical water losses by reducing the water pressure to the hydraulic model optimum value using a pressure reducing valve (PRV). MNF was high which indicates large physical water losses. Pressure and flow data resulted from the model were compared with SCADA Data system. The results show that most commercial water losses are because of customer metering inaccuracies. On the other hand, real losses are because of leakage on service connections to customer metering and leakage on transmission and distribution mains. They deal with continuous and not the intermittent supply. On our system we build a hydraulic model to find pressure and flow values in order to find the tanks percent of full with the elevation of each tank because we have deal with the intermittent supply. Real losses were calculated using the Minimum night flow then the model were performed as an application using ArcObjects to work under GIS for all zones and all water distribution networks within the intermittent supply parameters. [12]

S. Abdullah et al. proposed a framework based on GIS (base map) to facilitate data exchange and data integration between different branches (water, sewer, and transportation). This integration allows different employees in different enterprise to overcome the confusion especially on maintenance activities. They take the Khartoum State (KS) as a case study. They built Multi –Geodatabase in addition to Develop the search dialog and customization using VBA. [13]

Tabesh, M et al Proposed a model to find which pipe has the propriety for rehabilitation more than others in water networks. They consider many parameters for this calculation such as physical, hydraulic and empirical indices in addition to find the effect of each one to find the final model. They used GIS capabilities in the study area which showed that the pressure indices had the greatest effect on prioritizing the rehabilitation. Their contribution is to use Head Driven Simulation Method (HDSM) to analyze the hydraulic factors in addition to different measures for breakage. They combine the capabilities of these models with GIS conceptual model of prioritizing. This study was on a continuous water supply networks. [14]

Many definitions for leakage do exist. The main definition is the amount of water that is lost from the water distribution network pipes. There are many leakage assessment methods which are classified into two approaches. The first approach is the Top-down approaches and the second one is the Bottom-up approaches. Top-down approach is easier, cheaper and simpler that is used to estimate leakage in a specific system with the overall water balance and provide an overall picture of water losses. Bottom-up approach is more expensive and more complex, but it is more precise because it generally depends on the hydraulic measurements. It requires up-to-date and precise data. Real loss assessment using Bottom-up approach can be classified into two ways: the first one is 24 Hour Zone Measurement (HZM) approach and the second one is the Minimum Night Flow (MNF) approach [15]. Mutikanga et al study many methods, tools, theories and applications that have been developed over years in water distribution system to minimize water losses. They have criticized the gaps between water losses approaches and models theories and applications. The authors recommended the researcher to focus on the accuracy of input data to obtain perfect results in addition to focus more on the real losses. The authors encourage the researcher to consider water pressure measurements. Finally, the writers explain the importance of the strategic planning and consideration of different factors that affect the monitoring and planning for the existing and new WDN. GIS can be used as a tool to perform all these issues in addition to import other hydraulic software results to manage WDNs. [16]

Jaber M et al Perform the MNF for 30 zones from 361 zones in Kinta Valley were selected randomly as DMA. The minimum night flow (measured flow) was measured in the interval between 1:00 am to 5:00 am for each zone. They considered many physical, hydraulic and operational variables with MNF (L/s) such as pipe length (m) and pipe age (year), and number of connections. Then they performed the MNF calculation for all these zones which depend on its own characteristics. First, they calculated the weighted mean age of pipes for each zone, then they categorized pipes according to their diameter and pipe types then they compare the relationship between MNF and this different factor in the study zones to find how did these factors affected the MNF according to the variance between results in zones. Their contribution to the MNF (water loss) is the use of pipe length and weighted mean age. [17]

Amoatey et al used the MNF method using a DMA to find the net night use or the real losses where they use the formal equation that subtract the customer night use from the minimum night flow in the DMA. Customer night use estimated for two classes of users but they did not consider any unavoidable real losses. [18]

Reger et al use GIS technologies to find inexpensive geospatial way to be implemented in small water distribution systems or zones. They use the GPS to collect WDN features locations by building the dataset using the QGIS which is open source GIS software but the use of it needs an extensive background in data management to create data in QGIS. In contrast Esri's product (ArcGIS) has more capabilities with more user friendly, easy and flexible manner. They used CAD maps with no spatial data but spatial data enable the system operator to perform more analysis and give the abilities to accurate decisions.[19]

Fahid k et al designed a leakage monitoring system and focused on dividing the study area into DMAs with each one having its own defined permanent boundary and economic level of leakage that helped in detecting bursts faster and easier and DMA size etc. The DMA designing process pass through a set of steps: the first one is to plan and define the DMA, then making a site survey and finally implement the DMA. The leak monitoring in the designed DMA is performed by installing a flow meters in some critical and strategic points all over WDN. On the other hand, they used the bulk meters in different DMAs which enabled the network operator to give the priority to the DMA with greatest leakage value to be fixed first throughout the whole network. They used the WaterCAD software to build the hydraulic model. Such model didn't take into consideration many hydraulic parameters and they didn't link it with any GIS technology to find junctions with high pressure and pipes with high headloss values to give recommendations for the responsible company. [20]

Liang-Chien Chen et al built 3D geometric network model (GNM) and a building information model (BIM) which contains doors, windows and walls information to be used for 3D visualization by adding them to the GNM. They simulate the ladder trucks in a virtual 3D environment to find the best position for each ladder truck before the arrival of firefighters at the incident. 3D GNM is used to find the optimal path to the target buildings. [21] Sang-Hyun Lee et al used GIS and network analysis for rural tourism analysis that classified villages pursued to spatial centralization. They studied 43 villages and classify these villages according to different characteristics specifically their spatial characteristics such as accessibility. [22]

Ramesh et al used the GIS technology with hydraulic simulation software EPANET to estimate water demand. They performed the simulation for present demand and future demand scenarios. They considered different parameter to calculate demand but they did not consider customer meter readings which may differ from customer to another. [23]

Weifeng Li et AL proposed a method to detect leaks based on GIS by using the DMA strategy for effective detection, prediction and assessment of the probability of leaks in different pipelines. They proposed a model based on GIS for arranging water monitoring meters along the whole distribution network for better leak monitoring and managing in pipes network. They developed the pipe failure forecasting mode using data mining techniques, Genetic Programming (GP) using historic leakage information such as pipe material, age, diameter, length, leakage time and location. They focused mainly on the leak detection using historical data and meters distribution to monitor water leak for the real losses but they neglected commercial losses detection at divisional level. [24]

2.3 Geographic Information system

2.3.1 Geographic Information system definition

Water problems affect both the environmental and financial status in any country. In Palestine we suffer from water losses in general and in Nablus city particularly the statistics of 2012 shows that 38% from the total supplied water were lost. GIS is a special case of information system used for capturing, storing, checking, manipulating, analyzing and displaying data which are spatially referenced to the earth. [25] [26]The first known publication used the term GIS was in 1968 by .Dr. Tomlinson. [27]Dr. Tomlinson is recognized as the “Father of GIS “ who developed the first computer-based GIS for use by the Canada Land Inventory in the early 1960s. His effort in GIS domain led the Canadian government to give him its highest civilian award. “He pioneered its uses worldwide to collect, manage, and manipulate geographical data, changing the face of geography as a discipline.” [28] GIS supports spatial analyses because it visualizes locations to objects from different field of research such as, modeling the entire cycle of water supply network from the source to the household. GIS provides a tool for spatial data analysis and calculations in addition to allow users to make queries and to get answers. [29] There is no fixed definition of GIS because of the multiplicity of applications and differences on the identification of the objectives of this system. GIS is the science of computerized maps linked to databases that allow us to add, delete and modify in addition to perform queries in order to take the appropriate decisions. GIS is a Powerful system for linking sites and information about it and so it is a powerful tool for data visualization. [30] GIS data consist of two parts: Spatial Data and Descriptive Data. Spatial Data is information about the location and shape of geographic features with its coordinates. It connects feature relations with each other. Descriptive Data includes description of attributes associated with feature class characteristics which is stored in separate tables. GIS has two ways of representing spatial data (vector and raster). Vector data model represents the world by using points, lines, and polygons. It is used to store data that has discrete boundaries, such as electricity lines, water pipes, or streets. Deng et al used a method to combine vector data with the visualization of terrain because vector data used in many applications for the analysis and management of nature. [31]Raster data model represents the world as a surface divided into pixels (or cells) organized into rows and columns (or a grid). Each pixel has an associated value such as temperature. Raster is imagery from satellites, digital pictures, or scanned maps. It is used to store data that varies continuously, such as soil type, land use, a surface of chemical concentrations, rainfall, or an elevation surface. For example, in an elevation surface the pixel values may represent elevation above sea level which is represented as a grid of (usually square) cells. In the first phase of my research, I have picked up some previous scientific studies such as, methodological literature, previous works and industrial contexts. The second phase includes: understanding the problem and learning the GIS principles. Water problems are varying according to infrastructure of the study zone, availability of water in the study area, the way that used to distribute water in that area and the water network component and their characteristics. GIS help in representing all water network components and create the relation between all components to find the problems and try different solutions and choose the best one between all of the alternatives.

2.3.2 Geographic Information System as Decision Support System

GIS can be used as a tool for Spatial Decision Support System (SDSS) which is a decision making in time and space. SDSS is complex because it involves multiple objectives and constraints. It is a means to choose the best alternative among a set of alternatives in addition to its use as an intelligent and integrative tool for managing information, and knowledge in the desired domain. SDSS requires spatial information, structured or unstructured knowledge in addition to human determination. Decision making process can be with standard solution procedures (structured), or with no clear procedure (unstructured) or with combinations of both (standard procedures and individual judgments) to find the solution. The information for SDSS comes from different destinations such as maps and remote sensing …etc. This information is usually incomplete or imprecise and unstable with space and time. Thus, we need to manipulate it in an effective and efficient way using the human knowledge. Human Knowledge can be represented using the IF THEN rule base system. In writing this rule base system, we must avoid loops in the rule set and disjunction in the ancestry. Spatial decision making process involved information and knowledge sides [32] as shown in the figure 3 below. SDSS requires the integration between the spatial data and other algorithms, techniques or tools to decide the best decision between different alternatives. GIS can be considered as one of these tools [33]

GIS is a science which connects the computerized maps with the database. Uslu A et al use the Urban information system in addition to the GIS capabilities to process, evaluate and analyze the data that belongs to the water distribution system in Ondokuz Mayıs, which is a District in the city of Samsun, Turkey .They entered pipes data using GIS technology to represent the water distribution system but they didn't build a network and provide it with a topology between layers to make the system more intelligent. They used the GIS technology for automatic computation of node elevations from DEM. [34]

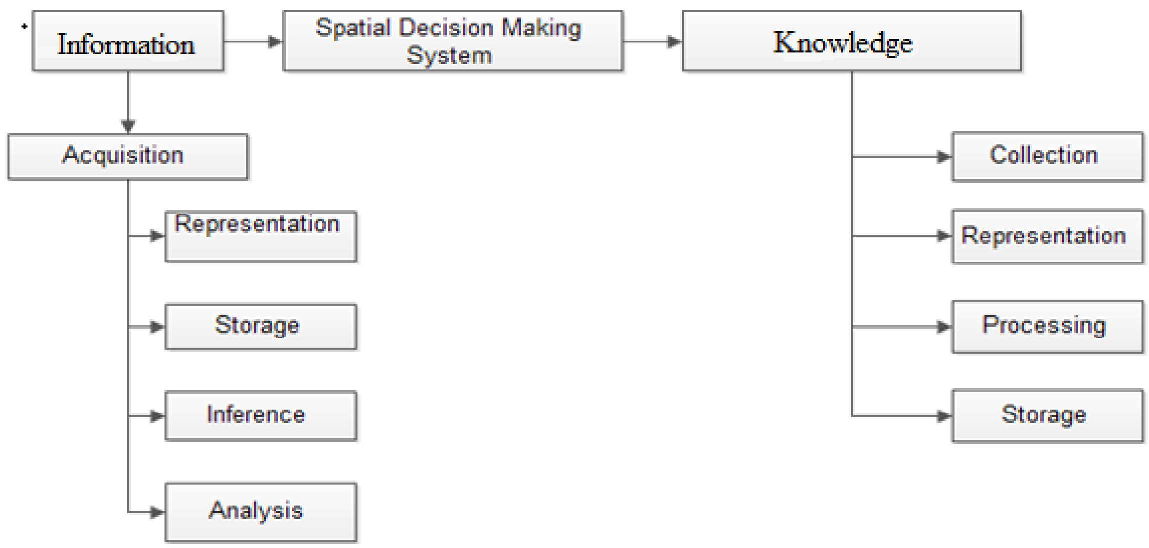


Figure 3: Spatial Decision Support System.

Any software may be an open source or closed software. There are many examples of open source GIS softwares such as: SAGA GIS, gvSIG, and QGIS, softwares. [19] An example of a closed software is ArcGIS software, which was selected to perform this thesis project. ArcMap 10.3 GIS software produced by the ESRI Company was used. ArcMap 10.3 software is a GIS software that provides query for vector and raster-based graphical and non-graphical data. ArcMap is used here because of its functions of displaying, updating, querying, analyzing, and reporting current graphical and verbal data, and it provides the user with the high-quality cartographic presentations.

2.4 Water Network as a distributed system and complex adaptive system

Water network is a network of distributed components each component has a specific task. Water network consists of large number of nodes such as customer meter, bulk meters, pumps, pipes and valves that are generally deployed in an ad hoc manner in vast geographical areas for remote operations. In my model, I have collected each group of tanks as a cluster and each cluster has a node (tank) that acts as the cluster head. The water network is having the ability to add large quantities of nodes (customers) without affecting the whole system or the performance or the effectiveness of the system so the Water network is a scale system. Another important characteristic in the water system is that it has the ability to add or delete new node (customer) at any time without affecting the characteristic of the system so the water system is a distributed embedded that will be explained in this research a case study for water system.

Transparency is needed in water system since the main goal in the distributed system is to hide the fact that the component and devices that form the distributed system are allocated widely in separate logical area and let it appear to the users as a single coherent system. Generally the transparency concept can be applied to several aspects of a distributed system that will be discussed as the most important ones and how it can be achieve in the embedded distributed system as a case study in water distributed system. Node localization refers to creating location awareness in all deployed water system nodes.

The Location information is one of the most important issues in the water system because it helps the system to detect the events and to rout packets between pipes, valves and roof tanks nodes to share its information and to easily detect problems. Water system is distributed and complex system. Location transparency is across large buildings or large areas. One of the main tasks of this network is to forward the water form water sources using the pumps to a specific tanks so the position of this tank and its elevation should be detected in the network. We have two ways to find the positions of theses nodes the first way is by GPS (global position system) but this solution is a costly solution, while the other solution is to use the predefined location nodes information using GIS technology coupled with a hydraulic system. On other hand in distributed embedded system. The scalability mean that the system is still scale and keep its performance even if we add more nodes in large quantities to the network the scalability in the water network allow customers or nodes within a building to be added in such a way that allow the system to still able to achieve its tasks without affecting the system performance. The water network need for scalability which give the network to add a large number of nodes without limiting the effectiveness or the performance of the network.

In this part I will analyze the water system from a Complex Adaptive System perspective, how to build intelligent model using GIS technology and hydraulic system. A. Rattrout et al defines CAS as a set of integrating nodes or agent that form a set of patterns of behavior. CAS can be applied in many fields that have several common that discussed and how these features apply to the water system. The complex adaptive system components interact to form the behavior of the whole system. The water system has many agents or component including users, pipes, tanks, wells customer meters, pumps, and roof tanks ... etc. The CAS component needs to adapt to the change in the environment. At water CAS level water adapts and change their internal model and behavior according to their temporal-spatial organization. For example when the water cycle starts, water tanks are adapting with the changes and modify consciously its content of water. Water networks are dynamic systems that by effect of its internal changes or by effects of external changes it is change over time. For example, water pressure and flow changes over time in an unpredictable way. Hence, a water network operation should be able to retrieve and adapt to the current network states.

John Holland identified some basic elements of CAS which is Aggregation, Tagging, Non-linearity, Flows, Diversity, Internal models and building blocks. In water system using GIS technology, each component in the water system is identified by special tag which represents Tagging mechanism. Water system is nonlinear system because the change of the output is not because of the change of the input and data changes form one zone to the other and from one water cycle to another. An example is when we pumped water to the zone not all water will be in tanks because some of them will go as real losses or as commercial losses which must be considered for losses calculations. The water system components are the building blocks for distributed systems services. [35] The complexity will be how to design water network that adapts to changes in structure, and has a minimal communication cost (Localization). Node localization refers to creating location awareness in all deployed nodes. I have clustered the water network for many zones with each one representing a DMA.

Conclusion

GIS is one of the best technologies that facilitate data management. It can be used to support spatial decisions because it considers all geographic data with data from multiple sources. So GIS is one of the best tools for water systems management.

3. Chapter Three: Our Approach for building water network

3.1 Water System Geodatabase

Database is generally used to store, maintain and manipulate data. Geodatabase is used to store spatial data or geometry data in addition to traditional data or multimedia data. Geodatabase contain a collection of datasets including feature classes, raster datasets and network datasets as geometric network or network dataset. We can modify and work with all these datasets with a Database Management System (DBMS) such as SQL or using ArcGIS. The geodatabase can be accessed, modified, and updated by SQL when it is stored as a spatial type. The geodatabase has a storage model with different feature classes and different data type such as point, line and polygon. For example, the water tanks feature class is stored in the geodatabase as point feature class and as a table with attributes and records. Each record is a feature and each attribute is a characteristic of that feature class records. The attribute is called shape that stored the point geometry. There are many advantages for storing data in a Geodatabase where we can create subtypes. Subtypes are branches from the main type such as the land use, commercial, Industrial, religious, and agricultural branches.

Information about water resources is inherently geographic. The worldwide water distribution network is continuously expanding. Pipelines are a means for water distribution but it does not mean they are free of risks. One of the most important risks that must be considered and detected is the leaks.

Before rehabilitation of the water network, we must check the network problems such as the connectivity relations between the network components and the location of the leak, its size, etc.

3.2 Water Geometric Network

Geometric Network is a new method of participatory decision relies on the creation of a GIS database. Water system consists of main components such as Water Source, Main Pipes, Laterals, Service Connection, Fittings and Water Sink. There are two water supply system which differ from country to another according to the water availability and water infrastructure which are Continuous supply and Intermittent supply.

Geometric networks provide a way to present common networks in the real world such as water distribution, electrical lines and water flow .Geometric network can model and analyze all these networks**.** In my water network I built Geometric networks (utility and river networks) not Network datasets (transportation networks) because Geometric networks allow agent to travel in only one direction at a time on edges. So agent can't choose which Path to travel. The destination is determined by external forces such as electromagnetism and water pressure. So the programmer has the ability to control the flow of the agent by controlling how outer forces affect the agent. In contrast, Network datasets such as street allow the agent to travel on edges in two directions. The agents are free to decide the path of travel besides the destination.

Geometric network consists of a set of feature classes. All the feature classes that participate in the geometric network must be stored in the same feature dataset which is created inside the file Geodatabase. New feature classes and new subtypes also can be created on ArcCatelog to make the editing easy. Feature Class is simply a table in a database that has record with geometry data. Each record has a type. This special field called geometry such as point, line and polygon. The moment I add them to ArcMap it becomes a layer, so the layer can't exist by itself it has to have data, table and feature class or source for it .The geometric network icon will appear inside the feature dataset in the Arc Catalog Tree when the geometric network is created. Geometric Networks such as water, electricity, sewer and gas networks consist of Edges (Line feature classes) since all edges end with a junction. Those have distance and direction Junctions (Point feature classes) Junctions may be one of two states: the first is to be end point of an edge and the second is to be an intersection between edges. If the point in point feature class is not available to serve as junction, an orphan junction will be created in the junction feature class. Edges and junction can be simple or complex. Simple edge is the edge that has two junctions at its two ends and it corresponds to a single edge element in the logical network. Complex has at least two junctions along its length so it consists of one or more edge element in the geometric network. Simple junction is the junctions that correspond to a point in the point feature classes that have two kinds: Source is the location where the flow originates and Sink is the location where the flow ends. The second kind of junction is complex junction (orphan junction) which is not built according to the user source data but it is built when the first edge is added to the geometric network.

There are many networks in the real world such as water distribution, electrical lines and transportation networks. GIS is used as a tool to represent all of these networks in order to manipulate, manage and perform many querying and analysis**.** Many research based on GIS technology are used in all types of these networks. GIS is widely used in urban planning for site location planning of different network components such as energy supply systems, gas supply network, and water systems. Yeo et al integrated GIS with climate, energy information to find location of energy supply plants. [36]Many researchers study the traffic problems using GIS. Mokashi et al used GIS for effective transport planning for London transportation considering the existed transportation challenges. Data collection methods vary between quantitative and qualitative methods to improve the existed transportation system [37]. Jiang et al used GIS technology for representing transportation network and predicting traffic flow. Jiang et al used the street-based topological representations. They used other modeling such as pedestrian modelling, crime analysis which helps for more analysis and better results. [38] Xinhao Wang was Integrate GIS and simulation modelling in order to support decision making. They used GIS to visualize all geographic data and results for traffic data modelling and simulation. [39] Bengang Li used the vehicle types and traffic conditions to predict traffic noise. They used GIS technology for noise modeling. [40] Many other researchers used GIS technology to monitor, manage, model and assess water distribution network. Ruggeri combined satellite data, GPS data, and GIS environment to assess of the Byzantine water supply system. [41]

3.2.1 Geometric Network Component

Geometric network contains edges and junctions (which are lines and points and it is given these spatial name in a geometric network). The edges are simple or complex edges defined when we created the geometric network.

Geometric network is created in the feature dataset. Feature classes in feature dataset will get additional behavior. Its behavior actually changes. It is not just simply a line and a point. We call them edges and junctions because the edges know what junctions are connected to and junctions know what edges are connected to. So there is some additional behavior with network feature classes when they are in a geometric network and that’s why we use these spatial terms for. Geometric network has a Connectivity relationship between the feature classes that you specify in your network. Now an important consideration about this, is that, a connectivity within a network is based on geometric coincidence that for we got a name geometric network. So when you are creating features in a geometric network or removing features how those features are connected is dedicated by their X,Y location. Connectivity index is a collection of tables that lives within the Geodatabase behind the seen. It stores all connectivity information between features in the network .If you have a primary information stored in the connectivity index about a specific feature and you decide to delete this feature information, that is stored in these tables it will be deleted automatically without the user interference because this connectivity information in these tables is not being shown in ArcGIS. We don't interact with ArcCatalog or ArcMap directly with these tables used by us behind the seen to maintain this connectivity and keep it up-to-date.

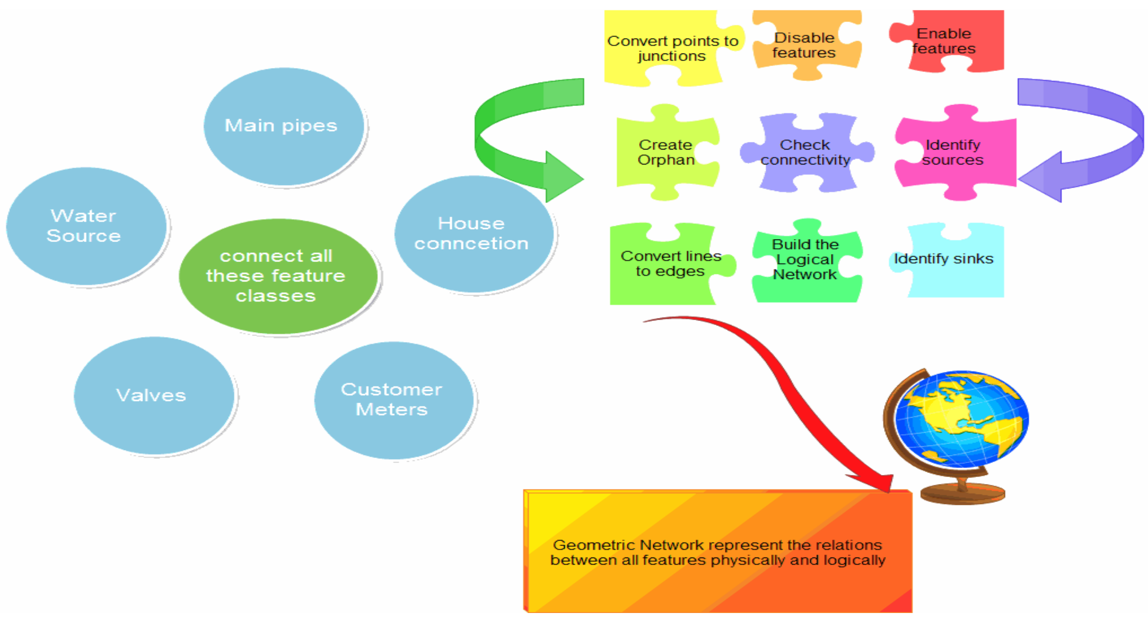


Figure 4: The Geometric Network Component How it is Manipulate And connect to provide the final Geometric network with all connected component.

3.2.2 Geometric Network Analysis

The geometric network faces two types of problems: the first one was the lack of connection (service connection) between the customer meter and pipe lateral. Thus there were many meters which are not connected to the network pipes and this is not acceptable in the geometric network. On the other hand, if we draw the service connection the model will involve a large number of pipes which means a complex process. The second problem is that many pipes are not connected to any edge. I have solved these problems and prepare shape-files that support the intermittent supply using the following scenario.

First of all I have transformed the contour lines to DEM which is an example of the models that helps us represent and understand the real world elevation. Secondly, I have assigned elevation to customers. As shown in figure 5.

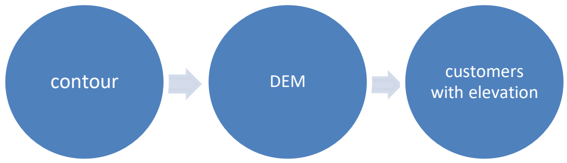


Figure 5: Transfer the contour lines to digital elevation model and assign elevation to customer.

The created shape-files is first, substituting tank shape-file. The Preparation of the Substituting Tank which is a tank for each group of meters that represents a set of roof tanks using GIS software. I have created the fishnet network that represents the substituting tank (fishnet network is a grid of points) then assigned each customer to the nearest Point (Substituting Tank) in the fishnet network, as shown in figure 6 below.

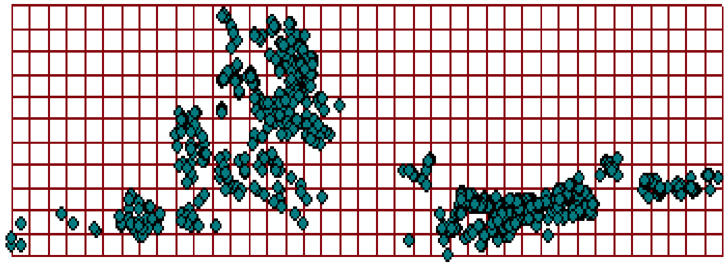


Figure 6: Fishnet network with customer meter.

The second shape-file is the Junctions shape-file. I have found the distance between customers and junctions to find the nearest junction for each customer. In excel sheet I have created a pivot table ordered by Points (Substituting Tanks) called customer to tank table. For each substituting tank, the Number of substituted Customers, Minimum Elevation of substituted Customers, Maximum Elevation of substituted Customers and Average distance from substituted customers to the nearest junction was calculated. Finally, I have linked this table with the fishnet network to obtain a substituting tank shape-file and add the following parameters to each substituting tank.

The parameters for each substituting tank are:

- Water level: Water level in each tank equals maximal customer elevation minus minimal customer elevation plus average tank height

$$[cust_{Max} - cust_{Min}] + Tank_{avh} \tag{1}$$

- Tank Diameter.

$$\mathbf{volume} = \frac{\pi}{4} * \mathbf{D}^2 * \mathbf{h} \quad \rightarrow \quad \boldsymbol{D_{equi}} = \sqrt{\frac{\boldsymbol{4*customers*V_{tank}}}{\boldsymbol{\pi*h}}} \tag{2}$$

V_{tank}= Average Volume per customer which is 2.5 , h = water level (as calculated before

- Tank Elevation. The Elevation of each substituting tank is equal to the elevation of its lowest customer plus average elevation of roof tanks above ground (in our case 25m).

$$Tank_{elev} = elev_{lowest\ customer} + elev_{roof\ tank\ abobe\ the\ groound} \quad (3)$$

The third shape-file is Tank Connections shape-file: I have created tank connection shape-file using GIS then I calculate the Tank Connection Properties as follow:

- Equivalent Diameter

$$d_{equi} = n^{\frac{2}{5}} * \boldsymbol{d_{av}} \quad (4)$$

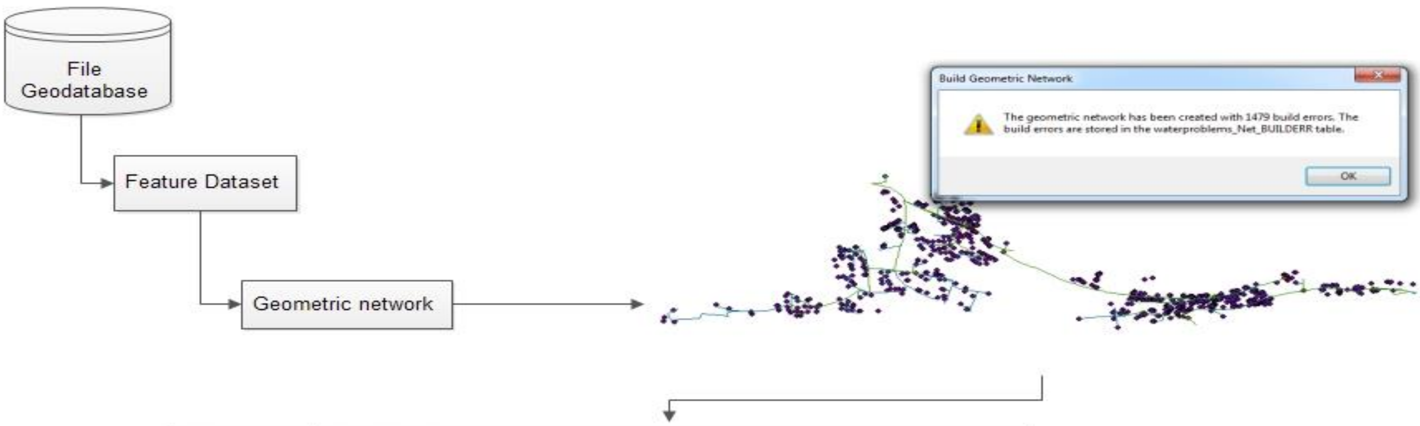
d_{av} : Average House Connection Diameter , which is 12.7

n: number of Customers.

- Length. Which is equals to average distance on it from customer meter.

The geometric network built, maintained and edited the errors in water pipes in the geometric network using the geometric network editing tool. The geometric network that's built in the feature dataset can detect seven kinds of errors that explained in a table in figure 7. I have faced two kinds of problems in Nablus city data which are: error 11 that mean "The feature's geometry has multiple parts ". An example shown in figure 8 below, since these two highlighted geometry parts are made up of disconnected or discontinuous parts. I have 10 errors of this kind. The second kind is error 16 "The junction is not connected to any other edge feature" as shown in figure 9. I have 1479 error of this kind, as shown in figure 10 .The errors stored in a table called NET_BUILDER, Figure 7 shows

NET_BUILDER table and the geometric network editing toolbar that have used to detect all the problems in the network.



Error code	Error description
10	The feature has an empty geometry.
11	The feature's geometry has multiple parts.
12	The feature's begin and end vertex are the same.
13	The feature has a geometry with zero length.
14	The edge feature is associated with the same from-to junction feature.
15	The junction is coincident with an edge-feature vertex having a different z-value.
16	The junction is not connected to any other edge feature.

Figure 7: The Geometric network build errors.

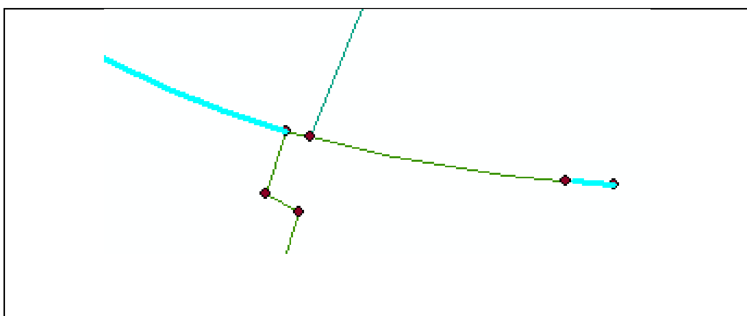


Figure 8: An example of error 11 in GN

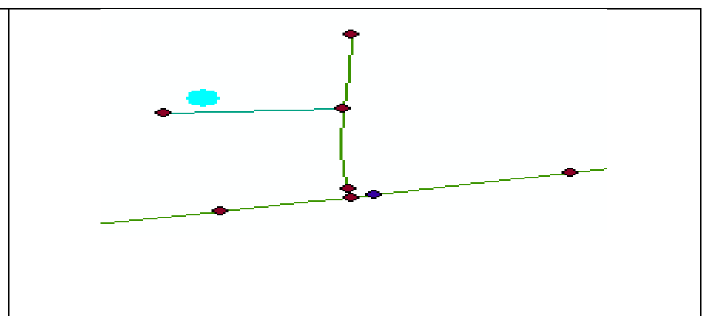


Figure 9: An example of error 16 in GN

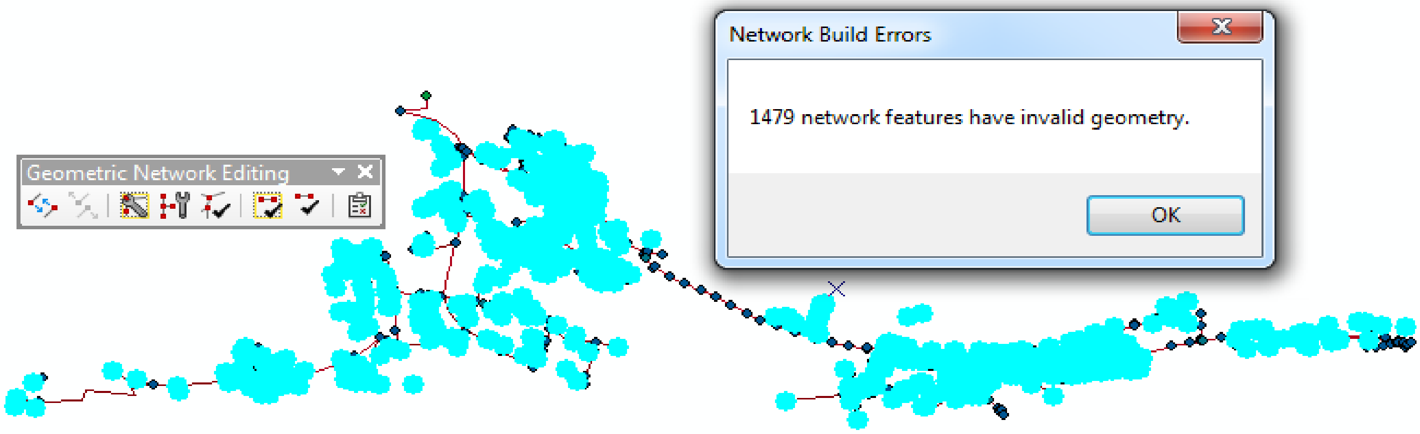


Figure 10: An example of the Geometric network errors where the junction is not connected to any other edge feature.

Using the utility network analyst I have traced other problems in the network such as find loops, connected and disconnected components. An example of loops detection is shown in figure 11. Figure 12 shows the corrected geometric network which is connected logically in a perfect way and we are able to perform any analysis on it.

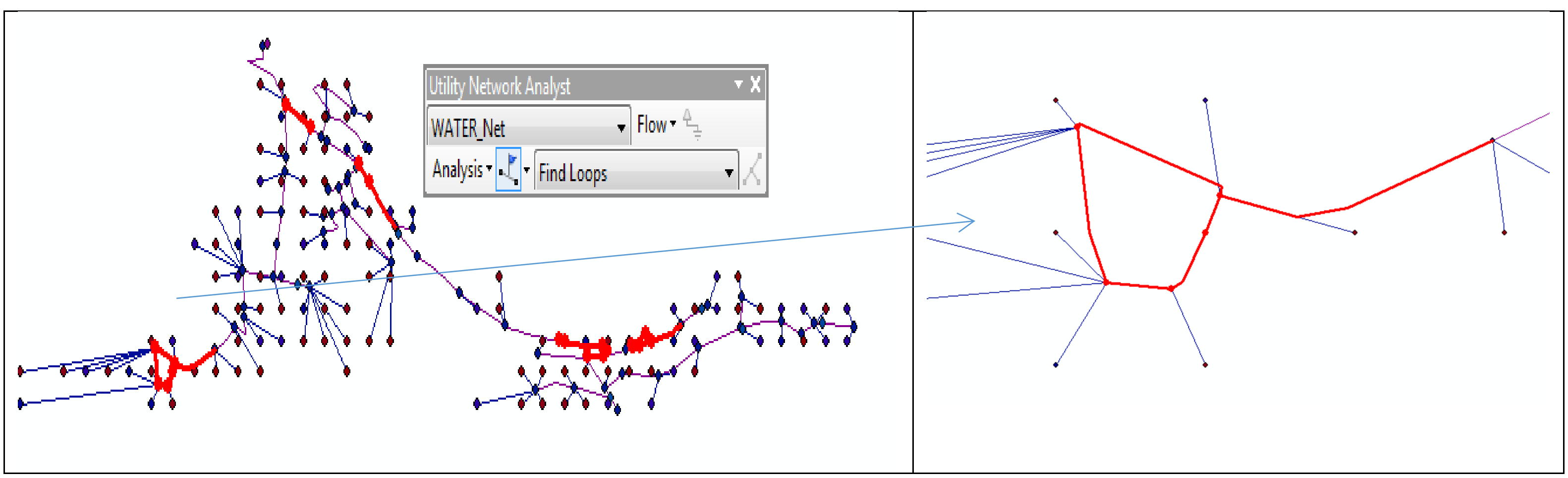


Figure 11: The corrected geometric network which is connected logically in a perfect way and we are able to perform any analysis on it.

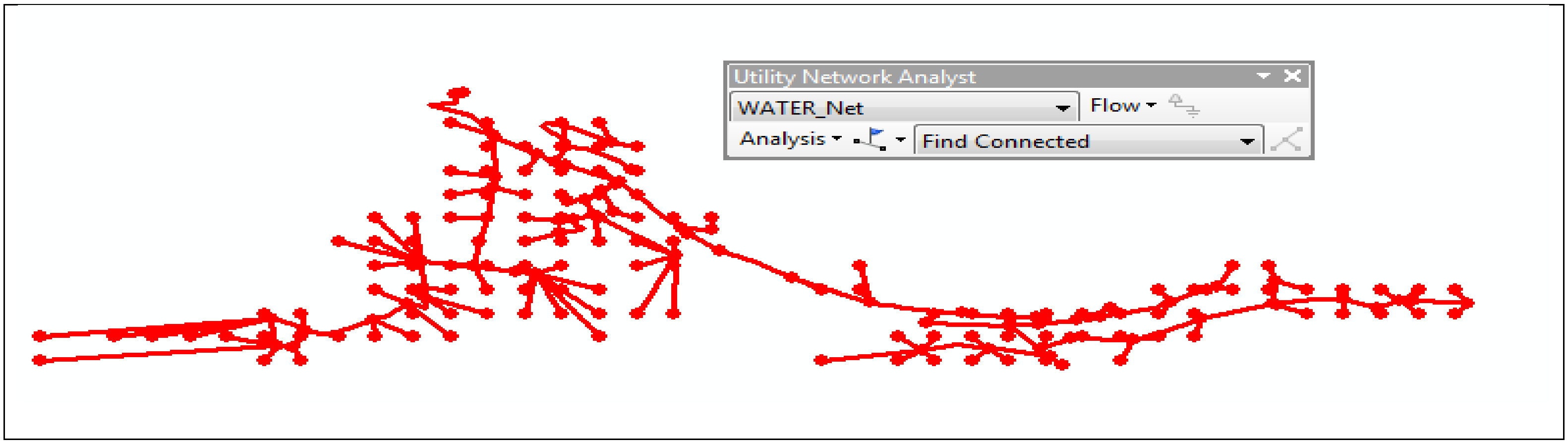


Figure 12: The Geometric Network Connected and checked using the Utility Network Analyst toolbar.

I have created the intermittent supply model which have been used to create the shape-file for any zone . Based on Geometric Network many analyses can be performed on the network such as determine the near valve to each pipe ,to easly take a decision on which valve to close when the pipes relate to it is burst as shown in figure 13.

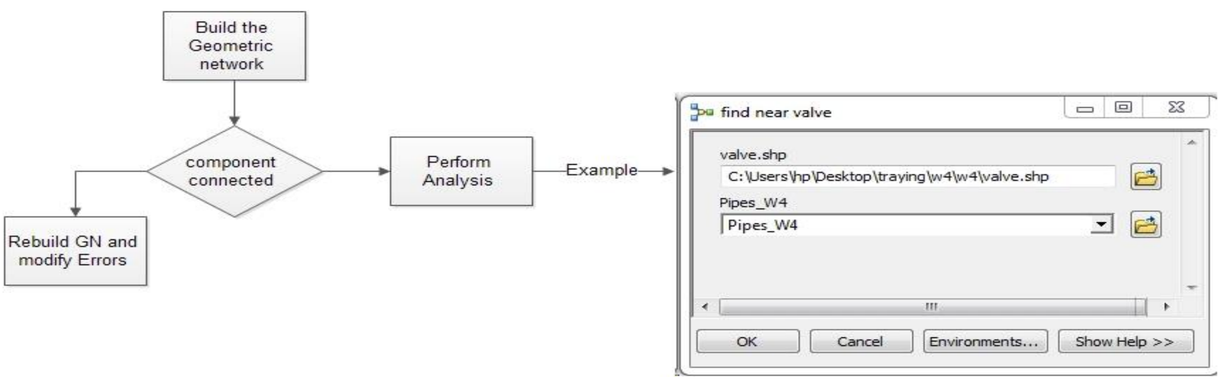


Figure 13: Geometric Network Analysis to find the nearest valve to each bursts pipes.

Conclusion

Water system can be ordered in a geodatabase that is used to build a geometric network connecting all water network components. Using geometric network I have analyzed water network and detected all problems and find solutions by fixing such problems.

4. Chapter Four: Simulation using WaterGEMS

4.1 Hydraulic Model Definition

Generally network modeling is a tool for giving the required answers such as, pipes rehabilitation. The hydraulic simulation of Nablus water distribution network was performed by WaterGEMS. WaterGEMS user can import different data types including ArcView, Arc Info, AutoCAD DWG, DXF files, Shape-files, relational database, such as the Microsoft Access and excel sheets. [42]

WaterGEMS provides an intelligent decision for water distribution since it is a Water Distribution Analysis and Design Software. It can be used for simulating network problems which can be easily identified and repaired. WaterGEMS tracks the flow of water in pipes, pressure at each node (pressure at junctions) and the height of the water in each tank. [43]

I have combined the capabilities of ArcGIS and WaterGEMS software to help network operators in analyzing malfunctions. The collection of all information is related to a water system based on geographical location that can help network operators to diagnose a network, study different solution of different problems, predict future situations and facilitate deeper understanding of the work performed on the network. This combination between the hydraulic simulation modeling tool and spatial data visualizing and management tool can help water network operator in decision making in the future to obtain optimal network operation, since water management goals cannot be reached in GIS application without linking it to the hydraulic simulation models. [44]

4.2 Build hydraulic model

I have built a Hydraulic simulation model for Nablus city using the capabilities of WaterGEMS and ArcGIS software. In ArcGIS, I have assigned the elevation to the customers (water tank). In WaterGEMS a hydraulic model was built using data from previous step by WaterGEMS hydraulic simulation software I have added the water pipes and added the junctions according to different principles such as demand, notable change in pipe diameter, pipe fork and because of an existence of a fitting. Junction will have data about elevation which are added by WaterGEMS.

The framework of hydraulic model relies on the creation of a model that simulates the water distribution network in real and helps the stakeholders in easier access to data and giving them results that help to maintain and repair different problems in WDN. To build the hydraulic model, shape-files that are prepared in GIS (pipes, substituting tanks, junctions, and source) are imported into Hydraulic model. Elevations assigned to different nodes such as tanks and I have assigned the hydraulic characteristics which includes the simulation starting date 8/26/2016, start time 9:55:00 PM , duration 50 hours, time analysis type (EPS) which is extended period simulation that observed for set duration of time throughout the day, hydraulic time step (hour) 0.050 hours. On the other hand, I have defined the control information such as mode of pump operation, check valve fixed in low pressure because we use the tanks to represent the substituting tanks (sink) not as a source of water so to define the water flow we need to fix the sink and source very clearly. The hydraulic models results of pipes headloss, nodes pressure and tank present full are explained in figure 16, 17 with the color coding for each property.

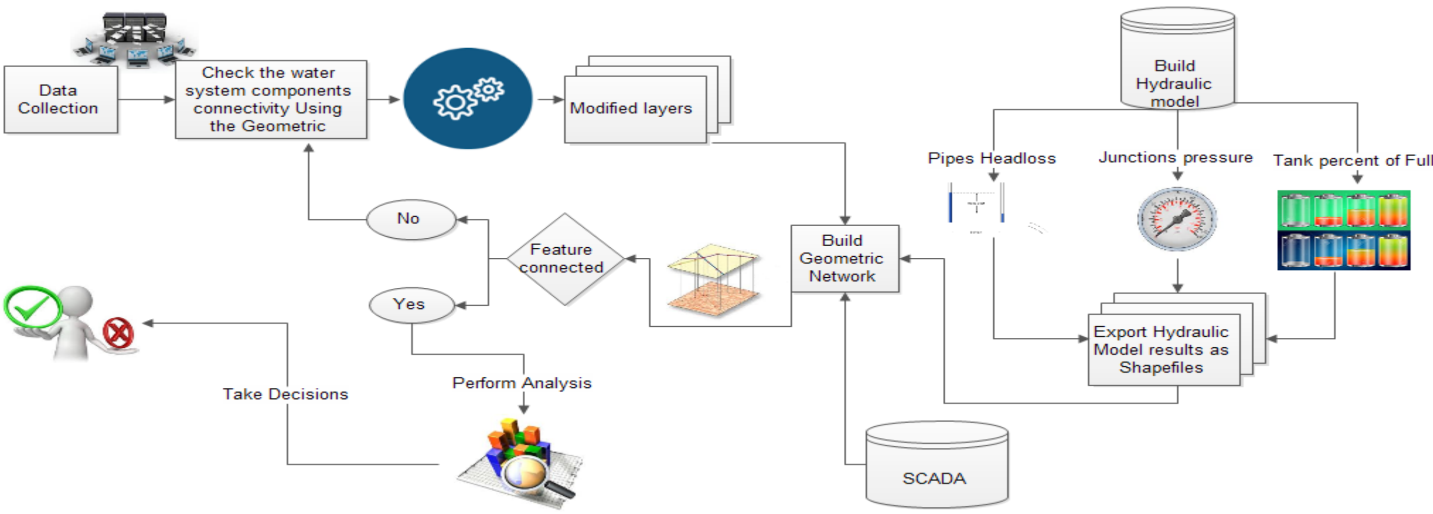


Figure 14: The whole model Estimating losses in Intermittent Supply system Using Geometric Network Based on GIS Hydraulic Modeling.

Figure 14 shows all water system components that interact to perform the required tasks of the system. WaterGEMS software is used to build the hydraulic model, ArcGIS is used to build the geometric network then its results are imported into ArcGIS to calculate water losses. Hydraulic model results are then compared to SCADA SYSTEM Data. SCADA is supervisory control and data acquisition (SCADA) which is a control system architecture used for high-level process supervisory management.

Using the hydraulic model results I can select tanks that are not hundred percent full when the 50 hours duration is finished and so I give recommendation to water departments to check water tank or to increase water pumping duration, select pipes that have no accepted headloss values and junction with high pressure.

The proposed hydraulic model in WaterGEMS for the study area provides the network operators with pressure readings at different junctions and different period of time during the water cycle. Table 1 shows some examples of the pressure readings at the start, during and at the end of the cycle. Junction 5 shows that the pressure values is increasing with the increasing of time .Other examples such as junctions 1, 2, 3 show the pressure readings at the beginning of the cycle. Finally junctions 7, 8, 9, 10, 11 show the pressure values at the end of the cycle.

Table 1:Hydraulic model results , different junctions pressure at different time during the restricted water suply hours per day .

Junction	Date	Time	Elevation (Meter)	Geometry X_Access	Geometry Y_Access	Pressure (m H2O)
Jun1	26/8/2016	9:55 PM	694.79	171,486.34	180,688.49	0.00
Jun2	26/8/2016	9:55 PM	726.67	171,372.41	180,764.44	-28
Jun3	26/8/2016	9:55 PM	690.24	172,209.78	180,470.34	-10
Jun4	27/8/2016	11:25 AM	690.22	171,199.55	181,160.11	16
Jun5	26/8/2016	9:55 PM	690.24	172,209.78	180,470.34	0.00
Jun5	27/8/2016	12:19 AM	690.24	172,209.78	180,470.34	4
Jun5	27/8/2016	5:22 AM	690.24	172,209.78	180,470.34	10
Jun5	27/8/2016	7:31 AM	690.24	172,209.78	180,470.34	17
Jun5	27/8/2016	10:7 AM	690.24	172,209.78	180,470.34	19
Jun5	27/8/2016	2:34 PM	690.24	172,209.78	180,470.34	25
Jun5	27/8/2016	5:43 PM	690.24	172,209.78	180,470.34	35
Jun5	27/8/2016	8:28 PM	690.24	172,209.78	180,470.34	42
Jun5	28/8/2016	12:46 AM	690.24	172,209.78	180,470.34	54
Jun5	28/8/2016	3:46 AM	690.24	172,209.78	180,470.34	60
Jun5	28/8/2016	6:58 AM	690.24	172,209.78	180,470.34	69
Jun5	28/8/2016	10:43 AM	690.24	172,209.78	180,470.34	80
Jun5	28/8/2016	1:31 PM	690.24	172,209.78	180,470.34	92
Jun5	28/8/2016	2:52 PM	690.24	172,209.78	180,470.34	105
Jun5	28/8/2016	11:55 PM	690.24	172,209.78	180,470.34	106
Jun6	26/8/2016	10:40 PM	668.46	171,196.80	181,173.14	37.86
Jun7	27/8/2016	12:34 PM	668.46	171,196.80	181,173.14	28.91
Jun8	28/8/2016	11:55 PM	716.52	172,360.70	180,384.44	80
Jun9	28/8/2016	11:55 PM	733.34	171,685.41	180,668.72	34
Jun10	28/8/2016	11:55 PM	667.68	171,199.55	181,160.11	129
Jun11	27/8/2016	11:55 PM	673.31	172,456.10	180,424.62	123

Other results of the hydraulic model are shown in Table 2 which explains some examples of tank percent of full during the Water pumping cycle. Each row represents a tank T1, T2 and T3 represent theirs percent of full at the beginning of the water pumping cycle.T3, T4 and T5 show how tank percent of full increase during the cycle. T6 and T7 show the tanks content of water from the beginning, through and until the end of the cycle.T8, T9, T10 and T11 show their percentage of full at the end of the cycle and how these tanks don't have a one hundred percent of full which give a recommendation to the responsible body to treat the problem in any way such as increasing the water pumping cycle time.

Table 2: The hydraulic model results , tanks percent of Full at different times during the restricted water supply houres per day.

Tank	Elevation (M)	Diameter (M)	Date	Time	Tank Load Percent
T1	690	2.57	26/8/2016	9:55 PM	0
T2	643.20	3.50	26/8/2016	9:55 PM	0
T3	678.12	1.01	27/8/2016	5:43 AM	15
T3	678.12	1.01	27/8/2016	10:13 AM	67.6
T3	678.12	1.01	27/8/2016	2:04 PM	100
T4	700.23	1.11	27/8/2016	2:04 PM	1.4
T4	700.23	1.11	27/8/2016	5:49 PM	62.7
T4	700.23	1.11	27/8/2016	6:49 PM	94.4
T4	700.23	1.11	27/8/2016	8:10 PM	100
T5	710.65	1.35	27/8/2016	8:10 PM	52
T6	742.66	1.96	27/8/2016	9:58 PM	0
T6	742.66	1.96	27/8/2016	10:58 PM	2.1
T6	742.66	1.96	28/8/2016	3:28 AM	47.4
T6	742.66	1.96	28/8/2016	5:13 AM	69
T6	742.66	1.96	28/8/2016	6:7 AM	80.6
T6	742.66	1.96	28/8/2016	6:55 AM	91.2
T6	742.66	1.96	28/8/2016	7:55 AM	100
T7	659.33	5.39	28/8/2016	9:22 AM	42.1
T7	659.33	5.39	28/8/2016	4:52 PM	63.1
T7	659.33	5.39	28/8/2016	11:55 PM	63.3
T8	665.81	4.55	28/8/2016	11:55 PM	58.9
T9	744.47	2.57	28/8/2016	11:55 PM	35.5
T10	744.63	1.03	28/8/2016	11:55 PM	35.6
T11	722.98	2.57	28/8/2016	11:55 PM	35.5

In this hydraulic model we have chosen the Darcy – Weisbach equation which is :

$$h_f = \gamma * \frac{l}{d} * \frac{8*Q^2}{\pi^2 * d^4 * g} \tag{5}$$

h_f *is friction head loss*

γ *is dimensionless friction factor* $[-]$

l *is length of pipe section* $[m]$

d *is diameter* $[m]$

Q *volume flow* $[m^3/s]$

g *is gravitationl acceleration* $[m/s^2]$

That relates the headloss, or pressure values. It considers friction loss along the length of a given pipe to the average velocity of the fluid flow. Friction coefficient and length of pipe affect the headloss. When the pipe length increases the headloss will increase. When the headloss increases the needed power for delivering water to customers will increase. When the pipe diameter decreases the headloss will decrease. When headloss is low this gives a good impression about the pipe state. In this model we want to analyze pipes headloss values at the beginning, during and at the end of the water pumping cycle.

When headloss increases, I need more electricity to let water reach customers when pressure is low means that the water doesn't reach to these zones. Headloss means more pressure is needed to let water reach these customers. When we increase the diameter the headloss will decrease then the pressure will decrease and so we will not need more power. Table 3 shows an example of different pipes headloss during water pipe pumping cycle. P1, P2 shows example of pipes headloss at the beginning of the cycle where the headloss is zero. P3, P4 and P5 show some pipes headloss in the beginning, during and until the end of the pumping cycle. P6, P7, P8, P9 and P10 show the pipes state at the end of the cycle where they are a pipes with high headloss.

Table 3 : The hydraulic model results of pipes headloss for different pipes with different diameters and materials.

Pipe	Diameter (Meter)	Material	Date	Time	Headloss
P1	250	Ductile Iron	26/8/2016	9:55 PM	0
P2	150	Ductile Iron	26/8/2016	9:55 PM	0
P3	100	Steel	26/8/2016	9:55 PM	0
P3	100	Steel	27/8/2016	4:37 AM	.54
P3	100	Steel	27/8/2016	4:19 PM	.90
P3	100	Steel	27/8/2016	9:40 PM	1.22
P3	100	Steel	28/8/2016	5:13 AM	.51
P3	100	Steel	28/8/2016	12:4 PM	0.35
P3	100	Steel	28/8/2016	11:55 PM	.22
P4	50	Ductile Iron	26/8/2016	9:55 PM	0
P4	50	Ductile Iron	27/8/2016	4:37 AM	2.95
P4	50	Ductile Iron	27/8/2016	4:19 PM	9.35
P4	50	Ductile Iron	27/8/2016	9:40 PM	18
P4	50	Ductile Iron	28/8/2016	5:13 AM	12.32
P4	50	Ductile Iron	28/8/2016	12:4 PM	13.30
P4	50	Ductile Iron	28/8/2016	11:55 PM	8.97
P5	12.7	Ductile Iron	26/8/2016	9:55 PM	0
P5	12.7	Ductile Iron	28/8/2016	12:01 AM	2.46
P5	12.7	Ductile Iron	28/8/2016	5:31 AM	6.12
P5	12.7	Ductile Iron	28/8/2016	8:28 AM	10:84
P5	12.7	Ductile Iron	28/8/2016	11:55 PM	48.48
P6	19.7	Ductile Iron	28/8/2016	11:55 PM	23.12
P7	26	Ductile Iron	28/8/2016	11:55 PM	10:25
P8	33.1	Ductile Iron	28/8/2016	11:55 PM	11.83
P9	12.7	Ductile Iron	28/8/2016	11:55 PM	30.25
P10	100.0	Steel	28/8/2016	11:55 PM	.27

The framework of hydraulic model relies on the creation of a model that simulates the water distribution network in real and helps the stakeholders to easy access data and giving them results that help to maintain and repair different problems in the WDN. To build the hydraulic model, shape-files that are prepared in GIS (pipes, substituting tanks, junctions, and source) are imported to Hydraulic model. Elevations are assigned to different nodes such as tanks which have been assigned to the hydraulic characteristics which include simulation start date 8/26/2016, start time 9:55:00 PM, duration of 50 hrs., time analysis type (EPS), hydraulic time step(hour) 0.050. On the other hand, I have defined the control information such as mode of pump operation. Pump1 and Pump2 definition for zone W4 are shown in figure 15 , check valve fixed in low pressure because we use the tanks to represent the substituting tanks (sink) and not as source of water. So to define the water flow we need to fix the sink and source very clearly.

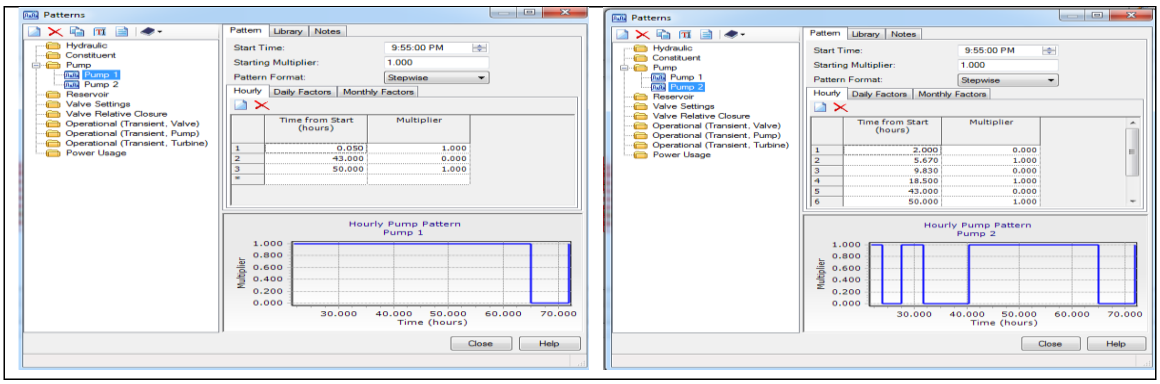


Figure 15: Pumps Definitions

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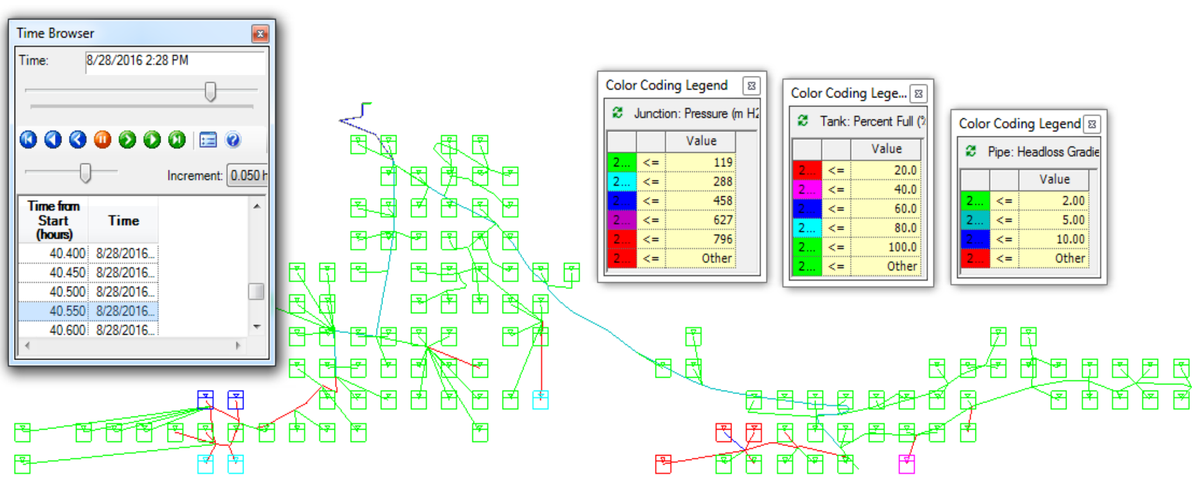


Figure 16: The Hydraulic model color coding after 40 hours

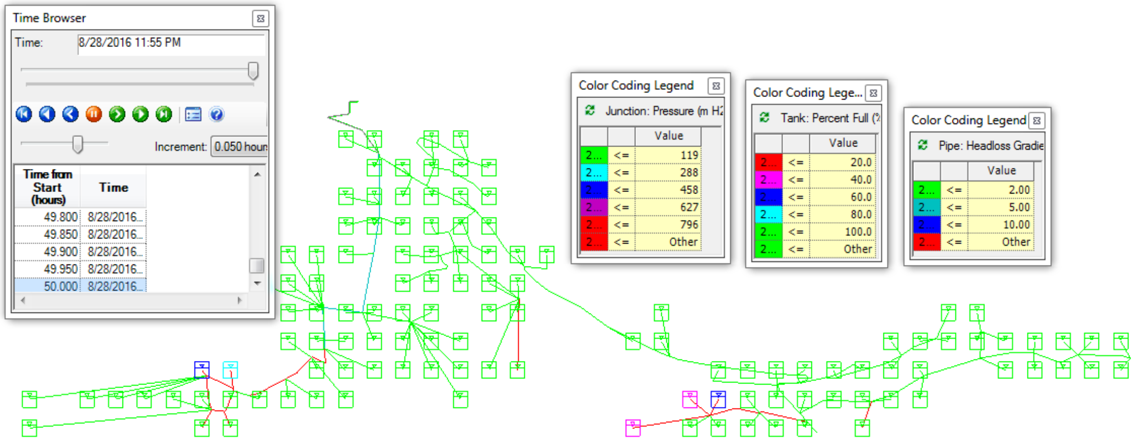


Figure 17:The Hydraulic model color coding after at the end of restricted water supply hours.

Conclusion

The hydraulic model simulation represent all water system measurement from the beginning of the pumping cycle, during the cycle, and finally at the end of the cycle , that includes headloss measurement, tanks percent of full, flow, and pressure at each junction.

5. Chapter Five: Our Approach for leak calculation

5.1 Leak Definitions and Leak Kinds in Water Distribution Network

Water loss is a major issue that requires an effective understanding of its causes to avoid them and avoid factors that influence it. Leak detection techniques vary according to the classification criteria used for classification. First one is according to how the detection is performed. We have three kinds: the automated techniques which detect the leak without the need to a human interference such as the sensors. The second one is the semi-automated technique which needs some human help such as the digital signals processing. Finally manual systems work only by human help. The classification according to the technical nature has two branches: the hardware base and the software base. Physical parameters can be used for leak detection such as liquid pressure and flow [45]. Leak detection technique in water pipelines can be hardware dependent or software dependent techniques. Water losses can be classified as commercial losses which are due to illegal water consumption, inaccurate customer metering and systematic data error .The second type is the real losses “physical losses” which are due to leakage from water pipes, service connections and pipe bursts in the distribution network. There are many approaches for leak detection. Many assumptions were used to find the amount and the location of water loss. Loss detection may be categorized as a hardware-based method or software-based method which used for cases with limited instrumentation. [46]

There are many approaches for leak detection in the WDN [47]

- Balancing Approach: compare water network input and output. We can predict the leak by calculating the difference between water flow entering the pipeline (supplied) and the output from the pipeline (consumed) by reading the customer meters as a consumed (output) value.

- Hydraulic analysis leak detection approach: this method depends on some measured values from the network such as flow rate and pressures. For example pressure values. If the real pressure value is less than the pressure value in a hydraulic model this means that there is a loss in that area.
- Monitoring signals Approach: it is an approach that depends on signals emitted when a burst happen. The burst caused a pressure drop which creates a pressure wave travelling at sonic velocity in both source and destination forms the leak. The time difference can be used to calculate the leak location depending on the nearest sensors around the leak (in both sides)
- Hydraulic parameters Approach: flow (such as minimum night flow) or pressure values indicate a leak, compared it with the normal and average values. Usually the increasing in the flow and the decreasing in the pressure, suggest new leaks. [48] Perez et al used the network nodes pressure measurements and pressure sensitivity analysis to localize the leakage. [49]

5.2 Leak Detection using Balancing Approach

Balancing approach is a comparison between a fluid amount enters the pipe network which is the water amount supplied by pump stations and the fluid amount that leaves the pipe network which is recorded by customers meters readings. The comparison performed on the whole zone data. We have compared SCADA data with the measured one that pumped to the zone. These large numbers show the importance of addressing water loss problem. Water losses can be classified as Apparent losses which involve the water used from the consumers but incorrectly metered or unmetered at all due to unauthorized consumption, consumer meter inaccurate and systematic data error .The second type is the real losses “physical losses” which involve the water that was lost from the network and not used at all due to leaks, pipe bursts in the distribution network. To check the commercial losses we perform a study on a seventeen building in the study area. The study shows that the commercial losses percentage was 17.3%. The commercial loss is equal to the sum of main meters readings minus the sum of meters readings. The commercial losses percentage is equal to the sum of main meters readings minus the sum of meters readings divided by the sum of the main meters readings multiplied by one hundred. Table 4 shows the details of the study, building names, number of meters in each building, main meters reading, commercial loss amount and commercial loss percentage.

Table 4: commercial loss calculation

Num	Building	Installation Date	Numb of meters	Main meters reading	Sum of meters readings	Loss in Sep/2016	Tank Loss %
1	Alsada building	7/25/2016	**19**	203	149	**54**	36.35142
2	Ghernata building	7/29/2016	**18**	268	239	**29**	11.94653
3	Aldawany building	8/5/2016	10	162	140	22	16.04584
4	sebaweeh building	7/30/2016	18	235	224	11	5.121896
5	Ishtaya building	7/30/2016	13	252	243	10	3.917525
6	Alkhalili building	8/3/2016	11	151	136	15	11.11111
7	Alfaraj building	8/3/2016	10	133	123	10	8.042242

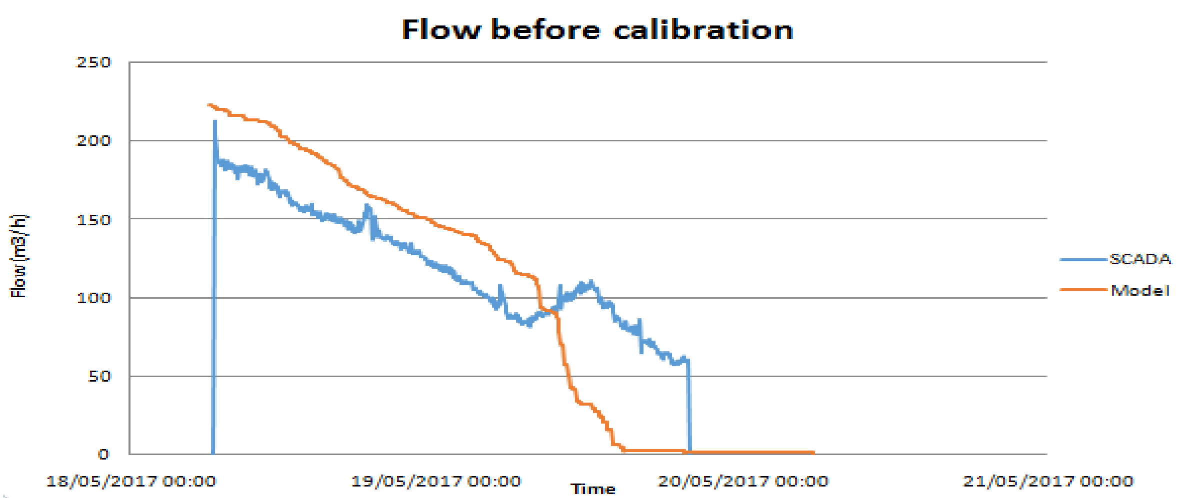
8	Aloloaa building	8/13/2016	16	187	179	8	4.442581
9	Alqalaa building	8/15/2016	10	80	70	9	13.46208
10	near castle building	8/15/2016	9	65	57	8	14.82661
11	Alfahed building	8/15/2016	11	130	74	56	75.77807
12	Alsharq building	8/20/2016	18	145	104	41	38.90219
13	Eskan albebe	8/25/2016	95	652	556	96	17.28406
14	Alyaqeen building	8/30/2016	15	93	84	9	10.162457
15	Albzra building	9/4/2016	11	45	36	9	24.514697
16	Salat_Street building	9/9/2016	26	141	84	57	68.138424
17	Al khateeb building	5/19/2016	25	435	296	138	46.671617

In this leak calculation we consider leaks in each building to find the highest leak percentage, Alfahed building have the highest leak percent in my study area which was 75%.

5.3 Leak Detection using Hydraulic Model and SCADA Data

I have used Hydraulic analysis leak detection approach which depends on flow rate and pressure values from the hydraulic model .then compare the flow of the model with SCADA data.

Figure 18: Flow comparison between WaterGEMS and SCADA data.



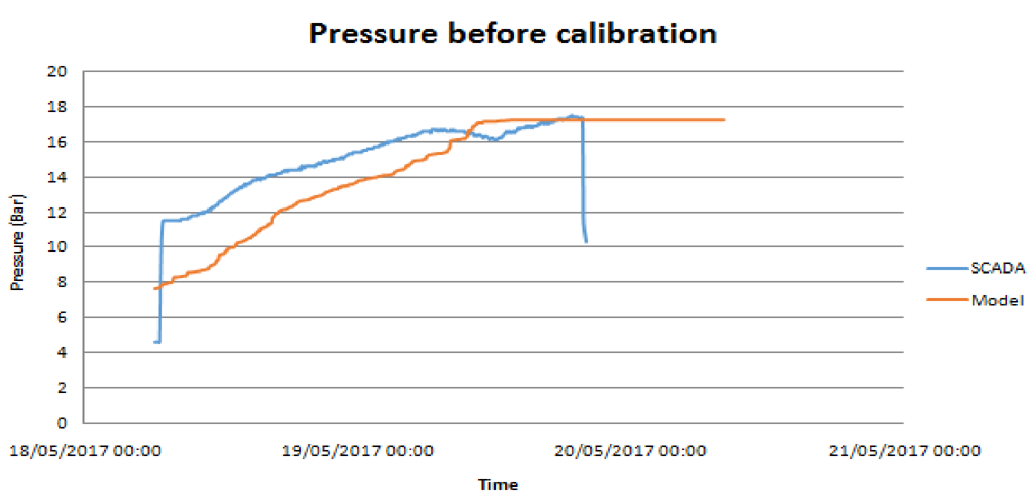


Figure 19 : Pressure comparison between WaterGEMS and SCADA data.

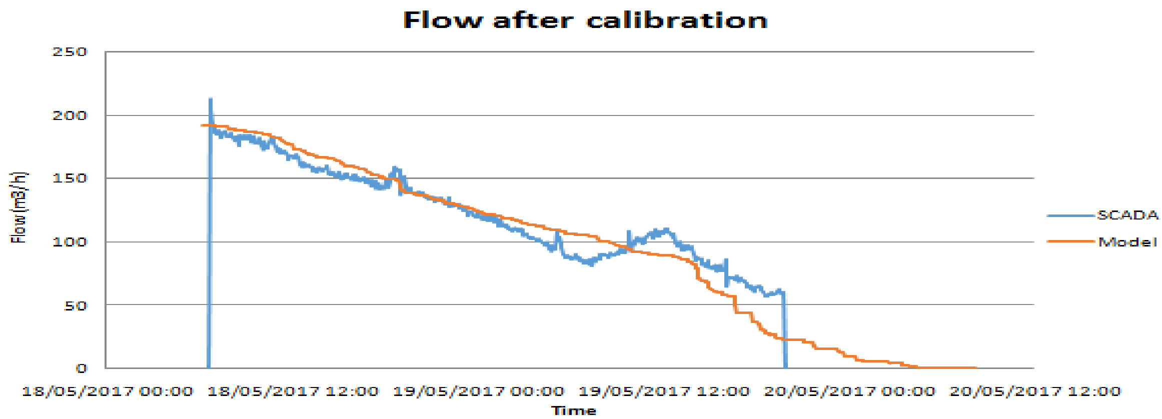


Figure 20: Flow after calibration.

Figure 21: Pressure after calibration.

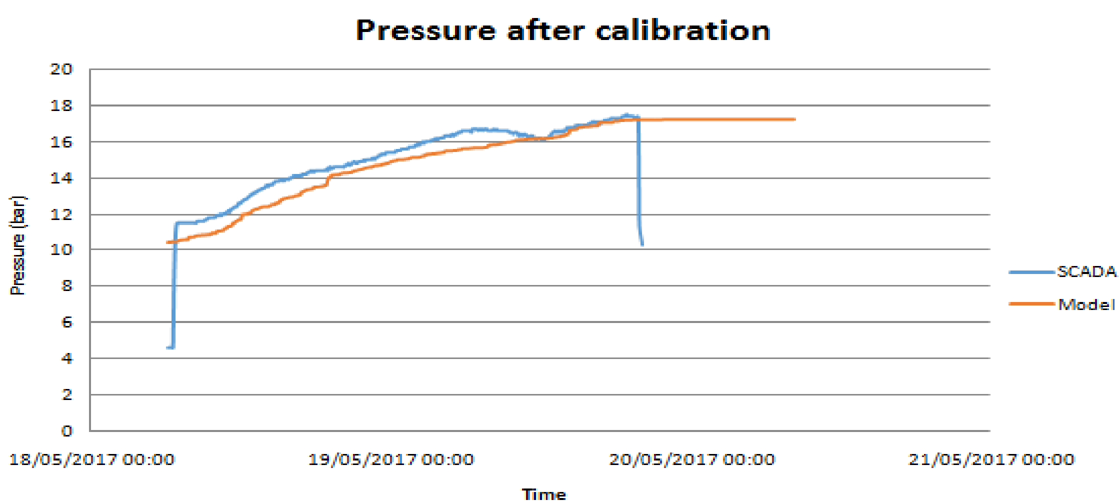


Figure 18 shows that there is a difference between the flow in the model and in the SCADA data .figure 19 shows that there is a difference between the pressure in the model and in the SCADA data, figure 20 shows flow calibration which is performed by increasing Tanks Size because in Al-Ameria the customer have bigger tanks because of theirs large houses. Figure 21 shows pressure calibration which is performed by modifies the roughness for some pipes.

5.4 Leak Detection using Minimum Night Flow Approach

MNF is a method used to evaluate water losses in a water distribution network in a well-defined District Metered Area (DMA). The measured flow is compared with the background minimum night flow (MNF). I have calculated Real Losses using the minimum night Flow, since the real losses are equal to the minimum night flow minus the customer night use and the background night flow. I have used W4 zone as a District Metered Area (DMA). The measured flow is compared with the background minimum night flow (MNF). Equation 1 explains MNF [50] which is the sum of the customer night use and the background night flow losses, the remaining flow is the real losses which are at my attention. Whereas equation 2 explains the background Losses [51]Location of DMA is Ameria in Nablus, (W4 Pressure Zone). DMA total Area is 2580 Dunums. Total number of subscriptions in District equal 1483. Length of the main distribution network is 10439 m. Total number of house connections is 328 Test Duration is (72 hours, and 12:00 – 4:00 MNF Test, Date 14/2/2017).

$$\mathrm{MNF} = \mathrm{Backgroundlosses} + \mathrm{legitemate\ consumption} \tag{6}$$

$$\begin{aligned} &B\mathrm{ack\ Ground\ Losses} = \mathrm{Number\ of\ Main\ pipes} * 9.6 * \mathrm{Averag\ pressure} + \\ &\mathrm{Number\ of\ service\ connections} * 0.6 * \mathrm{Average\ Pressure} + \\ &\mathrm{Length\ of\ service\ Connection} * 16 * \mathrm{Average\ Pressure} \end{aligned} \tag{7}$$

To Find the MNF, initially I decide the DMA which I will conduct MNF Test. Then I collected information from GIS department about the existing network (network length, no. of house connections, no. of meters, district boundaries, etc.). Then initial field survey of the study area and their boundaries was conducted, then installation of isolation valves was done in the boundary of study zone in order to separate the DMA from the pressure zone in the main distribution lines. Then perform field dry test: in order to test the boundary zone by supplying water to the study zone and cutting off water for all outside zones, and checking houses for the water supply if it is included in the study zone or not. Then field inspection of isolation valves after installation. After that update information from GIS about the study zone and its boundary according to the Dry tests and field inspection of isolation valves. Then programming the measurement equipment (Flow meter loggers, Pressure Loggers, etc.). Then Install the flow meter logger on the main supplying line, and pressure logger in the highest, lowest, station points of the study zone. Then start the study by operating the supplying pipe and closing all isolation valves for 72 hours. At the second day, we made a night study (12:00 – 4:00) by taking sample customer readings (50 meters) in order to determine the legitimate consumption during MNF. In the final stage, I performed data analysis and calculations and making reports.

Finally the delivered Minimum Night Flow in AL-Ameria district in Nablus city as a discreet metered area DMA from SCADA is 9.4 m^3/hr at date 14/2/2017 & time 04:51 am. Maximum Pressure in W4 at elevation 635 m equals 14.5 bars. Minimum pressure in W4 at the elevation of 746 m equals 4.5 bars as shown in and Average Pressure is 9. 5 bars. To find the customer Night Use, we took a sample of customer meter reading at the MNF time at 50 meter per each 1000 meter and collect its reading divided on number of sample meters to get the average consumption across all domestic meters is 109.8/50 which equals 3.61 Since 109.8 is the sum of meter readings at MNF time, then the correct Average legitimate consumption is [(3.61 + 7) / 2 = 5.305 (l/hr.)]. (7 is Global LNF) Finally the corrected total legitimate consumption is (5.305*1483)/1000 = 7.83 m^3/hr.

Conclusion

MNF is one of the most effective and known method to calculate Real Losses. The results show that MNF for W4 Zone is 9.25 (m^3/hr.) We analyzed the flow of W4 DMA which allows estimating leakage when the flow into the DMA is at its minimum rate. The minimum flow at the DMA occurs at night between 1:00 AM to 5:00 AM because usually the customer's demand is at its lowest percent of flow and the leakage component is at its highest percentage of flow. In our case the MNF was at 3:40 AM.

6. Chapter six: Software Modeling

There are many modeling languages used to describe companies activities, resources and constrains. There are two Software Process Modeling Languages (SPMLs) generations. The first one appeared in the 1990s but did not gain a wide support as the second one.[52]

6.1 Class Diagram

The class diagram shows the system classes to show the system structure. The class diagram defines each class attributes, objects and the relations between the whole system classes with each other. Figure 22 below shows the class diagram for our water system. The contour line class contains the contour lines, the Topo to Raster class have the parameter of the study area in addition to the conversion function used to convert the contour lines to DEM. Customer meters class contain all of the information about the customer meter layer which has been used with the DEM using the point extraction class to assign the elevation to all of the customer meters. The customer meter does not have a service connection with the house connection. So many customer tanks were not connected to the geometric network. So, we have created a Grid of Points (Substituting Tanks) which is the Fishnet class then we have assigned each customer to the nearest Point (Substituting Tank) in the fishnet class and find the distances between the customer meters and the substituting tank that have been assigned to it using the substituting tank and fishnet distances class. Then we have used connection generation class and the junction class that represent the points in the pipe line that have a substantial change in the water network to Create Pipelines between the Substituting Tanks and its closest Junction (tank connection class). The Geodatabase class holds all water network classes such as whole pipes, valves and resources classes. The Geometric Network class is the geometric network for the required zone. The ArcOBjects class represents the development environments that have been used to analyze the water network and calculate the leak.

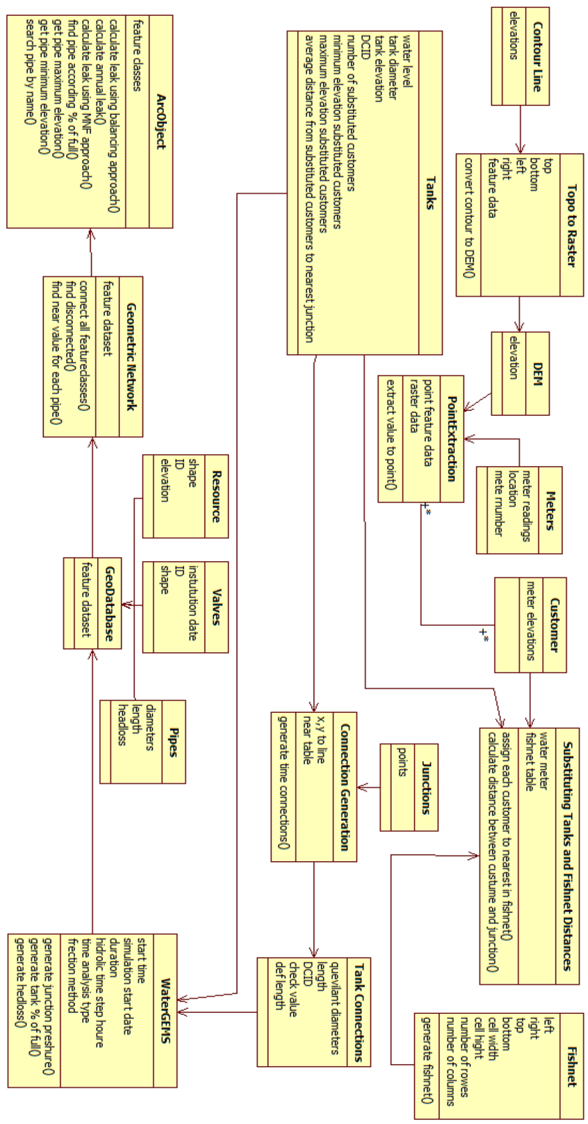


Figure 22: The class diagram of the whole water system.

6.2 Use Case Diagram

The used Case Diagram is a collection of scenarios that represents the interaction and the relation between the user and the system. The actor represents the user or another system that will interact with the system that we modeled. The use of "Use Case" is an external view of the system to review some of the actions a user can take to complete the task. Use Cases are used almost in all projects. Use Case helps to detect the needs and planning for the projects. During the first phase of the project, most Use Cases should be identified. An examples of a Use Cases in sales company when the user places a request is browse catalog "catalog" and select items, view shipping information and view payment information and receive the "conformation number" approval number from the salesperson.

The following diagram in figure 23 represents the Use Case diagram of our system. We have four actors which are the Admin actor, the SCADA System, hydraulic model generator, and the network operator. The admin operator imports the hydraulic model results in addition to convert the SCADA data to shape-files for the required zone to build water intermittent supply and build the geometric network and perform all the analysis. The admin may add, delete or modify layers. The SCADA data system provides our system with data about pumps. The hydraulic model generator provides the system with the hydraulic model simulation results. Finally, the network operator can calculate the monthly leak, annual leak using the balancing approach, calculate the leak by using the MNF approach, finding the nearest valve for each pipe in the WDN, showing pipes headloss, finding the pipes elevations, classifying the pipes according to their headloss value, show tanks percent of full, find tanks elevations, classifying tanks according to their percent of full and finally showing the junctions pressure.

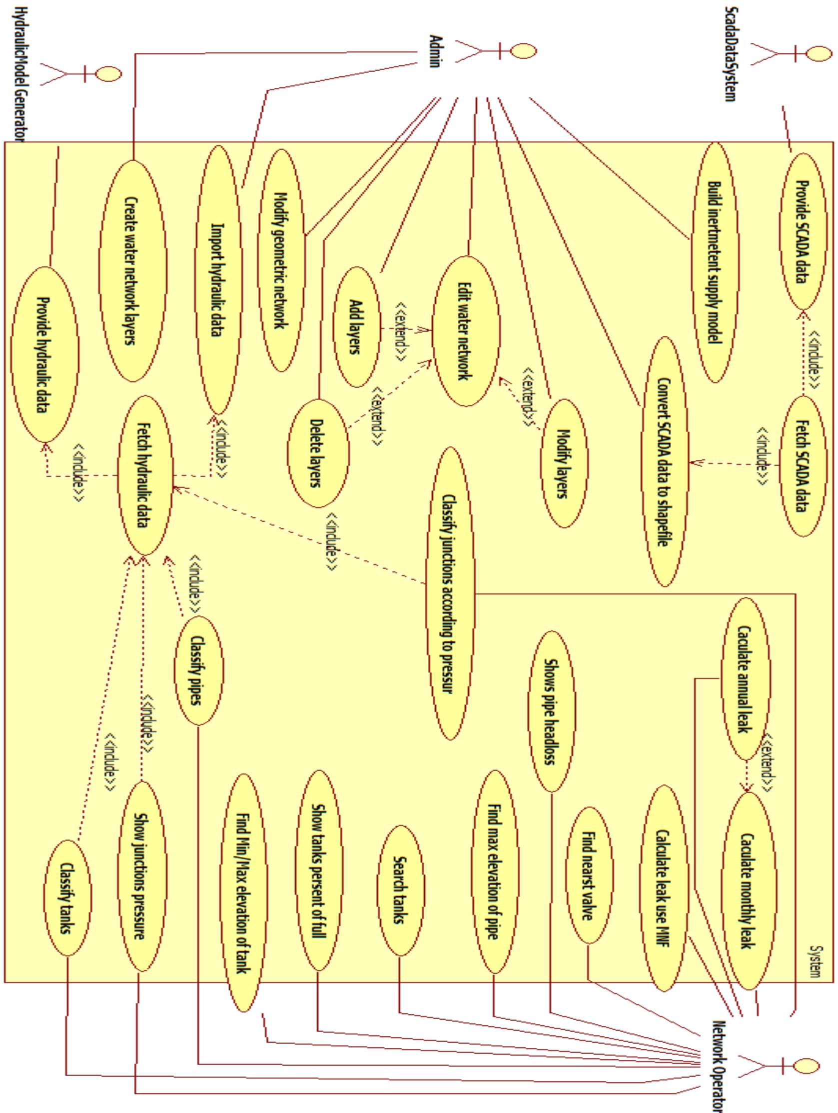


Figure 23: Use Case Diagram.

6.3 sequence diagrams

Sequence diagrams show how objects operate and interact in a specific scenario. The diagram shows the interaction in the sequential order. Many sequence diagrams used in this study is represent below. There are Messages between objects, written on arrows each message represents the interaction. When any sender sends a synchronous message he should keep writing until the response came back, on the other hand if the sender sends asynchronous message, he has the ability to continue processing and doesn’t need to wait for response.

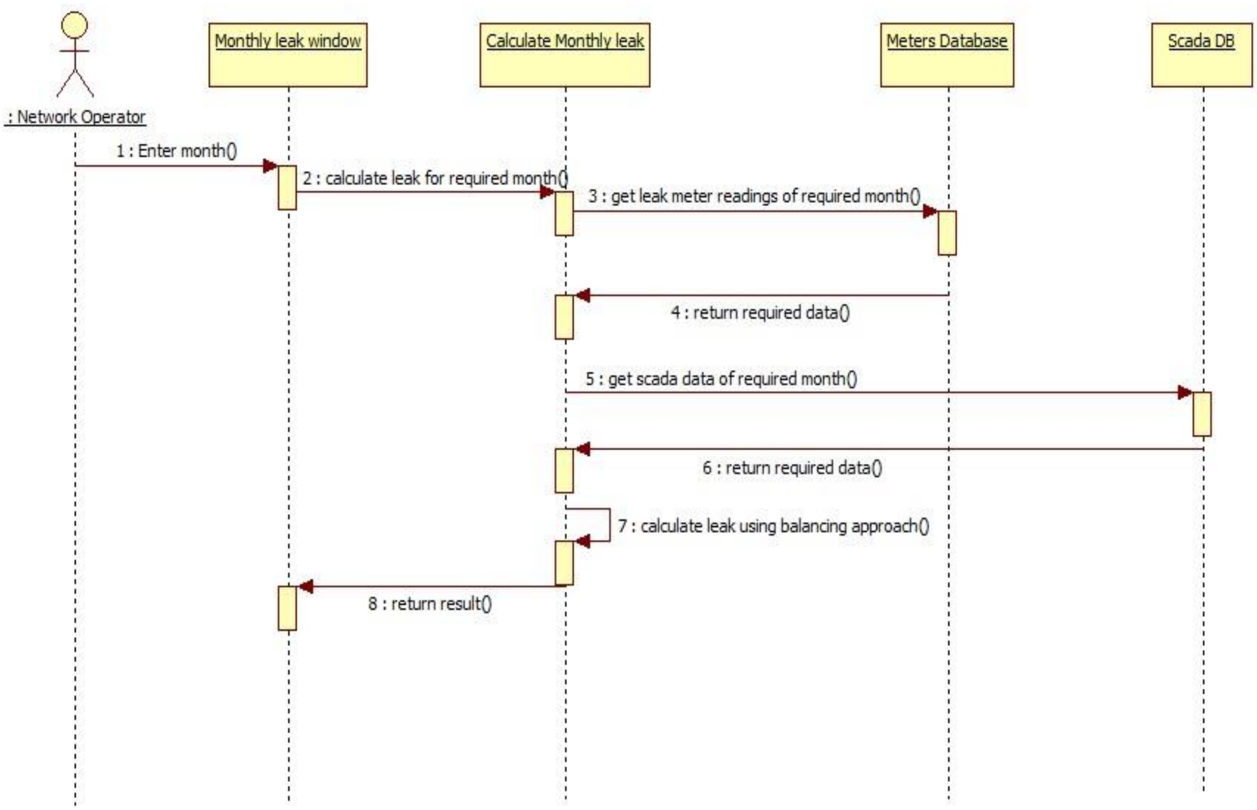


Figure 24: sequence diagram that represent the monthly leak calculation process.

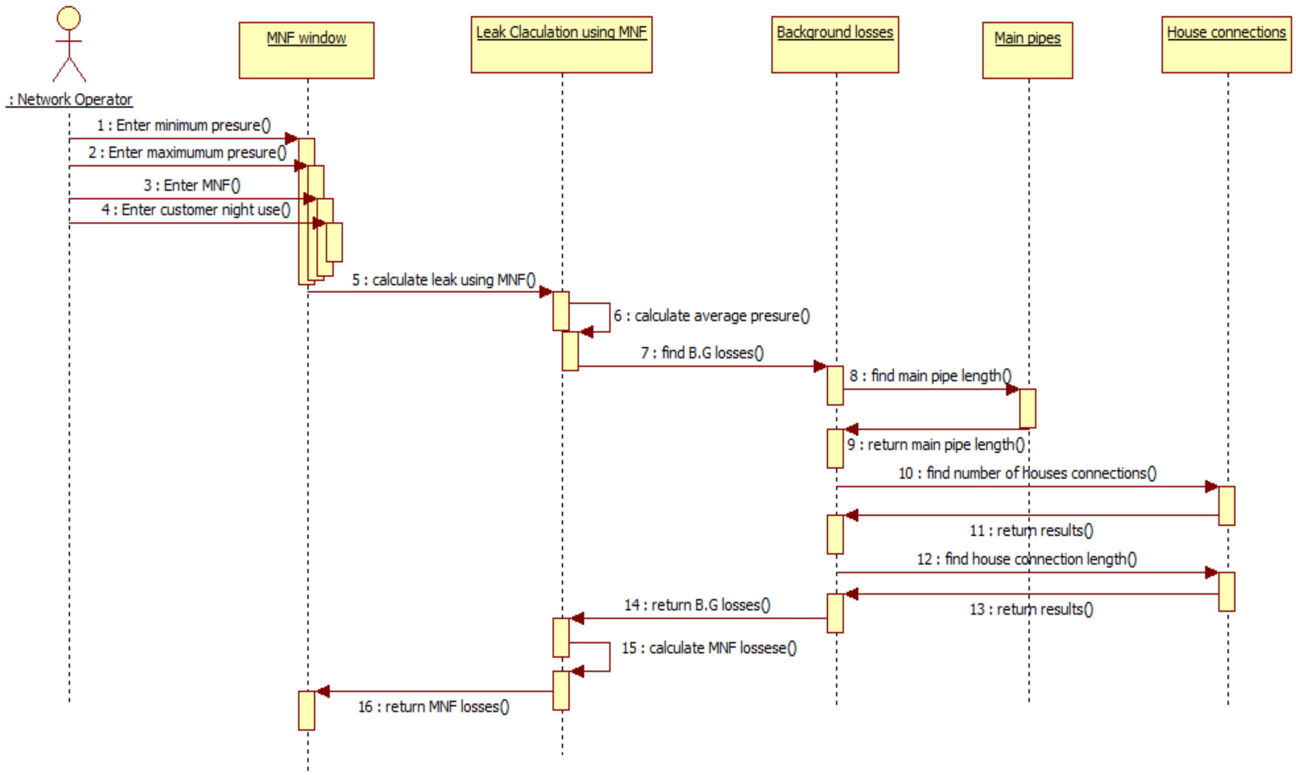


Figure 25: Find the leak using the MNF approach using the background losses calculation.

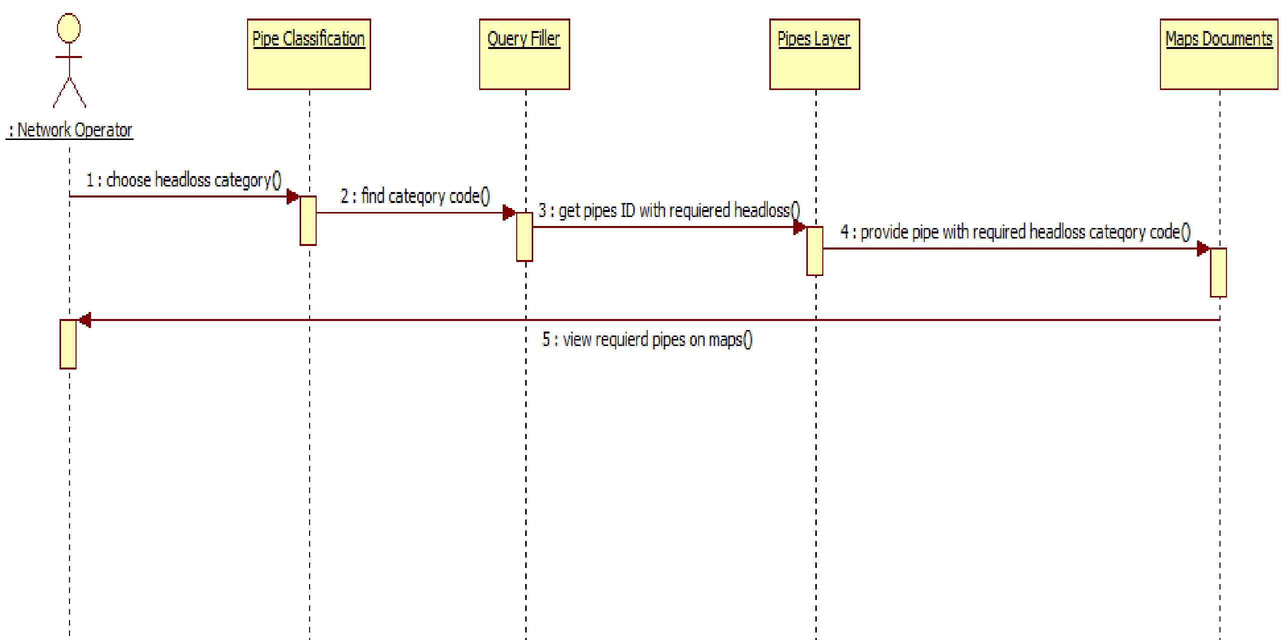


Figure 26: Pipe classification according to the headloss value.

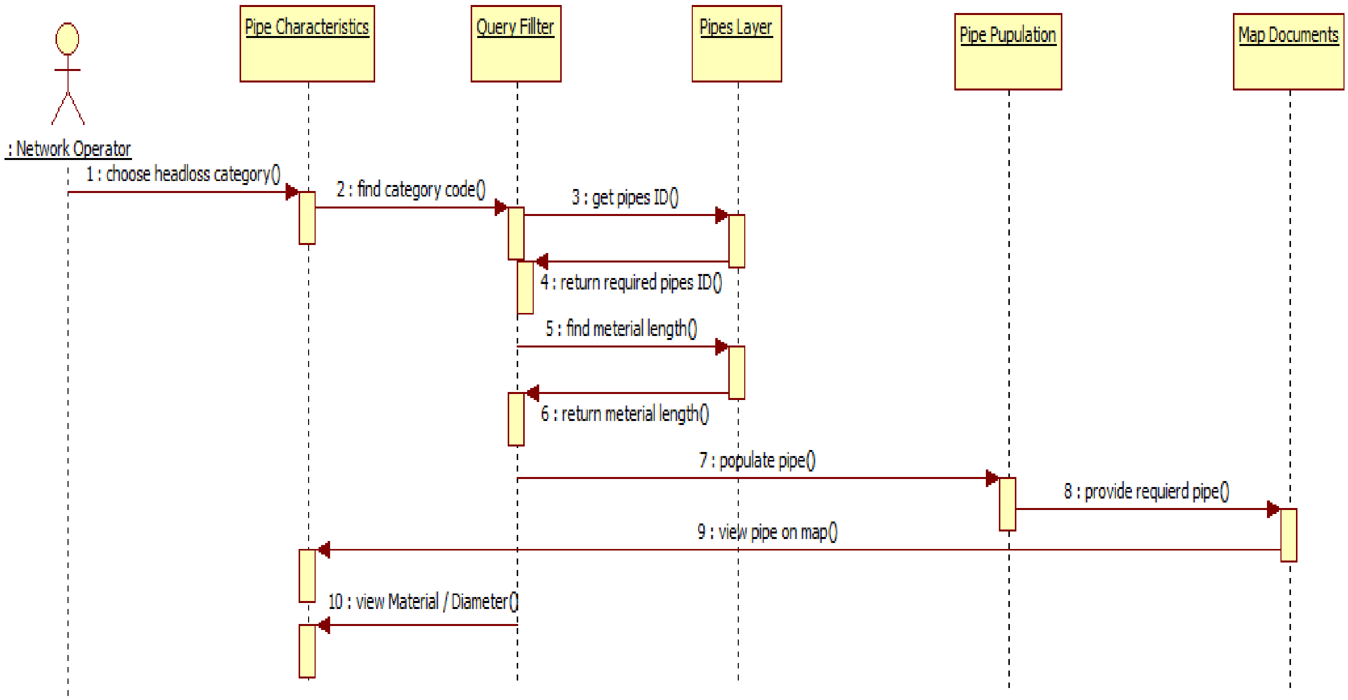


Figure 27: The sequence diagram to show specific pipe characteristics.

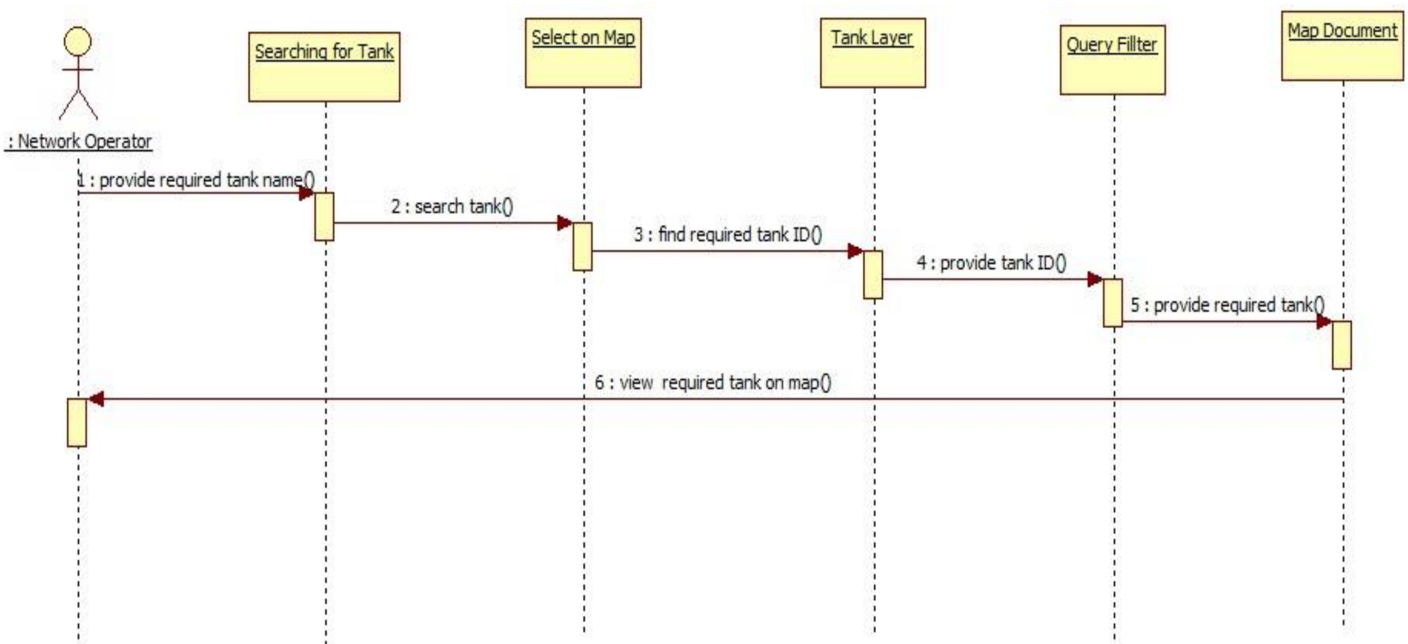


Figure 28: The sequence diagram to search about a Specific Tank.

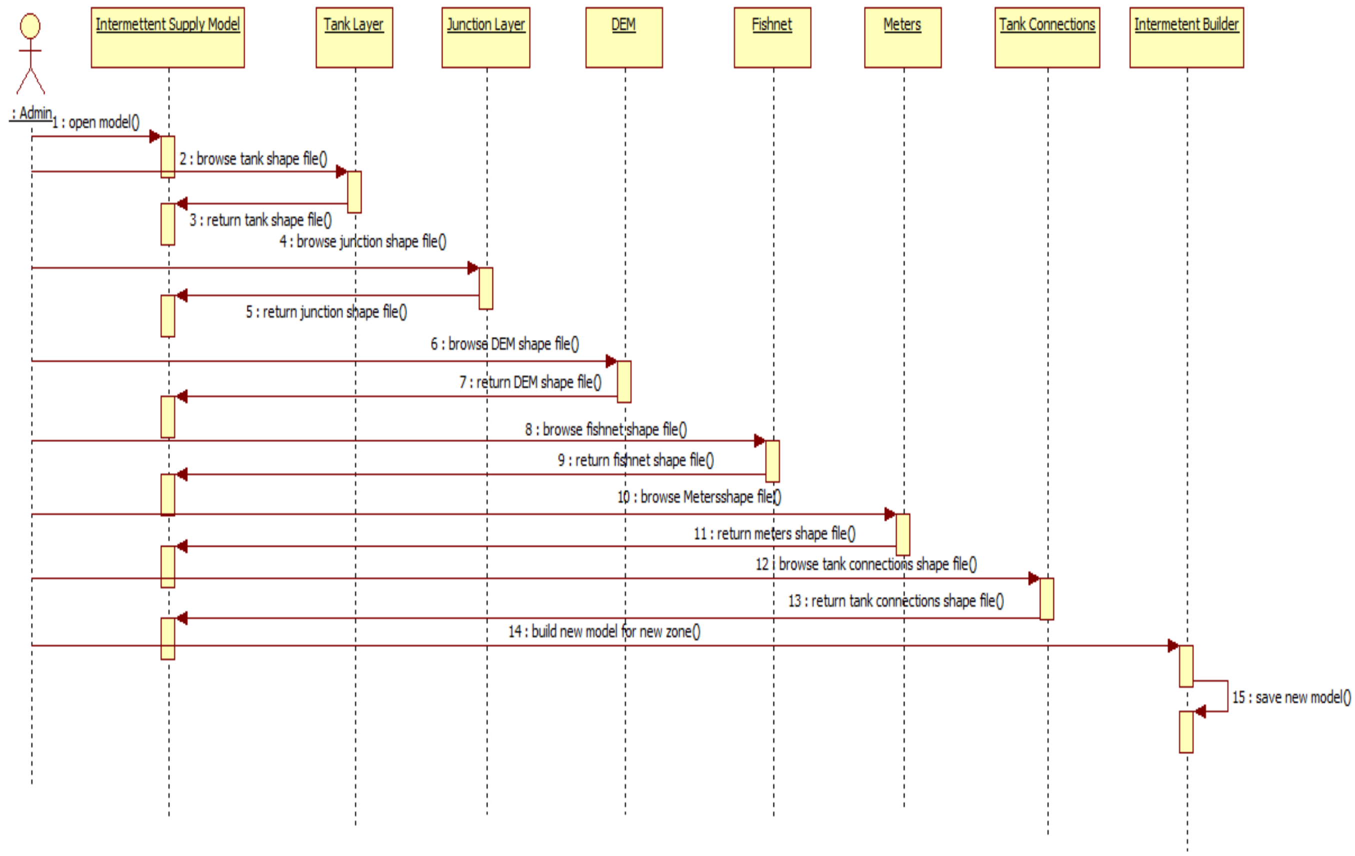


Figure 29: Build a new intermittent supply geometric network model for a new zone.

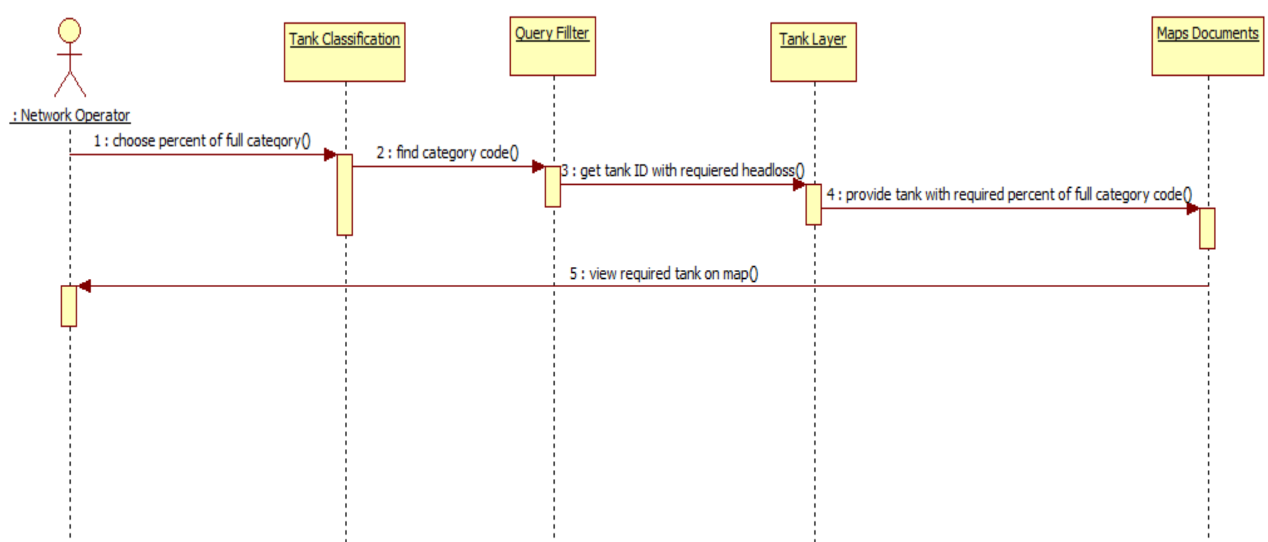


Figure 30: The sequence diagram to classify the tanks according to there's percent of full.

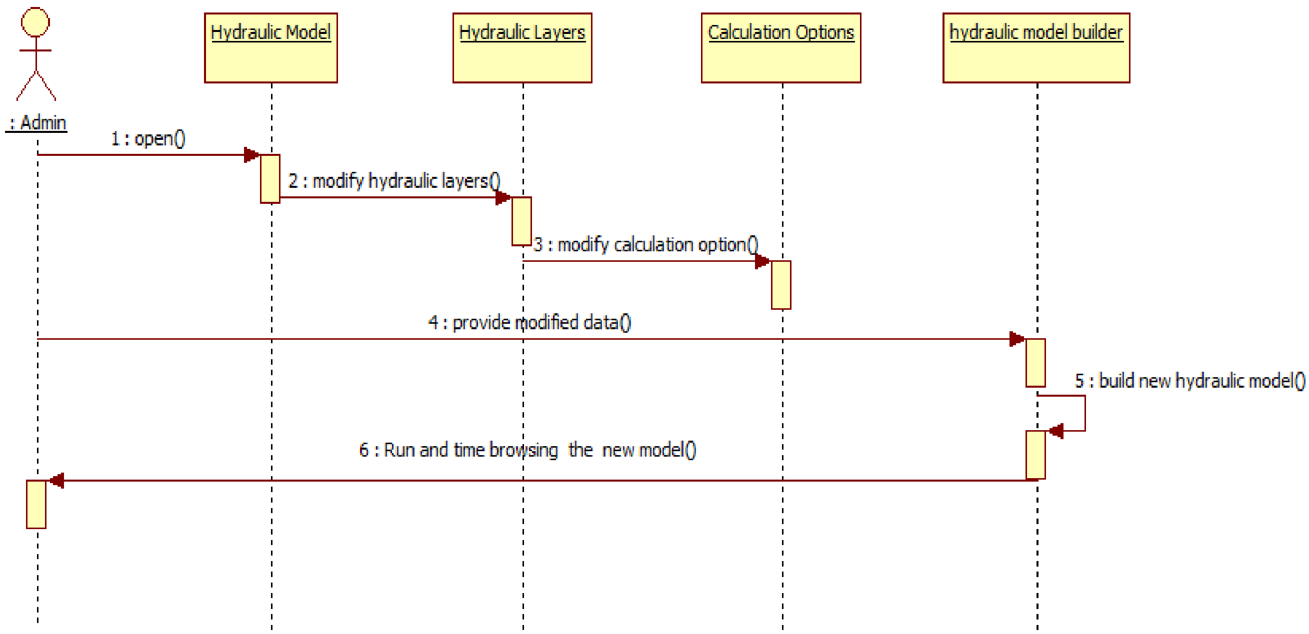


Figure 31: The sequence diagram using to build new or modify existed hydraulic model.

6.4 Activity diagrams

Activity diagrams represent the workflow of the system activities. Activity diagrams can be used to represent conditional activities or concurrent activities. The following diagrams represent some activity diagram of my system. Each shape in the activity diagram represents a specific component. A black circle represents the start of the work flow. An encircled one represents the end of the workflow. The actions are represented by rounded rectangles. A black bar represents the beginning or the finishing of parallel activities such as calculating two values in the same time to obtain a specific result. Finally the diamonds represent decisions.

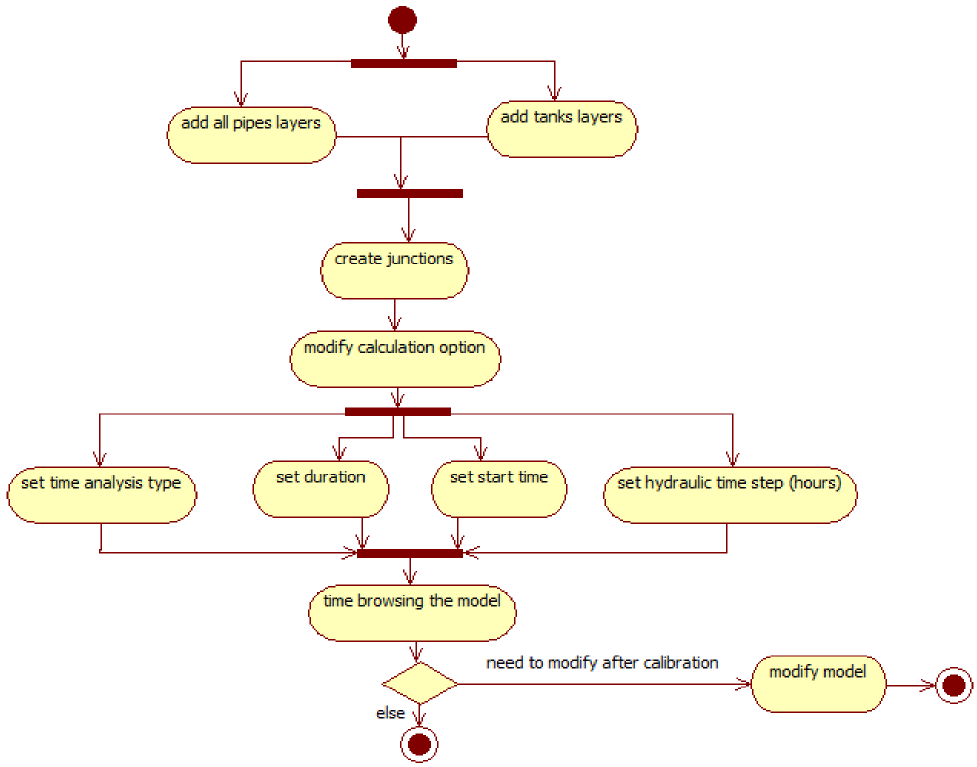


Figure 32: Activity diagram representing the process of creating the junctions layer according to substantial changes in pipes.

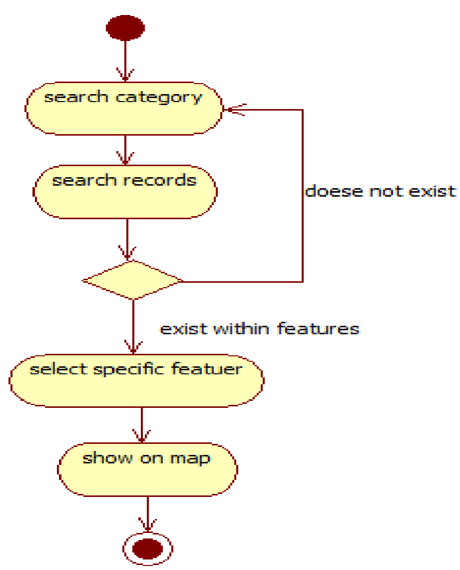


Figure 33: Activity diagram representing how the user can search a specific feature in a specific category.

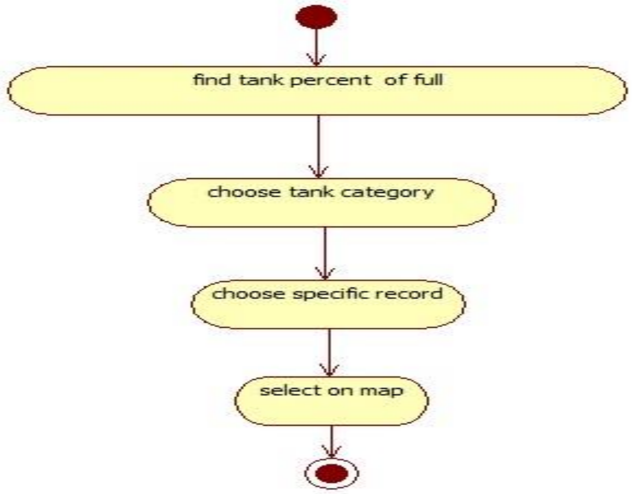


Figure 34: The Activity diagram used to find a specific tank according to its percent of full and select in the map.

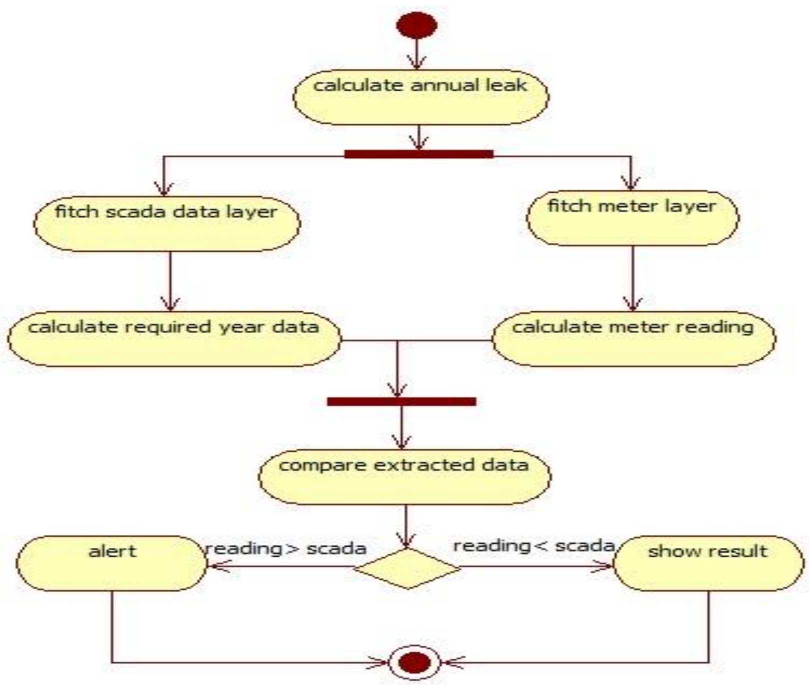


Figure 35: The Activity diagram used to represent the activities workflow to calculate Annual Losses.

Conclusion

All system diagrams were presented in this chapter show all system component and user tasks such as MNF approach calculation for different leak detection tasks.

7. Chapter Seven: Implementation

7.1 System implementation

I have built an extension for Nablus municipality data to calculate different leak percentages. I have created classes from all required feature classes including pipes and tanks classes to deal with all required field and perform all calculations. The whole system architecture is explained in figure 36.

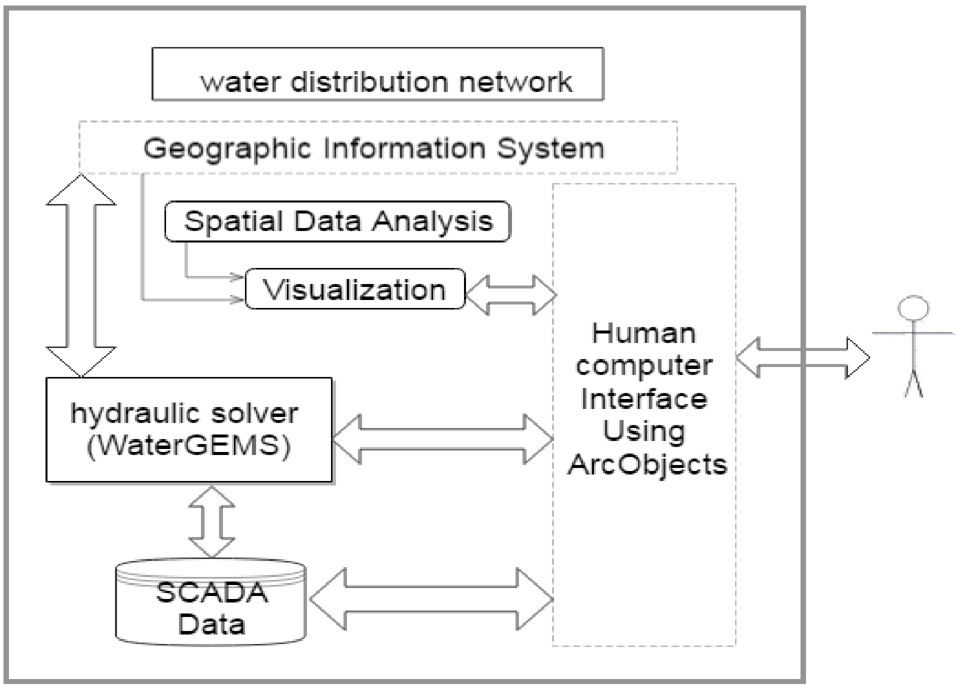
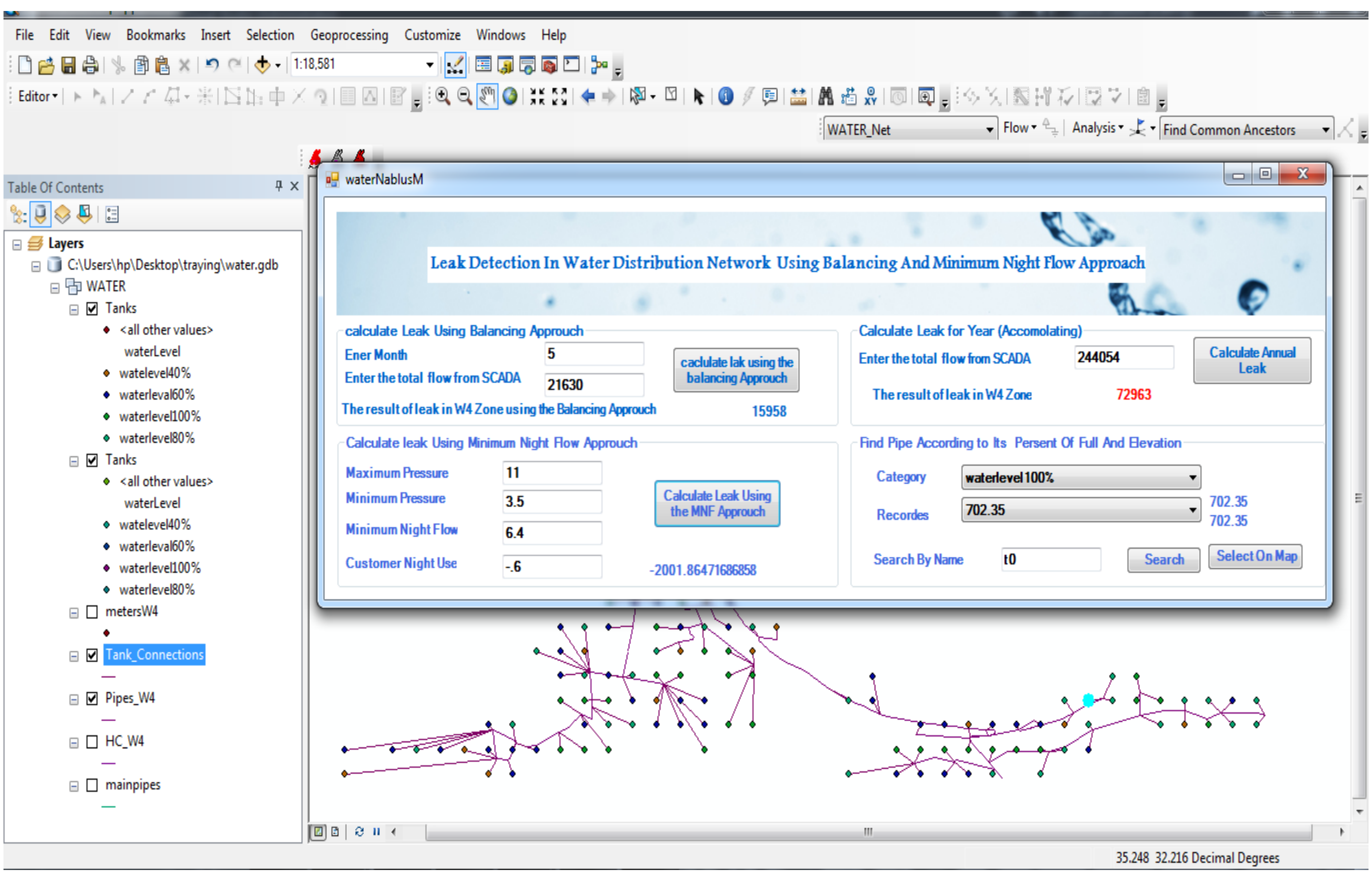


Figure 36: The whole architecture of the whole systems.

ArcGIS has very strong capabilities by itself; however ESRI always has been developing special tools for users. ArcGIS applications like ArcMap and ArcCatalog are built from ArcObjects. These objects are based on building block of things like maps, layers, patterns, tools, points, lines and polygons. Arc Objects are programmable pieces used to build ArcMap and ArcCatalog. Baiyi Jiang et al said that in addition to ArcMap and AutoCAD, you can also use advanced programming language, such as .NET, C++ etc. Users and programmers work with the same objects. There are more than 2700 ArcObjects Classes; each class represents a basic GIS part. ArcObjects classes are programed behind the seen using C++ programing language. Developer and user make objects of these Classes to develop on top of ArcGIS platform. I used ArcGIS platform which is ArcGIS for desktop, ArcObjects and programing software such as Visual studio (VB.NET in my case). We started our project with DLL file which is a dynamic link library which doesn't exist by itself. We can develop on top of ArcMap many things ArcGIS as toolbar. We created NablusWaterDepToolbar and Visual studio gave it a progId to let windows Know that it is ArcGIS toolbar. We have created Nablus water toolbar class and it is a Class inherited from base tool bar which is an abstract class located in ADF library and it has a lot of functions that any tool bar should have. I have created new ArcMap project using ArcMap class Library then I have created a new class from the extending ArcObjects (which is a new tool from the base tool class that represents my application). My application in my project represents the ArcMap which is created by Visual Studio. I have created objects from the layers and FeatureClasses and created new classes of my shape-files to deal with all data imported form WaterGEMS and ArcGIS Geometric network in one Screen and more user friendly window in addition to perform more operations and create new tools to perform new tasks under GIS such as search, selection, and automation of different processes. One of the most important classes is the FeatureClass which is simply a table in a database that has geometry and some records. Each record has a type defined in special field called geometry such as point, line and polygon. The moment I add them to ArcMap it becomes a layer, so the layer can't exist by itself, and it has to have data (table or source for it). Our application is used to manage, selecting, and search WaterGEMS and Geometric network results in addition to perform leak calculation using water Balancing Approach, minimum night flow method to find Real Losses. The system goes to the shape-files and read the customer meters automatically and compares the results with SCADA data to find the loss for each month in addition to find the accumulated water loss per specific year. Search on map to find tanks according to its percentage of full and its elevation. Since I have imported the hydraulic model results from WaterGEMS and the tank shape-file contains each tank percent of full to find which tank doesn't have a one hundred percent of full and provide a recommendation to the municipality to modify or increase the time cycle. The application is explained in figure 37.

Figure 37: The Application.



The following algorithms represent some of the main programing calculations.

Algorithm 1. Calculate leak for specific Zone in a specific month.

Input: Layers $[S_1, S_2 \ldots . S_n]$

Output :Leak amount at specific month at specific Zone

int leak= 0;

ILayer selectedLayer,

Answer←< >;

for each layer ϵ layers $[S_1, S_2 \ldots . S_n]$ **do**

    If layerName = meter **then**

    SelectedLayer ← **get_Layer_By_Name** (meter);

    Field ← **get_field_by_name**(month)

        while field ≠ NIL **do**

        Feature ← **get_next_feature_by_Cursor**;

        leake =leak+ featureValue;

    End if

End for

Return answer;

Algorithm 2. Calculate pipe lengths for back ground Losses

Input: Avgepre, pipesLayers [S_1, S_2 ….S_n]

Output : back Ground Losses

ILayer selectedLayer ;

IFatureClass field ;

Ifeature Feature ;

String Name;

for each layer € pipesLayers [S_1, S_2 ….S_n] **do**

Name ← **get_layer_name**

SelectedLayer ← **get_Layer_By_Name** (name)

Field ← **get_field_by_name**(pipeLength)

while field ≠ NIL **do**

Feature ← **get_next_feature_by_Cursor**

value← featureValue

length ← length+ featureValue

End for

Return answer;

Algorithm 3. Calculate annual leak for specific Zone.

```
Input: MeterLayer
Output :Leak amount at specific month at specific Zone
int  leak= 0;
int  annual leak = 0  ;
IFatureClass    field ;
Answer←< >;
For each month  €meter layer  do
Field ← get_field_by_name( monthNum)
while field ≠ NIL do
leak  ← Calculate_ Meters__sum _monthly
annual  leake = annual leak + leak;
End for
Return answer;
```

Conclusion

Using VB programing language under ArcGIS platform all leak calculations were performed for all required zone .the system were also able to fetch specific data from any shape-file on ArcGIS system.

8. Chapter Eight :Conclusion and future work

This thesis aimed at building a connected network that enables Nablus municipality to monitor water cycles and calculates leaks.

This research proposes to exploit and sort the various sources of existing data to extract useful information on the network and user behavior. Water data need to be organized to enable the developer to make analysis. All data that I have collected from NM was not GIS data but it was converted form AutoCAD format to GIS data, so it contained a lot of problems which need to be edited. I have performed many editing in the data such as creating the connectivity, defining simple edges, complex edges and junctions.

After I managed and ordered water system data in a network, I was able to make many analyses and take many decisions on it. Service connections were missed from water network and so there was a need for long time to be prepared, so the alternative solution was to create substituting tanks instead of the existing layout of tanks to create the whole system using the connected geometric network. I have succeeded to create and modify all water network components and create a geometric network that connects these entire components. Geometric network is used as a tool for inspecting the logical consistency of a network and verifying connectivity between two components in the network. I built the geometric network for Nablus city water distribution network that has an intermittent supply system. In the intermittent supply, the municipality aims to feed all zone by the required quantity (demand) of water for all customers. All customer tanks need to be full of water when the pumping water cycle ended. The Geometric network I built detected many errors including multiple part geometric features where some junctions are not connected to any other edge feature. I was able to figure out and fix these entire problems using new geometric network. Because of current problems in service connections, I have proposed some substituting tanks for each group of tanks. Each substituting tank has a set of characteristics explained in chapter three.

WaterGEMS, which is a tool for decision-supports systems, is used for water system simulations. It was used to improve our knowledge on water system behavior. WaterGEMS simulator provides pressure, flow, and head-loss measures during the pumping water cycle to enable us take many decisions.

In the first phase when the hydraulic model was created there was a difference between the proposed model results and the SCADA system readings where flow in the model was less than the flow in SCADA. We calibrated the model by increasing the Average Volume per customer or per specific home from 2.5m^3 to 3 m^3 because most of the houses in Al-Ameria are large houses so most houses have larger tanks which increase the flow in SCADA for filling all tanks in the zone.

After calibration, I have used loggers to measure pressure value on the real network and compare its reading with loggers reading one of the junction were analyzed is junction 5 on 28/4/2017 which was 8 bar on the logger reading and 7.7 bar on the model reading. Many other junctions pressure reading on the model were compared and their results were very close or equal to the model reading that justify the importance of building such a model that give an impression to the municipality if a problem or a leak exist in a specific zone depending on the model without the need to use sensors or logger that required high budget and a lot of effort.

The developed system used WaterGEMS hydraulic model to calculate domestic water tanks load, junction pressure, and pipes head-loss as explained before in chapter four. Hydraulic model results show tanks that do not have full load and this recommendation may lead the municipality to increase the pumping water cycle to feed all customers by the required quantity (demand) of water. High head-loss values mean high amount of power required to move a given volume of liquid through a pipe in a water network to restrict the friction. Hydraulic model gives the head-loss of each pipe, the results give recommendations for the municipality if this pipe must change or not according to the amount of wasted energy to pump water to the customers if its head-loss value is very high. If wasted energy is greater than the budget required for replacing this pipe, the municipality must change it.

I have focused on detecting existing leaks. My future work will focus on creating a model for predicting water leakage in WDS using data mining tools depending on many factors such as pipe length, diameter and materials. I will use data mining rules such as decision tree and support vector machine in my future research. On other hand, I am looking to build and facilitate the system work on WDNs. Using the hydraulic model provided me with a new knowledge that pipes characteristics such as its diameter and length affect loss causes, loss amount, waster energy so I thing that considering more information about pipes will help on identify loss location and prediction using GIS technology. I can achieve such goal by importing the hydraulic model results on GIS and so we can import other data mining resulted from predicting the exact loss location by manipulating all simulation results and data mining tools results on GIS software by VB programming languages.

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