إقــــــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

تقييم و تطوير الأداء باستخدام نظم دعم القرار المكاني لشبكة مياه مدينة غزة
(دراسة حالة منطقة النصر الشمالي)

Performance Evaluation and Development of SDSS for Gaza City Water Network (Case Study The northern Nasser Area)

أقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وإن هذه الرسالة ككل أو أي جزء منها لم يقدم من قبل لنيل درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

DECLARATION

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification

Student's name: **Hesham Majed Al-Rayess** — اسم الطالب: **هشام ماجد الريس**

Signature: — التوقيع: H Rayess

Date: — التاريخ: 2015/06/23

Islamic University- Gaza
Deanship of Graduate Studies
Faculty of Engineering
Civil Engineering Department
Infrastructure Engineering

الجامعة الإسلامية - غزة
عمادة الدراسات العليا
كلية الهندسة
قسم الهندسة المدنية
هندسة البنى التحتية

Performance Evaluation and Development of SDSS for Gaza City Water Network (Case Study The northern Nasser Area)

تقييم و تطوير الأداء باستخدام نظم دعم القرار المكاني لشبكة مياه مدينة غزة

(دراسة حالة منطقة النصر الشمالي)

Researcher:

Hesham Majed Al-Rayess

Supervised by:

Dr. Yunes Khalil Mogheir

A thesis Submitted in partial fulfillment of the requirement for the degree of Master of Science in Civil / Infrastructure Engineering, Islamic University, Gaza.

June - 2015

بسم الله الرحمن الرحيم

الجامعة الإسلامية – غزة
The Islamic University - Gaza

مكتب نائب الرئيس للبحث العلمي والدراسات العليا هاتف داخلي 1150

الرقم: ج س غ/35/ Ref

التاريخ: 2015/06/10 Date

نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **هشام ماجد مجدي الريس** لنيل درجة الماجستير في كلية *الهندسة* قسم الهندسة المدنية – البنى التحتية وموضوعها:

تقييم وتطوير الأداء باستخدام نظم دعم القرار المكاني لشبكة مياه مدينة غزة دراسة حالة منطقة النصر الشمالي

Performance Evaluation and Development of SDSS for Gaza City Water Network Case Study The northern Nasser Area

وبعد المناقشة العلنية التي تمت اليوم الأربعاء 23 شعبان 1436هـ، الموافق2015/06/10م الساعة الواحدة ظهراً بمبنى القدس، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

د. يونس خليل المغير	مشرفاً و رئيساً	....
د. مازن طه أبو الطيف	مناقشاً داخلياً	....
د. سامي محمود حمدان	مناقشاً خارجياً	....

وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في كلية *الهندسة*/ قسم الهندسة المدنية - البنى التحتية

واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق ،،،

مساعد نائب الرئيس للبحث العلمي وللدراسات العليا

أ.د. فؤاد علي العاجز

يقول الله تعالى في كتابه العزيز:

"وَاصْبِرْ لِحُكْمِ رَبِّكَ فَإِنَّكَ بِأَعْيُنِنَا

وَسَبِّحْ بِحَمْدِ رَبِّكَ حِينَ تَقُومُ"

سورة الطور - آية 48.

Dedication

To my mother, who taught me aspire, dream and gain knowledge without limits, my father who didn't spare any time or effort to support me in all of my life, whom I'm here because of them to my brother hammam and my sister hala.

Hesham,

Acknowledgements

I would like to appreciate the efforts of:

- **Dr. Yunes Mogheir** for supervising this thesis, providing , supporting information, consulting and for being patient.
- The team of technical staff at Municipality Of Gaza at water directorate and GIS department.
- Everyone who helped this research exists.

الخلاصة:

توسعت الدراسات في قطاع شبكات المياه بشكل كبير و اللجوء لتحديد اسباب الفاقد في الشبكات و كذلك العمل على التقليل من ذلك الفاقد و العمل على توصيل المياه طبقا للتوزيع الديموغرافي المتنامي بشكل كبير في الدول النامية بشكل خاص.

الهدف من هذا البحث هو الوقوف على تقييم الأداء وتطوير شبكة مياه مدينة غزة باستخدام النمذجه الهيدروليكية ونظم المعلومات الجغرافية. وتقييم كفاءة شبكة (منطقة النصر الشمالي) وتطوير نظم دعم القرار المكاني من شبكة مياه النصر الشمالي كنموذج تجريبي.

تم اتخاذ كافة البيانات من القياسات الميدانية و نتائج النمذجه من برنامج التحليل ، و قد تم استخدام برامج نظم المعلومات الجغرافية في تحديد التعداد السكاني. استخدمت جداول للحصول على بيانات الاستهلاك و توزيع السكان على كل نقطه في المنطقة المستهدفة.

استخدم تحليل نموذج هيدروليكي في منطقة النموذج الأولي و قد تم تحديد المشاكل التقنية في النموذج من خلال المعايرة و نظم دعم القرار المكاني. لعمل نمذجه بدقة عالية فقد تم تقسيم منطقة الدراسة التجريبية (المنطقة الأولى) للمنطقتين (منطقة أ و ب). و قد تم الاعتماد على مسجل القراءات لقياس الضغط في ست نقاط مختلفة على أنابيب التوصيل في حين تم قياس معدل التدفق يدويا داخل البئر ليتم بعد ذلك عمليه اقتراح لنظم دعم القرار المكاني في النموذج للمنطقتين أ و ب.

تم التوصل إلى دقة في المعايرة (الفرق بين النمذجه ومسجل القراءات) إلى ما يقارب 96٪. أشارت النتائج إلى أن 82٪ من المنطقة ب، تراوحت سرعة المياه بين 0-0.25م / ث بينما في المنطقة أ بنسبة 59٪. و قد نتج 70٪ من ضغط المياه في المنطقة أ عند قيمة 2 بار بينما في المنطقة أ فقد بلغت النسبة 72٪ عند قيمة 1 بار. القيم المنخفضة في السرعات نتجت من تسرب في شبكة التوزيع.

يمكن استخدام نظم دعم القرار المكاني المطور كنموذج للتطبيق في جميع مناطق التوزيع لمدينة غزة كما تم عمله في النموذج الأولي لتحسين كفاءة الشبكة وفعالية العمل. بالإضافة إلى هذا نتائج البحث ستكون تعتمد كأساس على نظام المتابعة و التحكم عن بعد لجعل النظام أكثر دقه و كفاءة وتحديد أي مشكلة مفاجئة في النظام وإعطاء بيانات بدقة عالية.

Abstract:

Studies have been expanded heavily at water networks sector. It is resorting to determine the causes of losses at networks, as well as to reduce the leakage and work on water delivery in accordance with the demographic distribution of the growing dramatically in developing countries specially.

The objective of this research is to stand on performance evaluation of Gaza City water network by using hydraulic modeling and geographic information system, assess the efficiency of network (The northern Nasser area from El Jalaa Street to Shiekh Radwan) and develop Spatial Decision Support System (SDSS) of The northern Nasser water network as a pilot scale.

All the data were taken from the field measurements, references and WaterCAD results. The population counts were generated from Geographic Information System (GIS) programs, and Excel sheets were used to get missing data.

A hydraulic model was analyzed at the pilot distribution zones. Calibration and SDSS used to identify the technical problems at prototype. A pilot study area (Zone 1) was divided into two zones (Zone 1A and 1B). Six data logger were put at pipelines which supply zones to measure the flow rate and the pressure. The data logger measurements used to calibrate the model. SDSS was proposed for the pilot area (Zone 1A and 1B).

Calibration accuracy (the difference between modeling and data logger values) nearly reached to 96%. The results indicated that 82% of Zone B, the water velocity ranged between 0-0.25 m/s while in Zone A the percentage is 59%. 70% of the water pressure at Zone A has 2 bars while in Zone B the percentage is 72% for 1 bar. The low values of the velocities may result from the leakage at the system.

The developed SDSS of the pilot scale study may be used at all zones of Gaza city to improve the network efficiency and effectiveness of operation. In addition, the results of this research will be the base of Supervisory Control And Data Acquisition (SCADA) system to make the system more automated and specify any sudden problem at the system and to give more accurate data.

Table of Contents

Dedication .... **III**

Acknowledgements .... **IV**

الخلاصة .... **V**

Abstract .... **VI**

LIST OF ABBREVIATIONS .... **X**

LIST OF TABLES .... **XI**

LIST OF FIGURES .... **XII**

Chapter 1: Introduction 1

1.1Introduction 1

1.2 Statement of the Problem 2

1.3 Thesis Goals and Objectives 3

1.4.Methodology 3

1.5 Thesis organization 4

Chapter 2: Literature Review 6

2.1 Introduction 6

2.2 Water Distribution Network (WDN) 7

2.2.1Pipes 8

2.2.2 Fire hydrants 8

2.2.3 Valves 8

2.2.4 Pumps 9

2.2.5 Water Sources 9

2.2.6 Water demand prediction 10

2.2.7 Transport Facilities 10

2.2.8 Transmission and Distribution Mains 10

2.3 System Configurations 11

2.4 Pump Characteristic Curves 12

2.5 Water utilities of Gaza 13

2.6 Modeling 14

2.7 WaterCAD 16

2.8 Calibration 17

2.9 Geographic Information System(GIS) 19

2.10 Decision Support System (DSS) 21

2.11 Supervisory Control And Data Acquisition (SCADA) 24

2.12 Concluding remarks 29

Chapter 3: Gaza City Water Network 30

3.1 Introduction 30

3.2 Network Structure 30

3.3.1 Pipes 34

3.3.2 Pumps 35

3.3 Operating system 35

3.4 Network zones 36

Chapter 4: Modeling Network Analysis 39

4.1 Modeling 39

4.2 Demand Pattern 40

4.3 Network Analysis 40

4.4 Network Evaluation 44

4.5 Evaluation Criteria 44

4.6 Pump curves 45

4.7 Pilot study Zones 46

4.8 Performance Indicator 49

4.9 Summary 49

Chapter 5: Model Calibration and Spatial Decision Support System 50
5.1 Calibration 53
5.2 Calibration procedures 53
5.3 Spatial Decision Making 55
5.3.1 Components of SDSS in Zone 1A 56
5.3.2 Components of SDSS in Zone 1B 61
Chapter 6: Results and Discussion 66
6.1 Modeling results Gaza city network 66
6.2 Pilot study results 69
6.3 Discussion 70
6.3.1 Gaza city network 70
6.3.2 A pilot study (Zone 1A and 1B) 70
6.4 Summary 71
Chapter 7: Conclusion and Recommendations 72
7.1 Conclusions 72
7.2 Recomendations 73
7.2.1 Gaza city network 73
7.2.2 A pilot study 73
References: 75

LIST OF ABBREVIATIONS

ALC	Active Leakage Control
CPU	Central Processing Unit
CAD	Computer-Aided Design
CP	Critical Point
DAQ	Data Acquisition
DSS	Decision Support System
DMA	District Metering Area
EPS	Extended Period Simulation
Ks	Nikuradse Roughness coefficient
m^3/day	Cubic meter per day
mm^3/yr	Million cubic meters per year
MOG	Municipality of GAZA
MOPAD	Ministry of Planning and Administrative Development
O&M	Operation and Maintenance
PWA	Palestinian Water Authority
PVC	Polyvinyl Chloride
PRV	Pressure Reduction Valve
SDSS	Spatial Decision Support System
SCADA	Supervisory Control And Data acquisition
TCV	Throttle Control Valve
WDN	Water Distribution Network
WSS	Water Supply System

LIST OF TABLES

Table 3.2 Zones inventory data 36
Table 4.1 Example of consumptions calculation at area zones 42
Table 4.2 Zone 1A component according feature 46
Table 4.3 Zone 1A pipes description 47
Table 4.4 Zone 1B component according feature 47
Table 4.5 Zone 1B pipes description 48
Table 5.1 Pressure readings from data logger at zone A 54
Table 5.2 Pressure readings from data logger at zone B 54
Table 6.1 Results zones analysis at water distribution system 66
Table 6.2 Pilot study area results (Zone 1A and 1B) 69

LIST OF FIGURES

Figure 1.1 Flow chart of the research methodology 4
Figure 2.1 Looped and branched networks... 11
Figure 2.2 Looped and branched networks after network failure 12
Figure 2.3 Building blocks of spatial decision support system. 24
Figure 2.4 Scheme describing the optimal operation of a Water Supply System using a SCADA system... 26
Figure 2.5 Conceptual scheme of the DSS prototype for leakage localization applied.. 28
Figure 2.6 Samples of modern SCADA control system 28
Figure 3.1 Gaza city water distribution network at WaterCAD 32
Figure 3.2 water network operation zones by ArcGIS 35
Figure 4.1 sample for demand pattern flow at WaterCAD for Gaza city 40
Figure 4.2 Junctions area distribution by ArcGIS. 41
Figure 4.3 Demand control center selection. 43
Figure 4.4 Demand control center table... 43
Figure 4.5 Pump characteristic curve at Kamal Nasser well (Remal 2) 45
Figure 4.6 Arial photo for Zone 1 case study 46
Figure 4.7 Zone 1A modeling network at WaterCAD.. 47
Figure 4.8 Zone 1B modeling network at water cad... 48
Figure 5.1 Data logger connected at Kamal Nasser Well.. 50
Figure 5.2 Distribution of data logger in the pilot study area.. 52
Figure 5.3 Pressure records curve at Kamal Nasser well 52
Figure 5.4 Flow records curve at Kamal Nasser well.. 52
Figure 5.5 Zone 1A layout of model components 56
Figure 5.6 Zone 1A histogram demand at junctions.. 57
Figure 5.7 Zone 1A pressure percentage at junctions.. 57
Figure 5.8 Zone 1A pipes diameter histogram. 58
Figure 5.9 Zone 1A pipes flow rate histogram. 58
Figure 5.10 Zone 1A pipes flow rate percentage... 59
Figure 5.11 Zone 1A pipes velocity histogram.. 59
Figure 5.12 Zone 1A pipes velocity percentage. 60
Figure 5.13 Zone 1B layout of model components. 61

Figure 5.14 Zone 1B histogram demand at junctions. 62
Figure 5.15 Zone 1B pressure at junctions. 63
Figure 5.16 Zone 1B pipes diameter histogram. 63
Figure 5.17 Zone 1B pipes flow rate histogram. 64
Figure 5.18 Zone 1B pipes flow rate percentage. 64
Figure 5.19 Zone 1B pipes velocity histogram. 65
Figure 5.20 Zone 1B pipes velocity percentage. 65
Figure 6.1 Zones flow rate curve 68
Figure 6.2 Average daily consumption for zones 69

Chapter 1: Introduction

1.1.Introduction

Water distribution networks play an important role in modern societies being its proper operation directly related to the population's well-being to deliver water to individual consumers with appropriate quality, quantity, and pressure in a community setting requires an extensive system of Pipelines, junctions, wells, pumps and Tanks.

Distribution system is used to describe collectively the facilities used to supply water from its source to the point of usage. In laying the pipes through the distribution area, the following configuration can be distinguished: Branching system, Grid system and combined system.

Network criteria, is recommended to get the most efficient and economical water distribution network are pressure, pipe diameter, head losses, design period, velocity and average water consumption.

At Gaza the water supply network suffers from many defects and high percentage of losses which make the network works randomly at hydraulic system without any development. Using Geographical Information System (GIS) makes operation, maintenance and planning of water supply more effective and economical.

Decision-makers in Gaza municipality and non-technical water managers in water system management and more specifically in water network assessment usually face difficulties in dealing with sophisticated tools of information such as GIS through its adopted applications such as Watercad, ArcGIS, Geomedia Professional and other applications.

Custom open GIS applications could act as Decision Support System (DSS) and to some extent as a Spatial Decision Support System (SDSS) which is a computer–based system designed to assist decision system. Typically, such a system will include spatial data relevant to the decision.

This lack of using an easy tools increased the worsening operation of the water network in Gaza, led to management difficulties despite of the availability of large set of data on water related parameters and factors.

The numerous situations of planning, strategic management and protection of resources which need to be solved nowadays favor a growing interest in the development of SDSS, capable of representing the dynamics of the system using geographical details which define social, economic and biophysical conditions.

This study will support decision makers to make water distribution network (WDN) more effective, suitable to serve people at Gaza city and to reduce the high leakage at network.

1.2.Statement of the Problem

Water distribution system at Gaza city suffers from many problems such as:

1. Erosion (especially pipelines) at the network.
2. No preventive maintenance is used which is the most important issue to make the network work effectively.
3. Random connections without any scientific method or any mathematical calculation for flow and pressure values.
4. Lack of future plans for demands and network operation at long term.
5. Intermittent supply which results in hydraulic and financial problems.
6. Many technical problems at the network resulted from lack of water resources; quality and flow.

1.3. Thesis Goals and Objectives

The main aim of this research is to evaluate and assist water distribution network at Gaza City, Using (WaterCAD) modeling and develop SDSS for the water network in The northern Nasser area as a pilot small scale from the city.

To be more specific, the objectives of this research are:

1. Evaluate the current situation of water network and identify the defects.
2. Make a database for water network which represents as base for developing plan.
3. Assess the efficiency of network (The northern Nasser area).
4. Suggest more alternatives of operation to make the water system more flexible and Identify the priorities for developing the water system.
5. Develop SDSS of The northern Nasser water network as a pilot scale.

1.4. Methodology

The steps that were used to achieve the objectives of the study are:

1. Literature Review: Search and make a review about previous studies in topics related with this research which may include water distribution network, modeling, Calibration methods and Spatial decision support system.
2. Data Collection: Data gathering from engineers, technical workers at Municipality (Water Directorate) and engineers at GIS department and field visit which includes all descriptive data (wells, types of pipelines, diameter and AutoCAD files for network)
3. Parametric study: This step to analyze the network and study approach by divide city for zones and use district meter to control the network more easily and reduce the high pressure at it at work stage.
4. Field visit for wells: To discover problems and evaluate the current situation of flow rate, pressure and efficiency at wells.
5. Network Model (WaterCad Model): We built modeling that simulated the real network by data collected about wells and network.
6. Decision Support System: This step to develop SDSS that helped Decision makers for useful approach to improve the efficiency at water network.

7. Analysis Results and Recommendations: After collect data and modeling analyzed it to represent it as figures and tables and describe the results to suggest effective solutions suitable with problems at network.

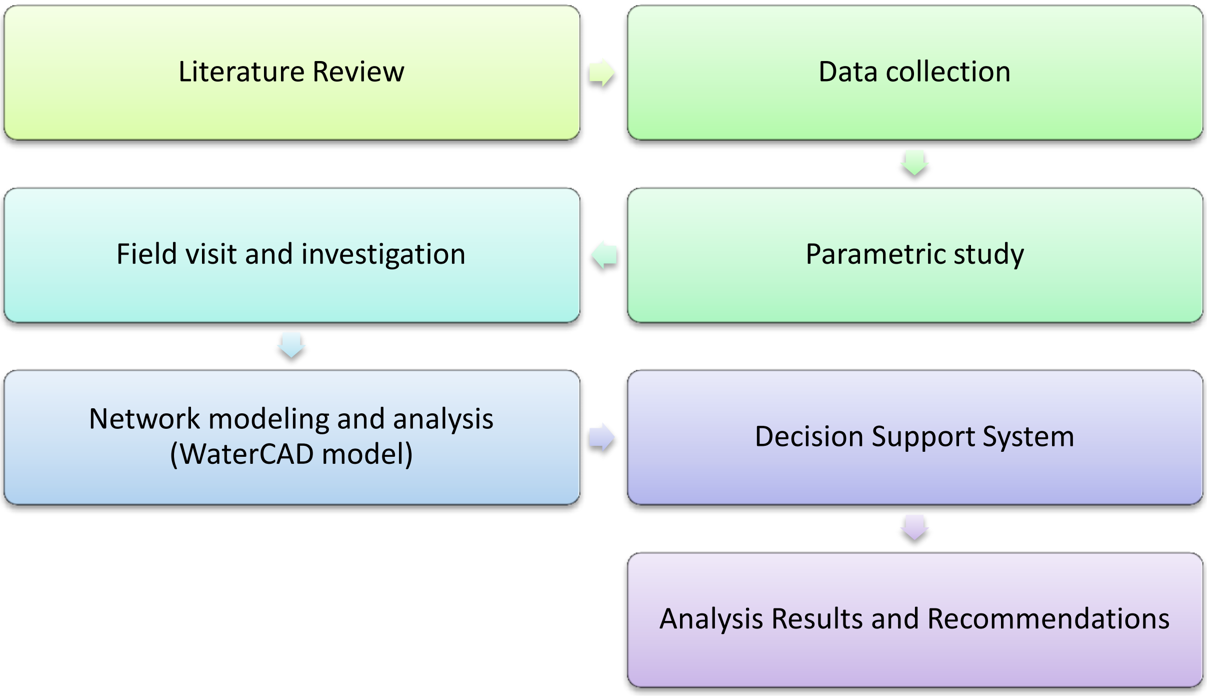


Figure 1.1: Flow chart of the research methodology

1.5.Thesis organization

This thesis consists of seven chapters as follows:

- **Chapter One (Introduction):** this chapter focus about make a vision about the reasons to make this study. It consisted from: introduction, statement of problem, goals and objectives and Methodology for work.
- **Chapter Two (Literature Review):** covers a general literature reviews published in previous studies for hydraulic modeling networks.
- **Chapter Three (Gaza City Water Network):** express the components of water network system at Gaza city.
- **Chapter Four (Network Analysis):** study zones and building the model and indicators for analysis step for modeling.

- **Chapter Five (Calibration and Spatial Decision Support System):** it explained the prototype of a new flexible spatial decision support system (SDSS) that can be extended on a modular basis and used interactively to support decisions with regard to sustainable water network.
- **Chapter Six (Results and Discussion):** study and discuss all modeling results and pilot study to achieve the aim from this study.
- **Chapter Seven (Conclusion and Recommendations):** conclusions and suggestions for future work are given at this chapter.

Chapter 2: Literature Review

2.1 Introduction

Water utilities provide clean water service to local communities and charge the service by the metered water consumption. However, not every drop of water produced reaches customers and generates the revenue for municipalities. Instead, a significant portion of drinking water is lost, due to either water dripping away from the distribution pipelines or the unauthorized water usage. Consequently, water utilities lose the revenue within distribution pipeline networks. Water loss represents a major fraction of non-revenue water (NRW) (Zheng, 2007).

The coming of age of the water infrastructure poses an increasing challenge for utility managers. One of the key issues is to assess the long-term development of network rehabilitation demand. The motivation is to ensure that sufficient funding is raised and appropriately allocated to achieve the foreseen level of service. As a result, the last decade of water infrastructure management has seen increased development, testing, and application of mathematical models in rehabilitation planning and network failure estimation (Scholten, et al, 2013).

In common engineering practice water distribution systems are designed using only heuristic criteria. Determining the optimal configuration and network parameters that can meet required flow and pressure rate are the result of hydraulic and cost-benefit analyses. The probability of system failure and other reliability statistics are very rarely included in such analyses (Dasic, et al., 2004).

The immediate consumers supply without any planned strategy hassled to inefficient operated systems, increasing the energy costs for water supply and distribution. With the actual concerns about sustainable development, the improvement of energy efficiency in Water Supply Systems (WSSs) must be of major importance (Coelho, et al., 2013).

Performance measures and indicators are used to support the managerial approaches to minimize different components of water losses. These concepts and methods have been adopted by countries around the world (Zheng, 2007).

2.2 Water Distribution Network (WDN)

Studies on Water Distribution Network (WDN) performance are a core issue as a tool for water management entities decision making. In order to achieve this goal it is necessary to know both the WDN's infrastructure registration and the hydraulic operating conditions (flows and pressures) for simulation computation (Alves, et al., 2014).

Simulation is an emulating process where system's performance is computed using a mathematical representation of the real WDN in order to reproduce the responses of real systems for the same input conditions. This, so called model, must be calibrated (Walski, et al., 2003.).

The improvements of energy efficiency in WSSs can pass through simple monitoring operations for leakages control to more complex operations such as the water demand prediction, pump systems optimization, storage production reservoir systems optimization and real-time operations. However, it is important to notice that WSSs should always satisfy the requirements of several consumption sectors, responding to demand in each place, in each time and with appropriate pressures (Viessman, et al., 2009).

A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. WaterCAD tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated (Vuta, et al., 2008).

2.2.1 Pipes

Pipes convey water from one point to another and a careful selection of pipe material is particularly important, because it avoids the following bad consequences:

- Increased water losses.
- Increased energy losses.
- Shorter pipe life time.
- Expensive maintenance of the system.
- Potential deterioration of water quality.
- Frequent interruption of supply.

Pipes used in water supply are made of various materials and depending on their resistance to the applied forces on it, they can categorize three groups (Abdul Rahman, et al., 2005):

- Rigid (Iron, Pre-stressed concrete, Asbestos cement).
- Semi Rigid (Steel, ductile iron).
- Flexible (PVC, UPVC).

2.2.2 Fire hydrants

A fire hydrant is a device used for firefighting that is connected to a water main and provided with outlets nozzles to which fire hoses can be attached for discharging water at high rate. One or more valves are provided for the operation of the hydrant.

The hydrant is one of the most important parts of the WDS and often one of the most ignored. To ensure their availability when needed, hydrant must be properly installed, operated and maintained.

The outflows from hydrant are generally within the range 30-500 m^3/hr and pressure from 10-100 m (Chatterjee, 2001) (Abdul Rahman, et al., 2005).

2.2.3 Valves

Valves are mechanical devices that used to start, stop or regulate water flow in WDS, it can be operated manually or automatically related to pressure or water level.

Generally, valves have three critical functions (Abdul Rahman, et al., 2005) (Walski, et al., 2001):

1. Flow or/and pressure regulation (flow control valve, throttle control valve, attitude valve, pressure reducing valve, pressure sustaining valve).
2. Exclusion of parts of the network due to emergency or maintenance (isolate valve like gate valve, butterfly valve, globe valve, and plug valve).
3. Protection of reservoirs and pumps in the system (float valve, non-return valve).

Valve can be operated manually or automatically. Automatic operation is usually related to; pressure or water level, flow rate or flow direction and certain time schedule.

2.2.4 Pumps

Water pumps are devices designed to convert mechanical energy to hydraulic energy. They are used to move water from lower points to higher points with a required discharge and pressure head.

2.2.5 Water Sources

Water sources like rivers, lakes and ground water aquifer are used in the system. These sources must be including in the system model. Groundwater aquifer is a municipal water source in Gaza City Operate from pump to supply the network (Walski, et al., 2001).

The estimation of water loss in the world is around 30%, meaning that a similar portion of energy is also lost. Multiple factors contribute to these energy losses in the water sector: inefficient pump stations, poor design of the networks, installations and maintenance, old pipes with head loss, bottlenecks in the networks, excessive pressures and inefficient operation strategies (Feldman, 2009).

Demands are not physically in the network like nodes or pipes. They are the driving force behind the hydraulic dynamics occurring in water distribution systems (WDS). Of course water is going out, thus common sense sees them as outputs of the system. They are estimated as parameters but very complex ones. Finally, from a control point of view they are nothing but disturbances that have to be rejected for a good service. Any place where water can leave the system represents a point of consumption, including a customer's faucet, a leaky main, or an open fire hydrant (Walski, et al., 2003).

2.2.6 Water demand prediction:

An accurate estimation of water demand is an important requisite for the optimal operation and design of a WSS. The prediction of water demand allows better approximations between the water supply flow rate and the water consumption flow rate, providing more resource savings and, consequently, more cost savings (Kiselychnyk, et al., 2009).

The presence of leakages in the network, they must be localized and repaired. The former task can be addressed with different sensors, such as: acoustic devices that correlate the noise in the pipe to the leakage position (Clark, A., 2012) (Hamilton, S., 2012) (Debiasi, et al., 2014).

Continuous improvements on water loss management are being applied, based on the use of new available technologies. Nonetheless, the whole leakage localization process may still require long periods of time with an important volume of water wasted before the leak is found (Perez, et al., 2011).

2.2.7 Transport Facilities

Moving water from the source to the customer requires a network of pipes, pumps, valves, and other appurtenances. Storing water to accommodate fluctuations in demand due to varying rates of usage or fire protection needs requires storage facilities such as tanks and reservoirs. Piping, storage, and the supporting infrastructure are together referred to as the water distribution system (WDS) (Walski, et al., 2013).

2.2.8 Transmission and Distribution Mains:

This system of piping is often categorized into transmission/trunk mains and distribution mains. Transmission mains consist of components that are designed to convey large amounts of water over great distances, typically between major facilities within the system. For example, a transmission main may be used to transport water. Individual customers are usually not served from transmission mains. Distribution mains are an intermediate step toward delivering water to the end customers.

Distribution mains are smaller in diameter than transmission mains, and typically follow the general topology and alignment of the city streets. Elbows, tees, crosses, and numerous other fittings are used to connect and redirect sections of pipe. Fire hydrants, isolation valves, control valves, blow-offs, and other maintenance and operational appurtenances are frequently connected directly to the distribution mains. Services, also called service lines, transmit the water from the distribution mains to the end customers (Walski, et al., 2013).

2.3 System Configurations

Transmission and distribution systems can be either looped or branched, as shown in Figure 2.1. As the name suggests, in looped systems there may be several different paths that the water can follow to get from the source to a particular customer. In a branched system, also called a tree or dendritic system, the water has only one possible path from the source to a customer.

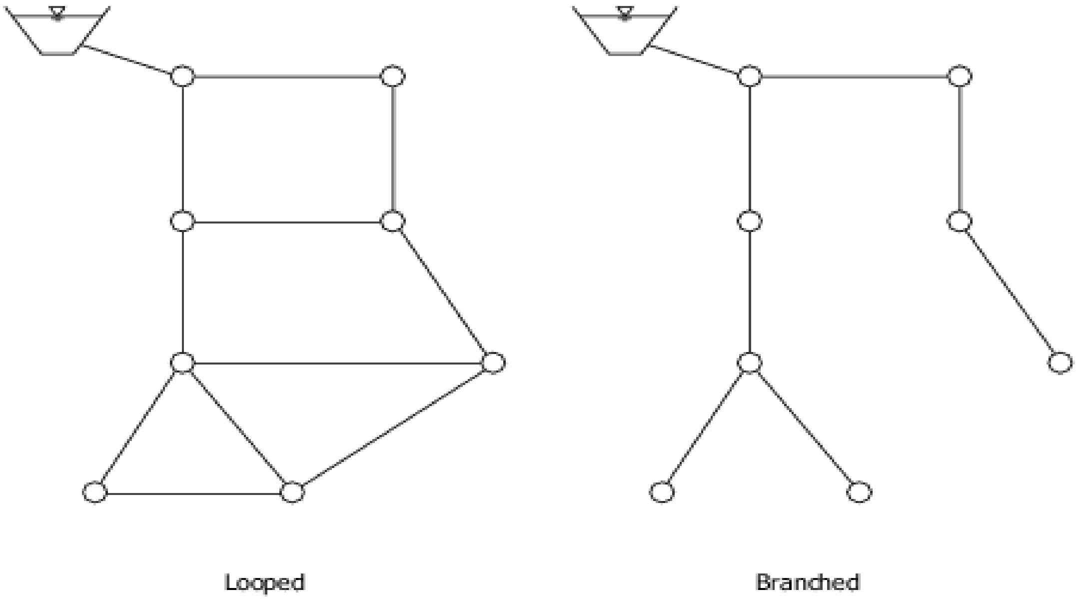


Figure 2.1 Looped and branched networks

Looped systems are generally more desirable than branched systems because, coupled with sufficient valving, they can provide an additional level of reliability. For example, consider a main break occurring near the reservoir in each system depicted in Figure2.2. In the looped system, that break can be isolated and repaired with little impact on customers outside of that immediate area. In the branched system, however, all the customers downstream from the break will have their water service interrupted until the repairs are finished. Another advantage of a looped configuration is that, because there is more than one path for water to reach the user, the velocities will be lower, and system capacity greater (Walski, et al., 2013).

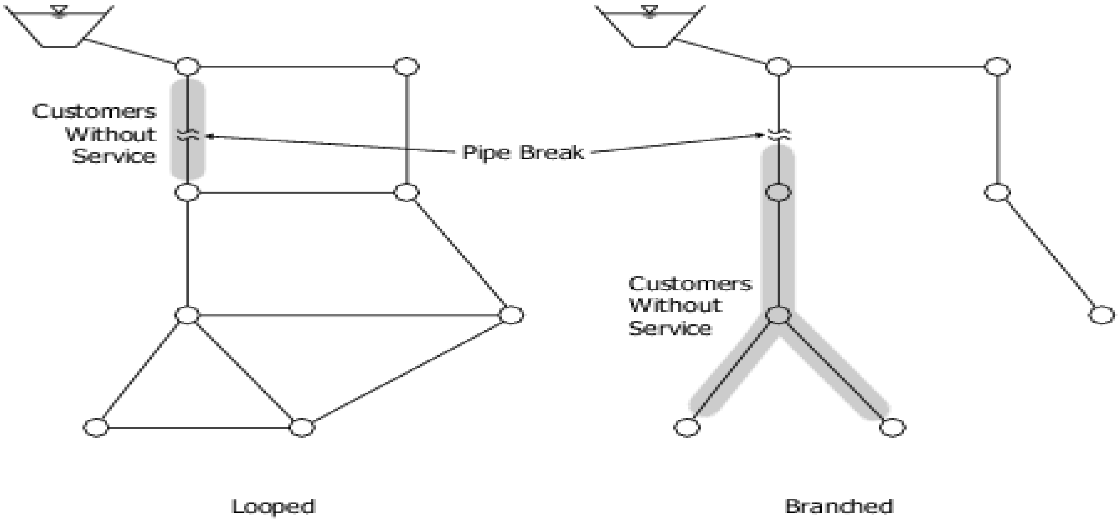


Figure 2.2 Looped and branched networks after network failure

Most water supply systems are a complex combination of loops and branches, with a trade-off between loops for reliability (redundancy) and branches for infrastructure cost savings. In systems such as rural distribution networks, the low density of customers may make interconnecting the branches of the system prohibitive from both monetary and logistical stand points.

2.4 Pump Characteristic Curves

Recall that hydraulic simulation models require data concerning the pump head versus discharge relationship. Generally, these models use some type of interpolation routine that fits a curve through selected points from the manufacturer's pump head characteristic curve. Because a curve-fitting method is used, the true head and discharge of the pump may differ somewhat from the curve, and error is introduced into the model. Numerical curve-fitting errors can be identified by comparing the manufacturer's curve with the curve produced by the hydraulic model (Walski, et al., 2003.).

A more likely cause of error when modeling pumps results from the use of old or outdated pump curves. For instance, suppose that you are modeling a system that uses 25-year-old centrifugal pumps, but the head versus discharge relationship shown on the manufacturer's pump curves reflects the performance of the pump when it was new. Normal wear and tear on a pump as it ages can cause the field performance to deviate from the performance illustrated on the pump characteristic curve. In fact, the pump impellers may have been changed several times since the pumps were originally installed. If so, the original pump curves will have little value because the head/discharge relationship of a pump is dependent on the characteristics of the pump impeller. In such cases, new curves should be determined based on field tests. Hydraulic network model calibration involves more than just adjusting pipe roughness values and nodal demands until suitable simulation results are obtained (Walski, et al., 2003.).

Energy losses, also called head losses, are generally the result of two mechanisms:

1. Friction along the pipe walls
2. Turbulence due to changes in streamlines through fittings and appurtenances.
3. Head losses along the pipe wall are called friction losses or head losses due to friction, while losses due to turbulence within the bulk fluid are called minor losses.

2.5 Water utilities of Gaza

Water utilities provide clean water service to local communities and charge the service by the metered water consumption. A key element of the information is its location relative to geographic features, other objects, established boundaries, etc. An information system is a framework by which to ask questions and obtain answers from a data resource.

GIS technology can be utilized by each of the following water utility function groups, but there are considerable differences in the uses and relative advantages of such technology:

1. Planning: planning the timed expansion of the water system (future demands).
2. Engineering: detailed design and construction of water facilities.

3. Operation and Maintenance (O&M): operating and maintaining water transmission and supply facilities.
4. Administration: managing the paperwork and dollars associated with operating the water system (Badwan, 2010).

2.6 Modeling

Some researchers developed an alternative approach for assessing leakage through network hydraulic simulation. In general, there is still a relatively low level of leakage reduction R&D funding by the industry and to make development of the system (Zheng, 2007).

Computer simulation models of water distribution systems represent the most effective and viable means for evaluating system response to various management strategies (Ennis, et al., 2014).

Engineers familiar with the CAD environment have grown increasingly dependent on the hydraulic software's usability, interface, and CAD-like features. Likewise, enterprise GIS software has not been tailored, both in terms of price and functionality, to serve the requirements of water distribution planning and analysis. As such, software for the analysis of water distribution systems was normally created in the CAD environment to receive acceptance from an engineering community already familiar with AutoCAD for other civil applications. No such software however, has been developed to integrate the water distribution modeler's needs with the data and spatial reference abilities of GIS (Schaetzen, et al., 2014).

Water utility engineers are responsible for ensuring the safe and efficient supply of drinking water. The role of a GIS in the analysis of a distribution system is to provide up-to-date and accurate data to be used in the engineering analysis. For years, engineers have exported data from GIS data sets to third party software for analysis and design of water distribution systems (Schaetzen, et al., 2014).

Water distribution model is a mathematical description of real system. Building a model need sequence steps start with gather information describing the network (Walski, et al., 2001).

Models that can represent detailed relationships among the components of a water supply system and evaluate alternative plans are invaluable for the decision makers to cope with future changes in water supply system (Chung, et al., 2008).

Water distribution system computer models have been in use since the middle 1960s and have evolved into sophisticated, user-friendly tools that are capable of simulating large distribution systems (U.S. Fire Administration, 2008).

Hydraulic simulators are numerical programs in which it is possible to implement models for water transportation and distribution. These models replicate the nonlinear dynamics of the networks by solving a set of hydraulic equations including conservation of mass and conservation of energy (Machell, et al., 2010).

Dynamic water distribution hydraulic model built up on the theory of network adjustment and delay simulation, while taking the water supply system to be convenient to manage into account. By running hydraulic calculations and dynamic simulations, hydraulic modeling software educes various hydraulic characteristics of network fittings and pumping stations, in order to analyze and diagnostic network operation condition, improve operation proposal, optimize network design and achieve the advanced network management. At present, lots of water supply companies are promoting the applications of hydraulic model in network operation (Xu, et al., 2012).

It is used: to predict the behavior of this system to solve a wide variety of design, operational and water quality problems and to predict pressures and flows in a water distribution system to evaluate a design and to compare system performance against design standards (U.S. Fire Administration, 2008).

Water mains model optimization investigations for a single pressure zone pilot-study DMA using the genetic algorithms. Initially, the investigations were based on custom and practice field data but making use of more logging. Some large leaks were found the lack of leakage detection in model maintenance studies could lead to less reliable selection of pipe roughness coefficients ks (Wu, et al., 2010).

Therefore, the hydraulic modeling is aimed to:

- Reveal which were the critical elements of the system (remarkable high points, hydraulic limits of branches for distribution to peripheral nodes); detect the need to change fixed settings with hydraulic valves, identifying their settings parameters; develop the optimal allocation for each sector of the pipeline and between the main branches; identify the sensitivity of the resource distribution as a result of any internal imbalances (losses, increasing needs) compared to the simulated distribution (Giunti, et al., 2014).
- For program optimization, network hydraulic modeling software shows a rich display of the water distribution system's features and gives an assessment of different rehabilitation plans under various operation conditions. It provides an important guide to the improvement and optimization of the network. In the course of the model simulation, some factors should not be overlooked, for example, the accurate prediction of water demand, the accuracy of hydraulic model, the reasonable selection of control point. As an effective tool for quantitative analyzing the performance of network system, hydraulic model provides useful information and data for evaluating and optimizing the network system so as to guarantee the design of the drinking water supply system is scientific, economical and security (Xu, et al., 2012).

2.7 WaterCAD

WaterCAD, produced and marketed by Haestad Methods of Waterbury, Connecticut, is a stand-alone hydraulic modeling program containing its own graphical editor and strong modeling capabilities that features a Windows-based interface to EPANET. WaterCAD can produce a distribution system network either scaled or schematically and with or without underlying DXF background maps. The resulting network can be color-coded to reflect modeling results, and WaterCAD also carries adequate annotation capabilities (Orange Water and Sewer Authority (OWASA), 1999).

WaterCAD: is a robust and comprehensive water distribution modeling program that can be customized with additional modeling platforms and modules as your modeling requirements grow and an easy-to-use hydraulic and water quality modeling solution for water distribution systems. Utilities, municipalities and engineering firms trust WaterCAD as a reliable, resource-saving, decision-support tool for their water infrastructure (Bentley, 2012).

Included and Available Interfaces: WaterCAD includes, out-of-the-box, two interoperable platforms, letting you choose the environment that best fits your skills and modeling requirements.

- Windows stand-alone: Enjoy unparalleled ease-of-use and versatility, multiple background support, advanced thematic mapping, powerful element symbology features and conversion utilities from CAD, GIS and databases.
- Run in MicroStation: Support for MicroStation is included at no additional cost; seamlessly use every WaterCAD feature within MicroStation's powerful engineering design and geospatial environment.

For data input and output, WaterCAD uses tables that are contained directly within the modeling environment, as opposed to a text-editing program. Data for populating the model which can be written to and output can be written from these tables using the database connectivity feature of WaterCAD. WaterCAD also has the ability to connect with Environmental Systems Research Institute, Inc.'s (ESRI's), GIS programs using the SHAPEFILE for model data import and export (Orange Water and Sewer Authority (OWASA), 1999).

Bentley WaterCAD V8i supports several methods of exchanging data with external applications, preventing duplication of effort and allowing you to save time by reusing data already present in other locations. For instance, you can exchange data with databases or a GIS system, or you can convert existing CAD linework to a pipe network (Bentley Systems, Inc, 2013).

2.8 Calibration

Water networks calibration has been thoroughly studied by researchers but almost evaded by practitioners. The high uncertainty in real networks together with the low number of measurements available makes the calibration problem a challenge (Shamir, et al., 1977).

All models of water distribution systems (WDS) require calibration. The precision of hydraulic models depends on how accurately they have been calibrated. The calibration parameters usually include pipe roughness, pipe diameters and demands, where the first two relate to flow conditions and the last one to boundary conditions. The corrosion and deposition processes, which occur over time after the pipe installment, make it more difficult to determine the actual pipe diameter. Therefore, in the absence of another value, nominal pipe diameters are generally used for model development, and the roughness coefficient is adjusted to compensate the change in diameter due to the pipe wall build-up (Vassiljev, A. and Koppel, T., 2006). The process of fine-tuning a model until it is able to simulate the conditions prevailing in the system for a particular time horizon with a degree of accuracy pre-established (Cesario, 1995).

Calibration of computer models for water distribution system (WDS) analysis is an essential performed step in the model building process. Calibration of pipe network systems consists of determining the physical and operational characteristics of an existing system. This is achieved by determining various parameters that, when input into a hydraulic simulation model, will yield a reasonable match between measured and predicted pressures and flows in the network (Darvini, 2014).

From the point of view of the model's hydraulic calibration, it is important to ensure that both flow values (concerning to systems' inflows and outflows as well as network's flow) and pressure values (or level in the reservoirs) are accurately simulated as it is not acceptable if the calibrated model just reproduce one these variables (Alves, et al., 2014).

The location of the measurement node is important in obtaining accurate determinations of the unknown demands. Demands are accurately determined by the model when measurements are made at sensitive nodes to the unknown demands (Al-Omari, et al., 2009).

The most challenging part of calibrating a model is making judgments regarding the adjustments that must be made to the model to bring it into agreement with field results. The following is a seven-step approach that can be used to guide model calibration (Walski, et al., 2003):

1. Identify the intended use of the model.
2. Determine estimates of model parameters.
3. Collect calibration data.
4. Evaluate model results based on initial estimates of model parameters.
5. Perform a rough-tuning or macro-calibration analysis.
6. Perform a sensitivity analysis.
7. Perform a fine-tuning analysis.

A Sensitivity analysis can be conducted to judge how performance of calibration changes with respect to parameter adjustments. For example, if pipe roughness values are globally adjusted by 10 percent, the modeler may notice that pressures do not change much in the system, thus indicating that the system is not sensitive to roughness for that demand pattern. Sensitivity analysis is conducted for the model. The final step in the calibration process is usually fine-tuning the model. This can be a time consuming effort if there is a large number of pipes or nodes to adjust (Ormsbee, and Lingireddy, 1997).

2.9 Geographic Information System (GIS)

A GIS is a system that allows capturing, managing, analyzing and displaying information geographically referenced. This kind of system is useful for the management of projects involving large volume of data and for the application of some analytical tools. In hydraulic simulation works, importing the model results into GIS provides high quality result display and additional analysis possibilities.

The information stored in a GIS is represented by a series of spatially referenced datasets. These datasets, which can be vector or raster based, are used to organize and manage both the geometry and attribute descriptions associated with various types of geographic features (ESRI, 2006).

A GIS provides a powerful analytical tool that can be used to create and link spatial and descriptive data for problem solving, spatial modeling and to present the results in tables or maps (Bice, et al., 2000).

More commonly, people use GIS to make maps; a GIS can also be used as a powerful analysis tool. It can be used to create and link spatial and descriptive data for problem solving, spatial modeling and to present the results in tables, graphics or maps. The most powerful feature of a GIS, from a planner's perspective, is probably the ability of GIS to integrate databases, through their spatial relationships, that would be difficult or impossible to do outside a GIS environment (Walski, et al., 2003).

The three views of GIS:

1. The Geodatabase View: A geodatabase is a spatially enabled relational database that has the ability to represent various types of geographic data, manage attributes associated with that data, maintain spatial relationships (topology and networks), and keep track of user-defined thematic layers and datasets.
2. The Geovisualization View: The geovisualization view is about working with maps and other views of geographic information including interactive maps, 3D scenes, global views, charts and tables, time-based views, and schematic views of network relationships.
3. The Geoprocessing View: A full-featured GIS will include a rich set of tools to work with and process geographic information. Tools are also used to operate on GIS-related objects, such as datasets, attribute fields, and cartographic elements, for displaying and publishing maps. These tools and data objects form the basis of the system's geoprocessing framework.

The role of GIS and related techniques in supporting spatial decision making processes. It was organized around the notion that GIS can provide limited support for decision making and that more sophisticated methods of decision support are required. Acording to Malczewski and others Four research themes emerged from the initiative:

1. Optimal schema for decision support in areas of ill-defined spatial problem-solving
2. Modeling and data requirements for SDSS
3. Technology and the implementation of SDSS
4. User requirements and organizational issues (Malczewski, 2004).

2.10 Decision Support System (DSS)

Decision support systems (DSS) may be considered to be a new generation of information systems, the goal of which is to try to discover what would happen if a series of decisions are taken or going even further, by automatically providing the decisions or suggestions that assist the manager (Adenso-Diaz, et al., 2005).

DSS is a computer-based system designed specifically for supporting the user in tackling semi-structured problems (Malczewski, 2004). DSS is also an integrated environment to share and manage data and to facilitate cooperation among different levels of users (Yingchun, et al., 2013).

A DSS has been defined in many different ways, but it can be regarded in general as an interactive, flexible, and adaptable computer based information system especially developed for supporting the recognition and solution of a complex, poorly structured or unstructured, strategic management problem for improved decision-making (BFG, 2000).

It uses data and models, provides an easy, user-friendly interface, and can incorporate the decision-makers own insights. In addition, a DSS is built by an interactive process (often by end-users), supports one or more phases of decision-making, and may include a knowledge component (Matthies, et al., 2007).

DSSs and SDSSs can be regarded as interactive, flexible and adaptable computer-based information systems, developed especially in order to support the recognition and solution of a complex, poorly structured strategic management problem to improve decision making (Volk, et al., 2010).

Typical DSS interactive and integrated components are:

1. Data and information management. The data and information component is key and central in developing a DSS. The focus is integrating database and connecting data islands into a dynamic framework with advanced display, mapping, query and presentation capabilities.
2. Analysis and modeling. The data framework provides the basis for further analysis and interpretation of data and information. Depending on stage and scope of the DSS the analysis can range from simple to complex including statistical and numerical models, economic and cost/benefit as well as User Defined and Custom tools.

3. Scenario management and alternative formulation. The DSS framework is capable of supporting and providing information (costing and prioritization) for project feasibility and planning projects as well as design and implementation. Upon implementation the project may have an operations component that requires real time and online decision making.
4. Decision making. Customizable GIS and Web based interfaces are tailored to meet specific needs and requirements. Advanced graphics, on-line access, custom rules and interpretations can be embedded into the DSS to support and provide the basis for decision makers to make timely, reproducible and well informed decisions (Keen, 1986).

DSS is required in support of strategic planning, typically within the context of policy-making and planning for which scenario analysis and simulations are particularly helpful. The spatial dimension is also very relevant and for this reasons DSS often become spatial decision support systems (SDSSs), by integrating functionalities or coupling with existing GIS tools (Matthies, et al., 2005).

The design of spatially targeted policies requires the support of robust methodologies, extensive data bases and elaboration tools, such as models, geographical information systems (GIS) and decision support systems (DSS) (Fassio, et al., 2005).

The spatial dimension is also very relevant and for this reasons DSS often become spatial decision support systems (SDSSs), by integrating functionalities or coupling with existing GIS tools. An ever greater emphasis is given in recent times to the involvement of stakeholders, or actors, in the development and implementation of DSS tools. On the one hand, this further complicates the matter by raising various problems and in particular those related to the management of the complexity inherent in socio-natural systems and the various sources of uncertainty. On the other hand, there is a trade-off between the attempt to simplify the intrinsic complexity, and the need for scientifically robust approaches and detailed high quality data. Providing transparent communication interfaces is a common problem in current DSS development efforts, whenever public participation is adequately considered (Matthies, et al., 2005).

The benefits of DSS usage might be divided into three groups: those at the managerial level, those at the operational level, and those at the personal (individual user) level. If we assume that improving individual decision-maker performance is a personal-level benefit we might ascribe to a DSS, then it is worthwhile to consider to what degree any DSS, including one using GIS technology, makes such a contribution. The problem and questions investigated here involved an assessment of the value, at the individual level, of using GIS technology as a spatial decision support system, or SDSS (Crossland, et al., 1995).

An SDSS may be considered to make a positive contribution to the decision-maker's task if it enables him or her to reach: a more accurate solution, a faster solution to a given problem, or both of these (Crossland, et al., 1995).

Among the available approaches for pressure management, the use of District Metered Areas (DMAs) also allows for a more accurate localization of the leakages in the water distribution network, which is achieved by monitoring the input and the output discharges for each district. Nowadays, this approach is widely used in practice, but its application is still largely entrusted to the experience of technicians. The optimal design of DMAs as part of a Decision Support System (DSS) for reducing the water losses has been addressed only recently in the literature. Some authors have proposed hybrid approaches for the automatic partitioning of a water distribution network, based on both meta-heuristic algorithms and on applications from the graph theory (De Paola, et al., 2014).

An application of an SDSS to solve a decision making problem may increase the efficiency of the data and information processing operation, it is not the real aim of the system. More important, a DSS aims to improve the effectiveness of decision making by incorporating judgments and computer-based programs within the decision making process. The system should support a variety of decision making styles that may be present in a particular problem solving process. Consequently, the key feature of any SDSS is that it does not replace a user's judgments. The purpose of such a system is to support a user in achieving 'better' decisions. To improve the decision making, SDSS involves the knowledge, intuition, experience, initiative, creativity, etc. of the users. It provides judgmental information in the form of preferences about the significance of impacts, which cannot be expressed a priori in a formal language. The system should help the users to explore the decision problem in an interactive and recursive fashion. To this end, the ability of a GIS to handle judgments involved in the planning process is of critical importance, if the system is to be used as a SDSS. This calls for a representation of the judgments, values, arguments and opinions in the system. One way of doing this is to incorporate decision analytical techniques (e.g. multi-criteria analysis), into the GIS-based planning process (Feick, et al., 1999) (Jankowski, et al., 2001).

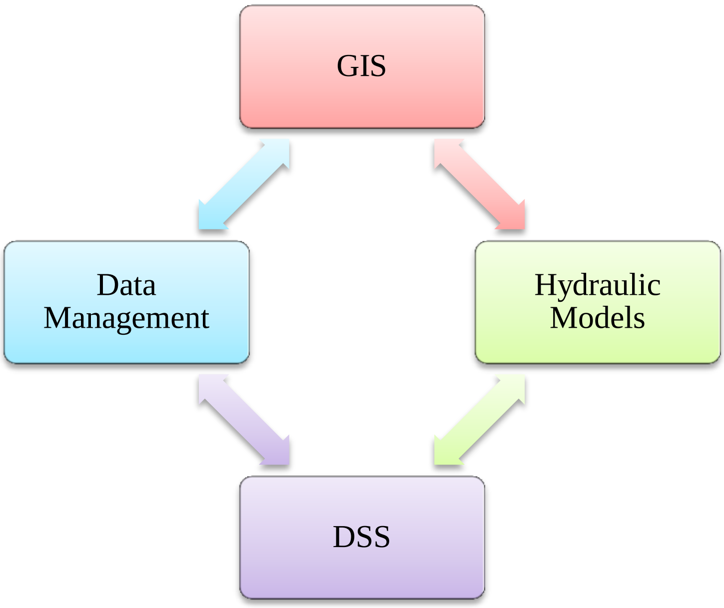


Figure 2.3 Building blocks of spatial decision support system *(Denzer, 2004)*.

2.11 Supervisory Control And Data Acquisition (SCADA)

Supervisory Control and Data Acquisition (SCADA) networks provide great efficiency used for monitoring and controlling numerous industrial and infrastructure processes in critical industries and infrastructures such as water, gas, oil and power generation systems (Rezai, et al., 2013).

SCADA systems typically incorporate sensors and actuators that are controlled by programmable logic controllers (PLCs) which are themselves managed using a human–machine interface (HMI). SCADA systems were originally designed or serial communications and were built on the premise that all the operating entities would be legitimate, properly installed, perform the intended logic and follow the protocol (Goldenberg, et al., 2013).

Table 2.1 Functional decomposition of an automation system

SCADA Layer	Automation System
PLCs Layer	
Machine Layer	Plant

Real-time strategies allow optimal operational adjustments to possible variations in the networks such as sudden fluctuations in demand, contributing for the efficiency improvement of the WSSs (Coelho, et al., 2013).

The potential savings from the use of SCADA systems are from 10% to 20% of total WSS energy consumption. Making the system automatic, efficiency is increased and a reduction on costs occurs (Gellings C. et al, 2009).

The main functions of a SCADA system are data acquisition, data communication, data presentation and control (Walski, et al., 2003).

In a supervisory control system for a water network, the optimal control procedure interacts with the real network through the SCADA system. It must receive information about the current state of the network, in terms of: water volumes in reservoirs, status of pumps and valves, latest demand readings, pressure and/or flow readings at selected points (Cembrano, et al., 2000).

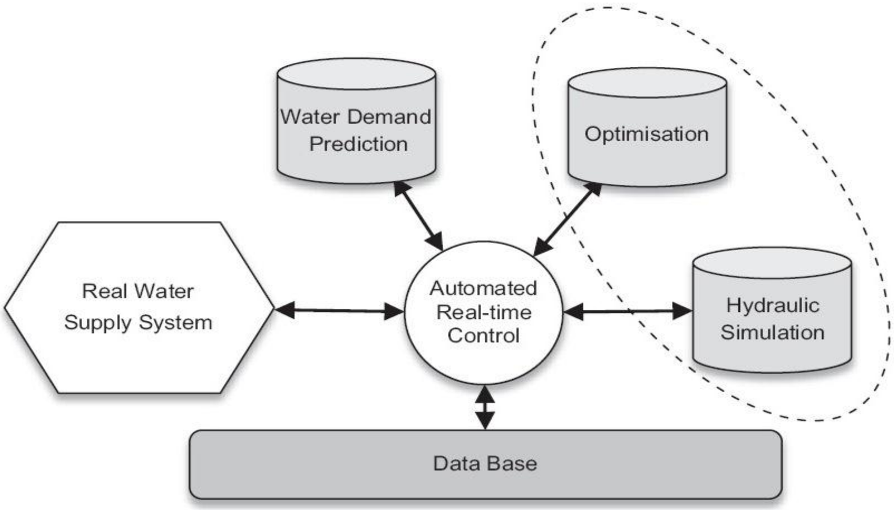


Figure 2.4 Scheme describing the optimal operation of a Water Supply System using a SCADA system *(Coelho, et al., 2013)*.

The automated real-time control system allows data management and the transmission of information between both modules and the WSS that is intended to be optimized. A data base is also necessary to record the history of water consumption and all the characteristics of the real network (Walski, et al., 2003).

The DMA instrumentation, pressure and flow sensors at DMA inlets and pressure sensors at certain DMA inner nodes are required which offer on-line measurements. Traditionally, this instrumentation and its corresponding measurements are integrated in the SCADA system used to perform the supervision of the overall network. In general, the sensor measurements are stored in the raw database which contains the raw metered data. Nonetheless, this data may be affected by certain errors, such as outliers and missing data which prevent its direct use since it may cause a wrong performance of the SCADA supervision processes. Normally, a validation process is applied to this data to remove those errors and to try to reconstruct the lost information when possible. This validated data is stored in the validated database. Regarding the DSS for leakage localization, this tool is linked to this validated database in order to obtain the on-line measurements of the DMA instrumentation. By this means, when establishing the settings of a given scenario, database time series which store the validated sensor data of a certain DMA network must be mapped with the hydraulic model of this DMA (Meseguer, et al., 2014).

The assessment of the benefits arising from the installation of a SCADA system:

1. **Greater effectiveness and efficiency in operation**: The information made available by SCADA systems also helps to improve the system operation, namely a better management of the storage capacity, the optimization of the pumping stations operation and pressure management.
2. **Greater effectiveness and efficiency in maintenance:** The availability of remote information about water levels (tanks), flows (pipes), pressures (nodes) and power (pumping stations) allows an early detection of faults, which in many situations may reduce its severity, and consequently imply less corrective maintenance costs.
3. **Reduction of water losses:** This technology allows an efficiency increase in the ALC, due to essentially two reasons: tank's water levels monitoring, which allows the detection of leakage and overflows; and night flow monitoring coupled with step testing (closing of valves), enabling easier location of leaks.
4. **Improvement of the systems reliability and resilience:** In extreme situations, for example in case of natural hazards, by remotely controlling and monitoring in real time the system operation, the SCADA systems enable a better decision making, providing the ability to perform faster and better responses (Temido, et al., 2014).

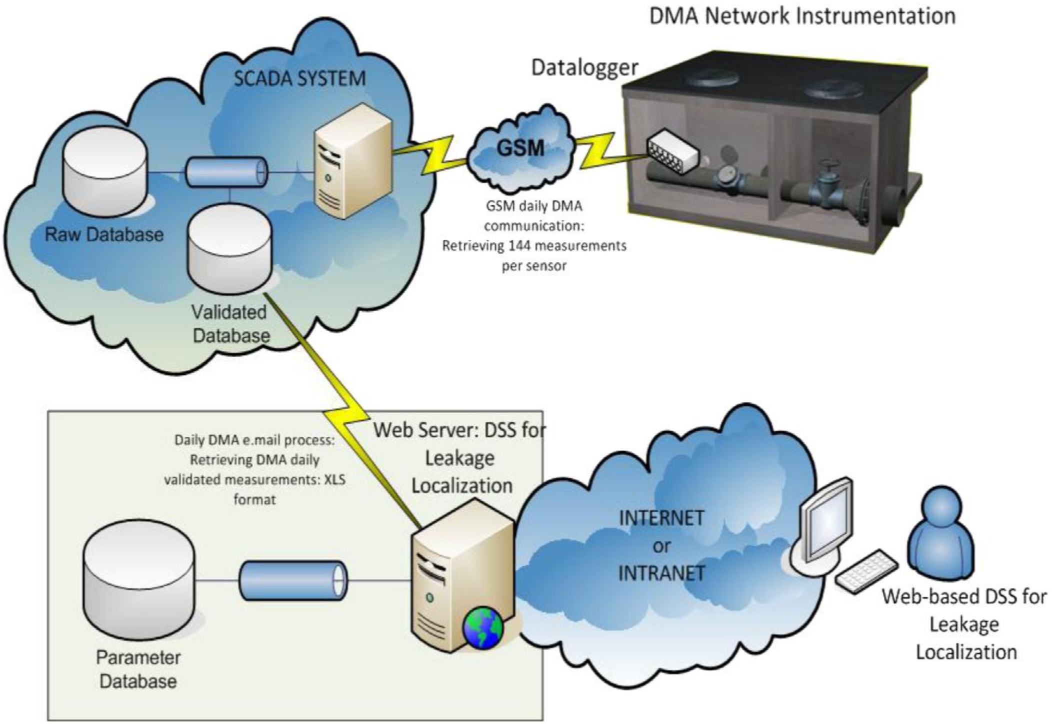


Figure 2.5 Conceptual scheme of the DSS prototype for leakage localization applied *(Meseguer, et al., 2014)*

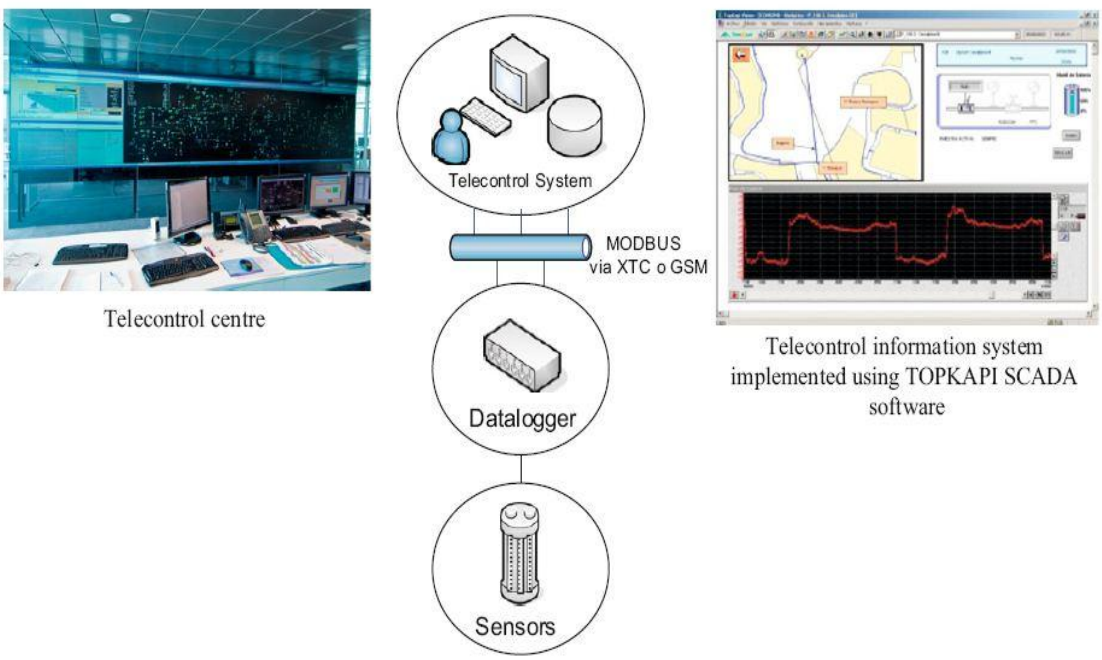


Figure 2.6 Samples of modern SCADA control system

2.12 Concluding remarks:

A general review was made in this chapter for all system needed, WaterCAD program, hydraulic modeling, calibration, DSS and SCADA. At next chapters, hydraulic modeling, calibration and DSS will be studied in addition to prototype will be made to get results and effective recommendations.

SCADA at this study will not be applied but it was explained as a component of the WDS and how much it can be helpful for the water system.

Chapter 3: Gaza City Water Network

3.1 Introduction

Gaza city is considered one of highest overpopulation regions in the world. There are 588,033 people in 45 km^2. It is considered one of the poorest regions of water resources. The existing supply of potable water in Gaza depends on well sources abstracted from the aquifer (Shaker, 2007).

This chapter provides a base for water network at Gaza city and the current system and the way of operation. This chapter will make a focus on defects at operation.

The distribution system depends mainly on direct pumping from the wells to the distribution network (the pressure at network from Pumps only). These pumping stations (Well Pumps) are managed manually through operators who are located as three consecutive 8-hour shifts along the day and many of wells managed automatically through SCADA system. Decisions are made according to observations and feedback which is delivered through phone calls.

3.2 Network Structure

Water Supply System (WSS) in a municipal district is usually constructed of a large number of pipes connected together to from loops and branches. Although the calculations of water flow in a network involve a large number of pipes and may become tedious, the solution to the problem is based on the same principles that govern pipelines and branching pipes previously discussed. Generally, a series of simultaneous equations can be written for the network (Hwang, et al., 1996).

1) At any Junction, ΣQ = Zero (junction equation).
2) Between any two junctions the total head loss is independent on the path taken (loop equation).

The water utility supply system in Gaza city water network consist of : Pipelines (3038 pipes) near 412 km with varies material (Asbestos cement, Steel and UPVC) and Diameter For steel (2", 3", 4", 6", 8", 10", 12", 14", 16", 18", 20") and for UPVC (110mm, 160mm, 200mm, 225mm, 250mm, 280mm, 315mm, 355mm), nodes (2414 junctions) which represent the valves (near 1500 valves) distributed at city with varies diameters and wells (74 water wells) located in different regions in Gaza strip as illustrated in Figure 3.1 using Palestinian Grid Coordinates (GCS_Palestine_1923).

According Figure 3.2 Gaza city network was divided to 58 zones varying in size, complexity, topography, and source management.

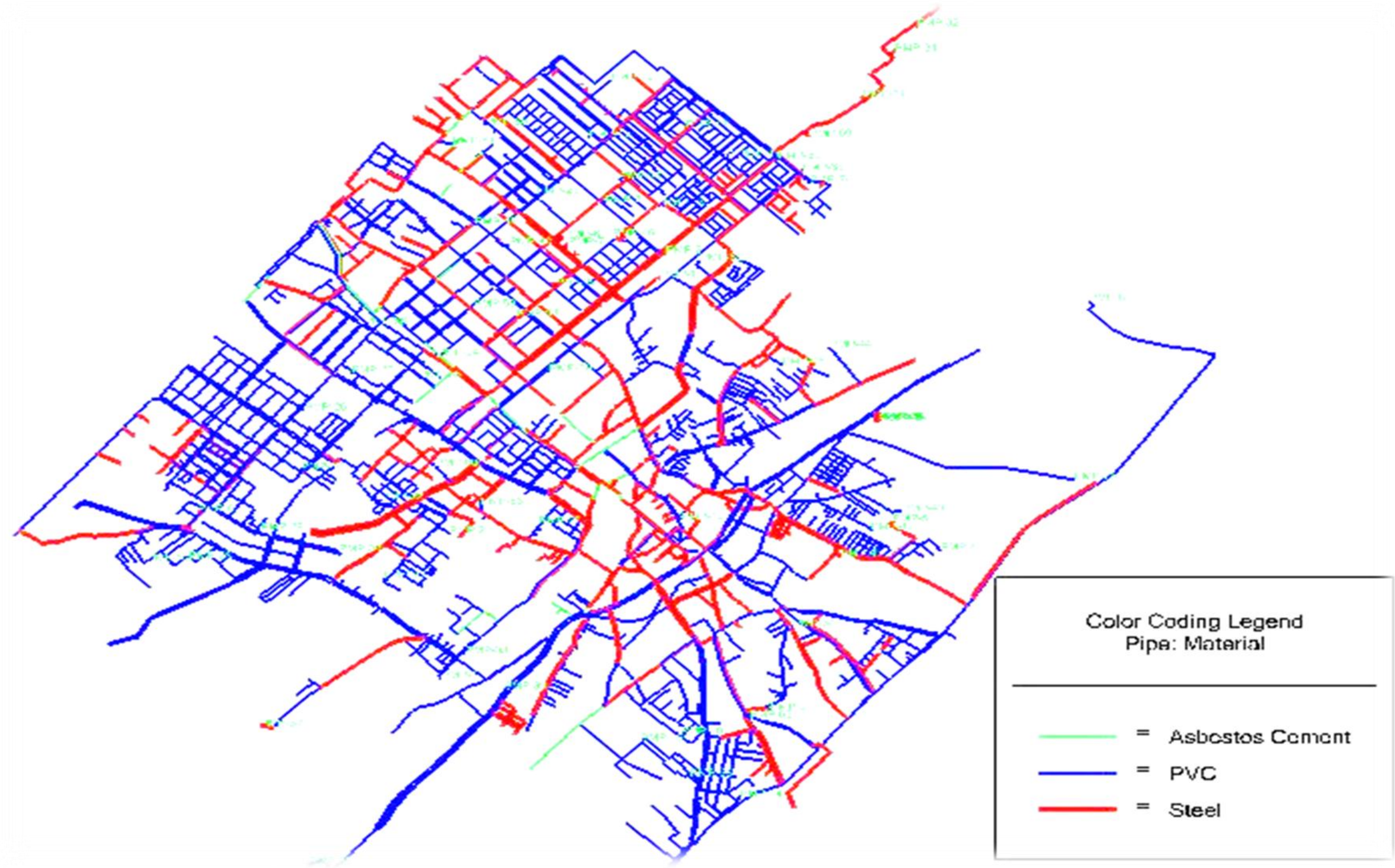


Figure 3.1 Gaza city water distribution network at WaterCAD

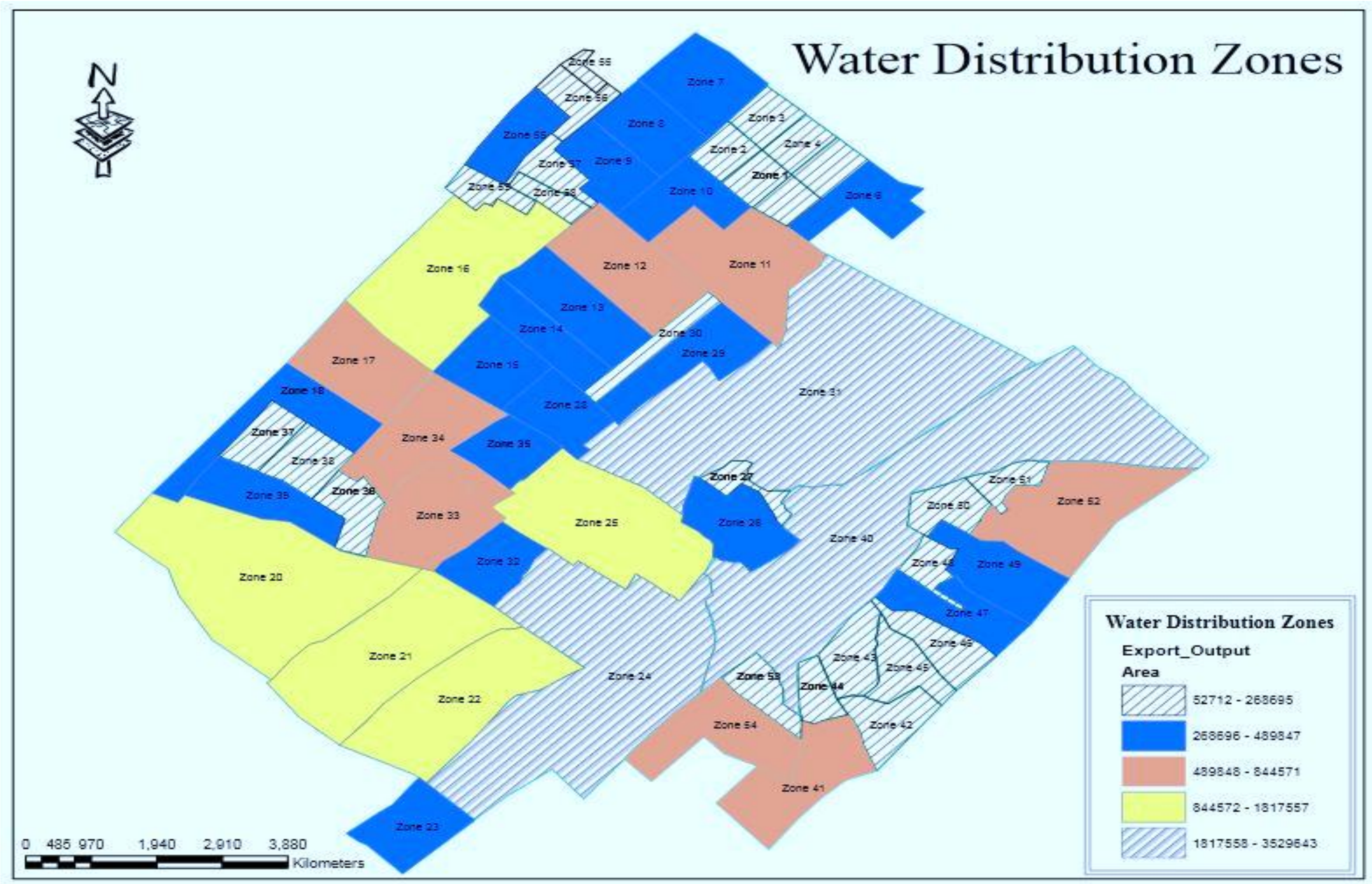


Figure 3.2: Water network operation zones by ArcGIS

3.3.1 Pipes

Water network consists of different types of pipes from material and diameters. This study make a primary inventory data for pipes as shown in Table 3.1 .

Table 3.1 Pipes description at water distribution network

Diameter	Length (Steel) (m)	Length (UPVC) (m)	Length (Asbestos Cement) (m)	Length (All Materials) (m)	Percentage %
2"	2,786	0	0	2,786	0.68
3"	37,840	0	1,233	39,073	9.47
4"	23,320	0	1,829	25,149	6.10
110 mm	109	239,722	0	239,832	58.13
6"	17,175	0	2,295	19,470	4.72
160 mm	0	19,257	0	19,257	4.67
200 mm	0	1,026	0	1,026	0.25
8"	8,959	0	222	9,181	2.23
225 mm	0	21,407	0	21,407	5.19
250 mm	0	873	0	873	0.21
10"	6,079	0	995	7,074	1.71
280 mm	0	3,863	0	3,863	0.94
12"	3,408	0	2,414	5,822	1.41
315 mm	0	3,670	0	3,670	0.89
14"	1,339	0	0	1,339	0.32
16"	5,807	0	0	5,807	1.41
18"	692	0	0	692	0.17
20"	6,265	0	0	6,265	1.52
All Diameters	113,780	289,819	8,988	412,586	100%
Percentage %	27.58	70.24	2.18	100.00	

70.24% of the used pipelines is UPVC, 27.58% of pipes are consisted of steel take first category with high percentage because the most of distribution lines consists of UPVC and at the second category as transmission lines but at the last Asbestos Cement and with new projects it will be less.

3.3.2 Pumps

Pumps have a production rate varying between 50 to 220 m^3/hr. The pumping set is protected against low level water in the aquifer by means of dedicated sensors. Every year, Gaza municipality construct new water wells to compensate the increase consumption of water due to the overpopulation, in two or three years, the number of water wells were 74 wells. The water wells are conventionally comprised of a pump, a chlorine dosing unit, a water manifold, an electrical switchboard, a sand trap and a standby diesel generating set.

3.3 Operating system

Gaza operating system consists of two cycles for distribution according to supply areas, density of population and water sources (high amount of flow or low). The operating system was planned by elevation at zones. Cycle 1 (Shejeia) was operated for the high elevation level and cycle 2 (sabra) was operated for the low elevation level. According to the operation cycles, the boundary of zones is determined and controlled by valves. The number of control valves in Gaza network is near 100 valves.

3.4 Network zones

Table 3.2 presents an inventory data for each zone component and water source for each zone:

Table 3.2 Zones inventory data

Zone	Pipes	Pipes material	Junctions	Wells source	Total flow amount m^3/hr	Population
Zone 1 A	32	UPVC and Steel	24	Kamal Nasser	65	3897
Zone 1 B	56	UPVC and Steel	42	Kamal Nasser	65	8408
Zone 2	46	UPVC and Steel	34	Sheikh Radwan 8	60	3944
Zone 3	59	UPVC and Steel	45	Sheikh Radwan 8 + El jala	140	7522
Zone 4	33	UPVC	27	Eiada + El jala	140	6890
Zone 5	47	UPVC and Steel	36	Eiada	70	6958
Zone 6	106	UPVC, Steel and asbestos cement	87	Sheikh Radwan 9	180	17254
Zone 7	55	UPVC and Steel	44	North wells	900	7332
Zone 8	81	UPVC and Steel	57	North wells	900	10180
Zone 9	67	UPVC, Steel and asbestos cement	58	Sheikh Radwan 7	320	8780
Zone 10	55	UPVC and Steel	47	Sheikh Radwan 1+3+4	260	8504
Zone 11	66	UPVC and Steel	56	Sheikh Radwan 13+7+ Abo Elba	280	20197
Zone 12	103	UPVC and Steel	87	Sheikh Radwan 1 + Becdar + Palestine	165	9456
Zone 13	79	UPVC, Steel and asbestos cement	64	Elthawra + Khalil El wazir	130	5121
Zone 14	50	UPVC, Steel and asbestos cement	44	El gondi	60	5028
Zone 15	66	UPVC, Steel and asbestos cement	55	Ahmed shawqi	70	2468
Zone 16	193	UPVC, Steel and asbestos cement	161	El gondi	305	22032
Zone 17	62	UPVC and Steel	48	Ashgal	60	4758
Zone 18	83	UPVC and Steel	63	Ashgal + Quds + Abo Hanifa	155	5000
Zone 19	26	UPVC, Steel and asbestos cement	23	Tunis	60	3932
Zone 20	57	UPVC and Steel	47	Quzat + Abo hanifa	120	10000

Zone 21	29	UPVC and Steel	25	Quzat + Civil defense	120	3116
Zone 22	31	UPVC and Steel	25	Quzat + Civil defense	120	5320
Zone 23	7	UPVC, Steel and asbestos cement	5	Al samoni	60	511
Zone 24+31	550	UPVC, Steel and asbestos cement	471	El safa wells and North wells, Shorfa, Qata, Dola, Orabi	1320	100306
Zone 25	242	UPVC, Steel and asbestos cement	206	El safa wells ,North wells, Shhibar, Abdullah Azam, and El dairi	1400	37846
Zone 26	77	UPVC, Steel and asbestos cement	65	Al basha	70	8860
Zone 27	25	UPVC, Steel and asbestos cement	21	Al basha	70	3938
Zone 28	66	UPVC, Steel and asbestos cement	56	Sheikh Radwan 1	180	4930
Zone 29	41	UPVC, Steel and asbestos cement	40	Al yarmouk	60	7406
Zone 30	20	UPVC and Steel	19	Al yarmouk	60	2429
Zone 32	40	UPVC and Steel	36	Said syam	70	3648
Zone 33	35	UPVC and Steel	30	Civil defense	70	6754
Zone 34	109	UPVC and Steel	89	Sheikh ejleen 2	60	6449
Zone 35	70	UPVC, Steel and asbestos cement	59	Sheikh Radwan 1 + Ahmed shawqi	160	5820
Zone 36	26	UPVC and Steel	19	El weqai + Barcalona	126	6296
Zone 37	20	UPVC and Steel	19	El weqai	60	1660
Zone 38	108	UPVC and Steel	85	El weqai + Barcalona	126	3108
Zone 39	29	UPVC and Steel	28	El weqai	60	1718
Zone 40	305	UPVC and Steel	242	El safa wells and North wells	1400	59344
Zone 41	69	UPVC and Steel	57	El halal	60	6290
Zone 42	14	UPVC and Steel	11	El montar	70	2730
Zone 43	24	UPVC and Steel	22	El montar	70	5072
Zone 44	10	UPVC and Steel	9	El montar	70	3490
Zone 45	21	UPVC and Steel	20	El qastal	60	3417
Zone 46	51	UPVC and Steel	44	Zimmo	200	6962
Zone 47	43	UPVC, Steel and asbestos cement	40	Zimmo	200	10510
Zone 48	14	UPVC and Steel	13	Abo abli	120	4008
Zone 49	50	UPVC and Steel	38	Zimmo	200	8154

Zone 50	37	UPVC and Steel	35	Lafi	60	7629
Zone 51	6	UPVC	5	El sourani	60	1067
Zone 52	18	UPVC and Steel	15	El batesh	80	4597
Zone 53	29	UPVC and Steel	24	Elhaj Adel	70	3970
Zone 54	48	UPVC, Steel and asbestos cement	5	Halima	180	16710
Zone 55	24	UPVC, Steel and asbestos cement	22	Halima	180	10478
Zone 56	33	UPVC, Steel and asbestos cement	32	Sheikh Radwan 7	320	7695
Zone 57	23	UPVC, Steel and asbestos cement	21	Sheikh Radwan 7	320	6848
Zone 58	18	UPVC and Steel	13	Becdar + UN 3	110	8421

Table 3.2 shows distribution zones according operation system. It contained descriptive data: number of pipes at each zone, pipes material, number of junctions, wells sources and total flow amount from wells.

Chapter 4: Modeling Network Analysis

Modeling and WDS gives the potential to predict the effects of operational and physical changes to both hydraulics and water quality. There are a large number of software packages available for modeling the hydraulic and water quality characteristics of a WDS. Some examples include EPANET, Stoner Synergee, WaterCAD, Cybernet, Piccolo, MIKE NET, H20NET and InfoWorks.

Hydraulic simulation model computes hydraulic heads at junctions and flow rates through links for a fixed set of reservoir levels, tank levels, and water demands over a succession of points in time. From one time step to the next reservoir levels and junction demands are updated according to their prescribed time patterns while tank levels are updated using the current flow solution. The solution for heads and flows at a particular point in time, which involves solving simultaneously the conservation of flow equation for each junction and the headloss relationship across each link in the network, is solved by the Gradient Algorithm. The hydraulic time step typically used for extended period simulation is one hour (Vuta, et al., 2008).

Chapter 4 is divided into two parts: the first for the analysis of Gaza city network which includes 58 zones , the second for a detailed analysis of Zone 1 as a pilot case study. Zone 1 is supplied from Kamal Nasser well.

4.1 Modeling

The boundary conditions must be set using the pressure and flow measurements registered in the DMA inlets: the pressure measurement at every time instant k is set at every DMA inlet while the total measured DMA inflow is distributed using a constant coefficient (base demand) in each demand node. Thereby, the same consumption pattern is assumed for all demand nodes in the DMA.

4.2 Demand Pattern

Demand pattern is one of critical component at the system, from which is identified how much capitals consume to describe in graph.

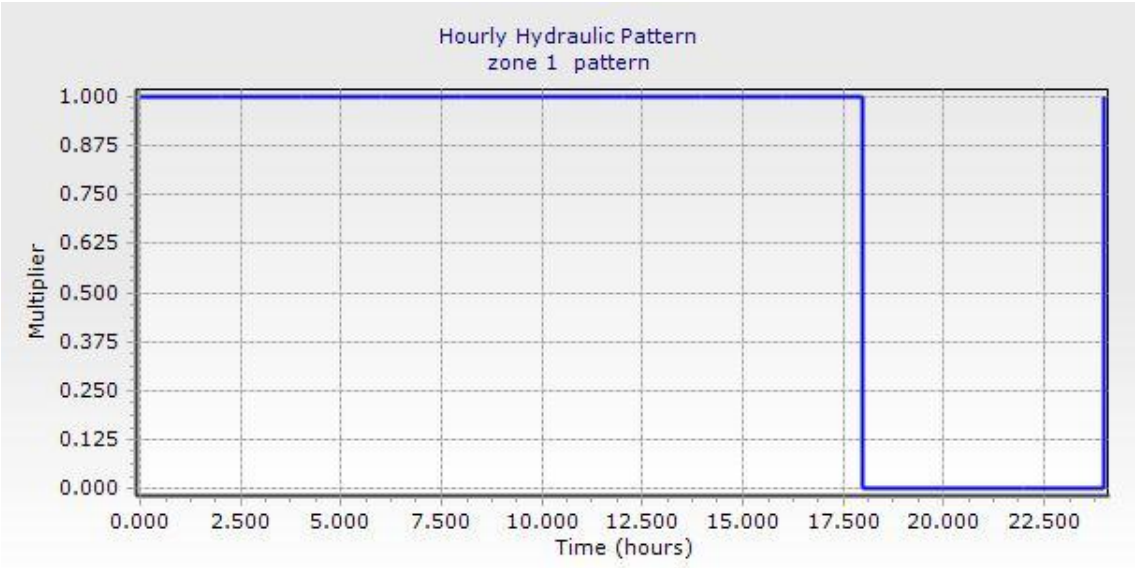


Figure 4.1 sample for demand pattern flow at WaterCAD for Gaza city

Fig. 4.1 explains the distribution approach at each zone where the consumption is assumed equally at all supply interval (18 hours). The multiplier is constant at value equal one during all the eighteen operating hours. It means that all operating hours are critical not only in specific interval.

4.3 Network Analysis

74 water wells supply the 58 zones according the distribution system presented in Figure 3.2. From WaterCAD program, each zone was separately analyzed to get the results at network from pressure, flow, demand, and velocity by modeling procedures:

1. From zones, make geo-referencing from water directorate after entry the network at WaterCAD, and take population at each area from GIS department at municipality.

2. A shape file for junctions was made at each zone to get service area. The shape file was edited at ArcGIS. The area was calculated and exported as database file.

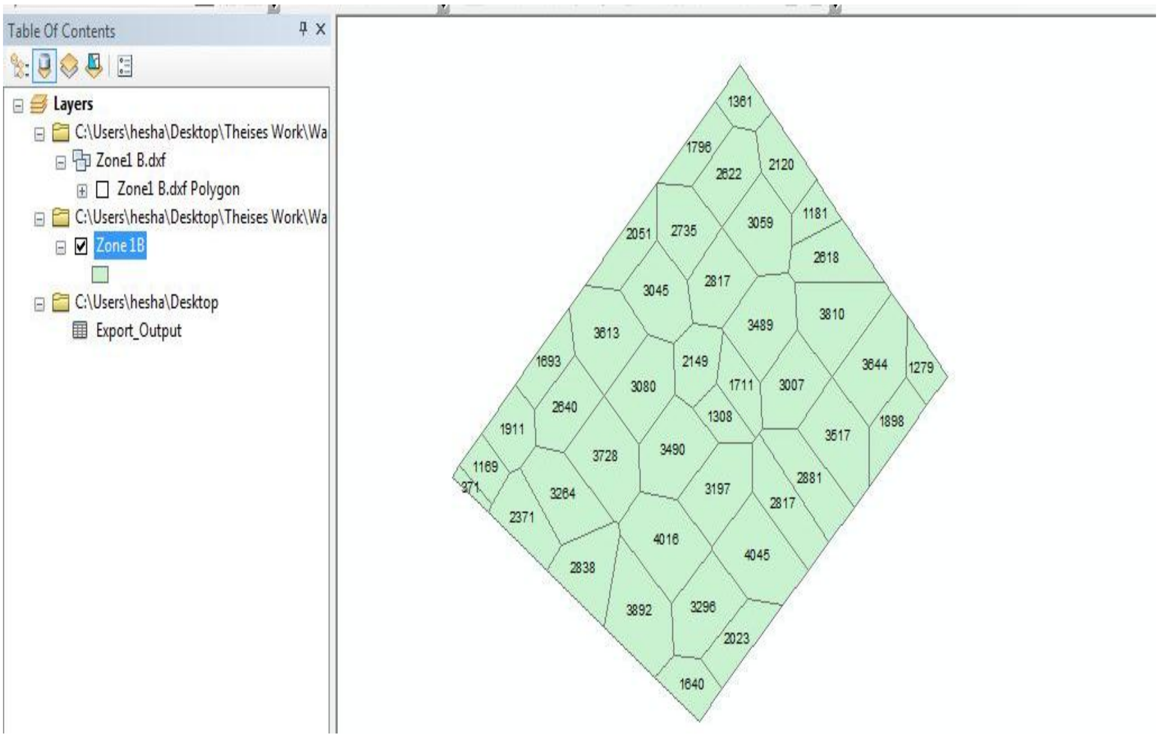


Figure 4.2 Junctions area distribution by ArcGIS.

Figure 4.2 shows each polygon that represents an area with junction. Each zone has its own of consumption value.

3. A template was made to calculate the consumption and inhabitant at each junction. According to Palestinian Water Authority (PWA) study and municipality, the daily consumption for inhabitant between 80-160 L/day/cap.

Table 4.1: Example of consumptions calculation at area zones

Junction No.	ID	Label	Elevation (m)	ELEMENT ID	Area (m2)	Density	Cap. For Junction	Consumption (M3/d)
1	734	J-279	53.52	734	6300	0.02484	156.49	25.038
2	735	J-280	65.3	735	5452	0.02484	135.43	21.668
3	1501	J-583	50	1501	3510	0.02484	87.19	13.950
4	1507	J-585	48.25	1507	14330	0.02484	355.95	56.952
5	1508	J-586	54.55	1508	25845	0.02484	641.98	102.717
6	1511	J-587	36	1511	19706	0.02484	489.49	78.319
7	1582	J-612	42.06	1582	11616	0.02484	288.54	46.166
8	6114	J-2356	63.62	6114	16478	0.02484	409.31	65.489
9	6122	J-2358	56.03	6122	37264	0.02484	925.63	148.100
Total Area (m^2)					140501		3490.00	Total capita consumption 558.400
Total Area by Arc GIS (m^2)					140377	M2		
Total Population (Capita)					3490	Capita		
Density					0.02484			

Table 4.1 shows the template made from data at WaterCAD (ID, Label and elevation) and ArcGIS (Element ID and Area), density calculated by divided total population to total area.

After that a column was made for multiple area with density to distribute the number of capita at all junctions and multiple all results with the average daily consumption for capita to get total consumption of junctions.

4. A demand control center was used to transfer these values for all junctions. The pattern was selected according to the operation hours.

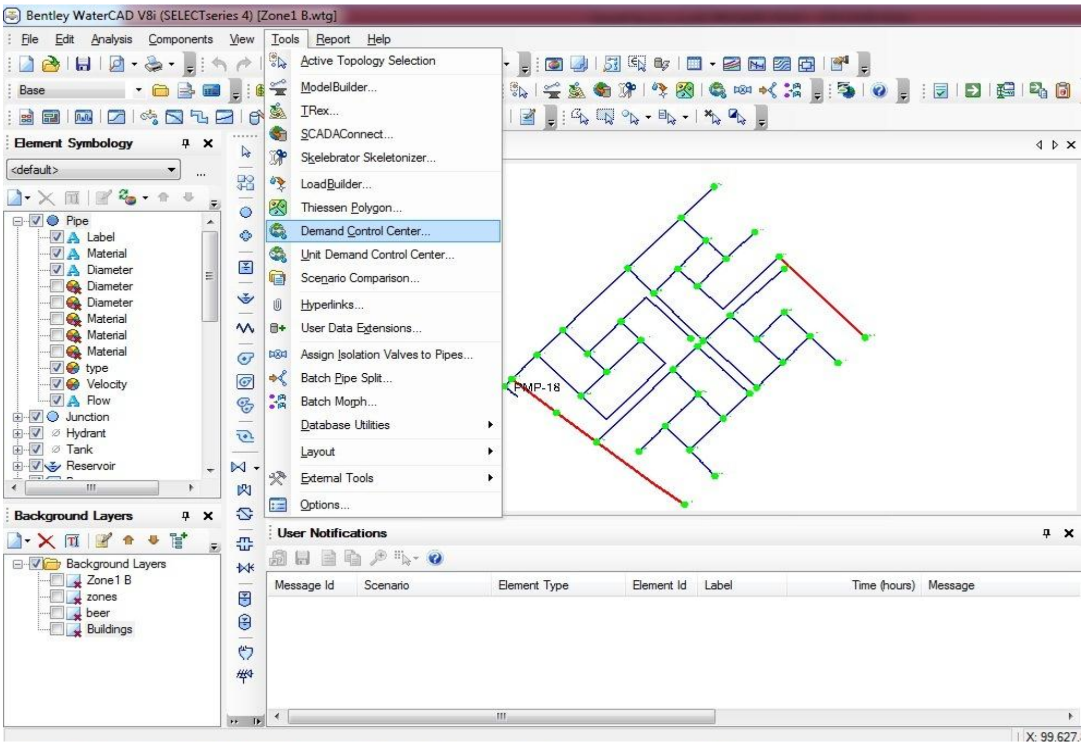


Figure 4.3 Demand control center selection.

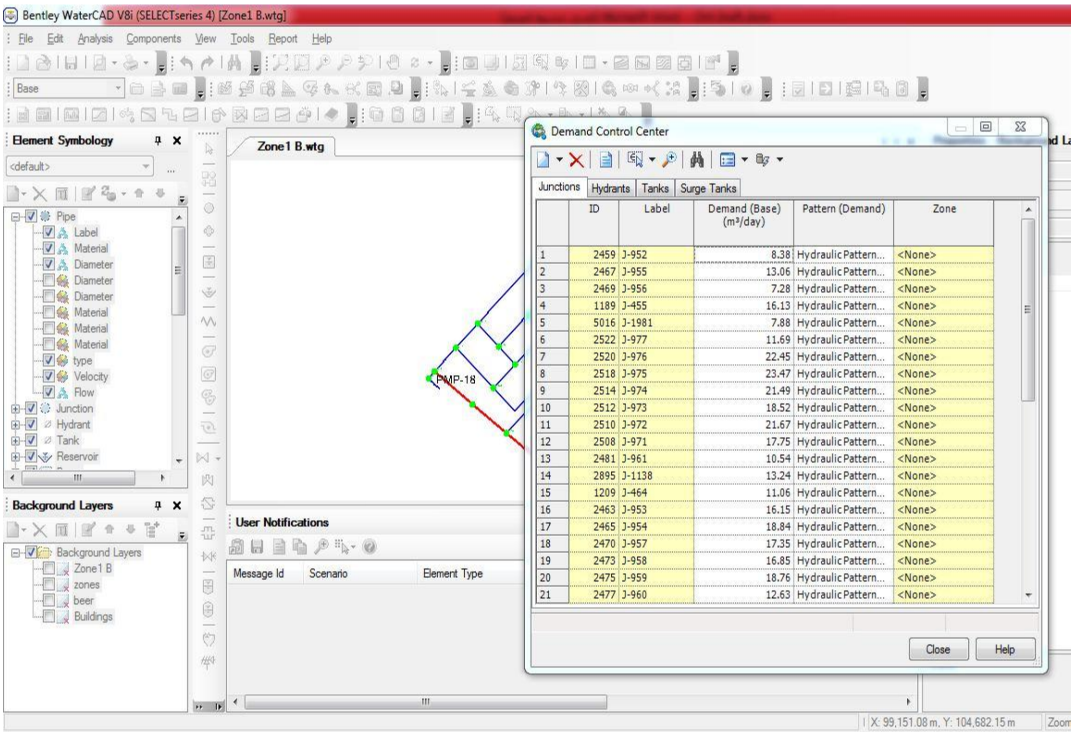


Figure4.4 Demand control center table.

5. A demand pattern, pump curve at WaterCAD were made by extended period simulation (EPS) for analysis to WDS.
6. The model was validated to be sure no problems and made analysis to get all results.

4.4 Network Evaluation

The hydraulic evaluation conducted to develop this master plan was performed using a computer model of the reclaimed water distribution system. This part provides a discussion of the evaluation criteria, computer model development, and calibration. Hydraulic modeling results for the existing system are also presented at chapter six.

4.5 Evaluation Criteria

In many ways, all pipe network programs are similar. Each determines the distribution of flow in a pipe network and calculates the resulting pressures. They determine head losses in pipes with the user's choice of either the Darcy-Weisbach or the Hazen Williams energy loss equation. Then, almost all programs form and solve a matrix. Programs using the Hardy-Cross method, which solves for each flow rate iteratively, were dropped from consideration for this comparison, because this method's convergence is too slow for even simple water systems.

Many of the additional criteria used in adding or eliminating models to the comparison process are discussed below.

The evaluation approach discussed in this section focuses on meeting key criteria under projected conditions such as maximum day demands and peak hour demands. The key criteria for evaluation of the adequacy of the reclaimed water system include system pressures, velocity, headloss, and storage requirements. Criteria for modeling of new proposed pipelines are also discussed.

- System Pressures
- Velocity and Headloss
- Storage Volume Requirements
- Storage Evaluation Approach

4.6 <u>Pump curves</u>

Pump characteristic curve is one of important element, which add energy at the system. Since water flows from higher energy location to lower energy, pumps used to boost the head at desired locations to overcome piping head losses and physical elevation differences.

It describes the behavior condition for pump and the capacity of well at variable pressure according to demand and operating time. To make analysis more realistic and have accurately results, we made a test for wells to get this curves and used for pump definition at WaterCAD.

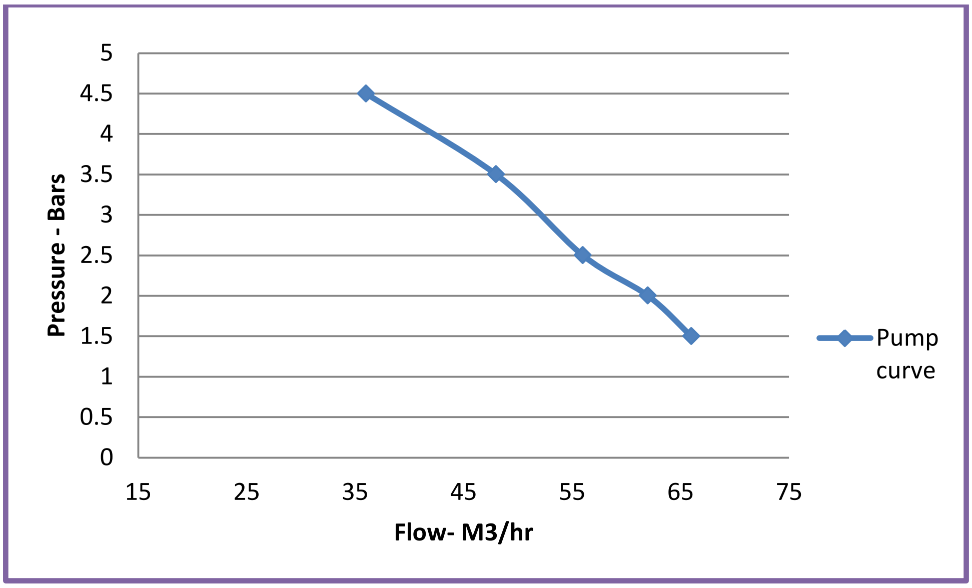


Figure 4.5 Pump characteristic curve at Kamal Nasser well (Remal 2)

Figure 4.5 shows that pump of Kamal Nasser well located at Sheikh Radwan area in a good condition and work without any problems.

4.7 Pilot study Zones

Zone one was divided to two zones: (A) for high elevation at the west side and (B) for low elevation at the east side.

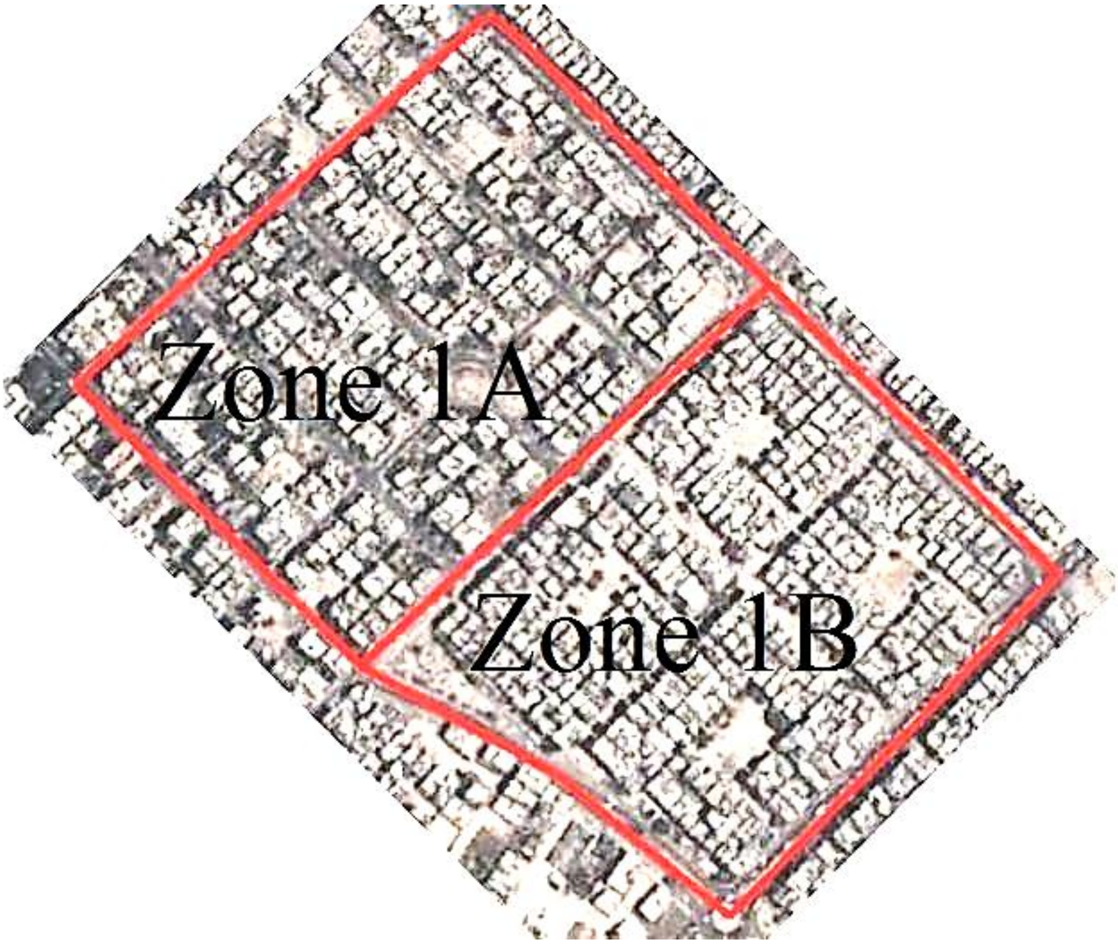


Figure 4.6 Arial photo for Zone 1 case study

Zone 1A has populations more than zone 1B according to the number of buildings and population count from GIS department at Gaza municipality.

Table 4.2 Zone 1A component according feature

Type	Number
Pipe	32
Junction	24
Gate valve	3
Pump	1
Reservoir	1

Table 4.3 Zone 1A pipes description

Diameter	Type	Length(m)
4"	Steel	294.5
110mm	UPVC	2254.5
160mm	UPVC	651
Total Length		3200

32 Pipes with variables types and diameters are covered 24 junctions at zone A and control for distribution from Kamal Nasser well and 3 gate valves.

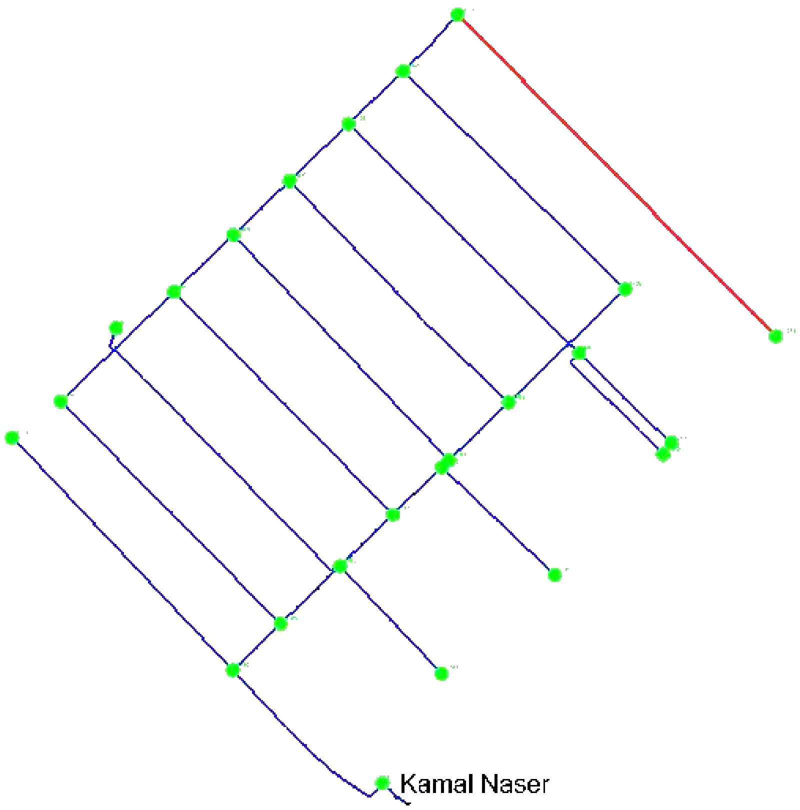


Figure 4.7 Zone 1A modeling network at WaterCAD

Table 4.4: Zone 1B component according feature

Type	Number
Pipe	56
Junction	42
Gate valve	2
Pump	1
Reservoir	1

Table 4.5: Zone 1B pipes description

Diameter	Type	Length(m)
4"	Steel	291
8"	Steel	288
110mm	UPVC	2573.5
160mm	UPVC	479.5
Total Length		3632

56 Pipes with variables types and diameters are covered 42 junctions at zone B and control for distribution from Kamal Nasser well and 2 gate valves.

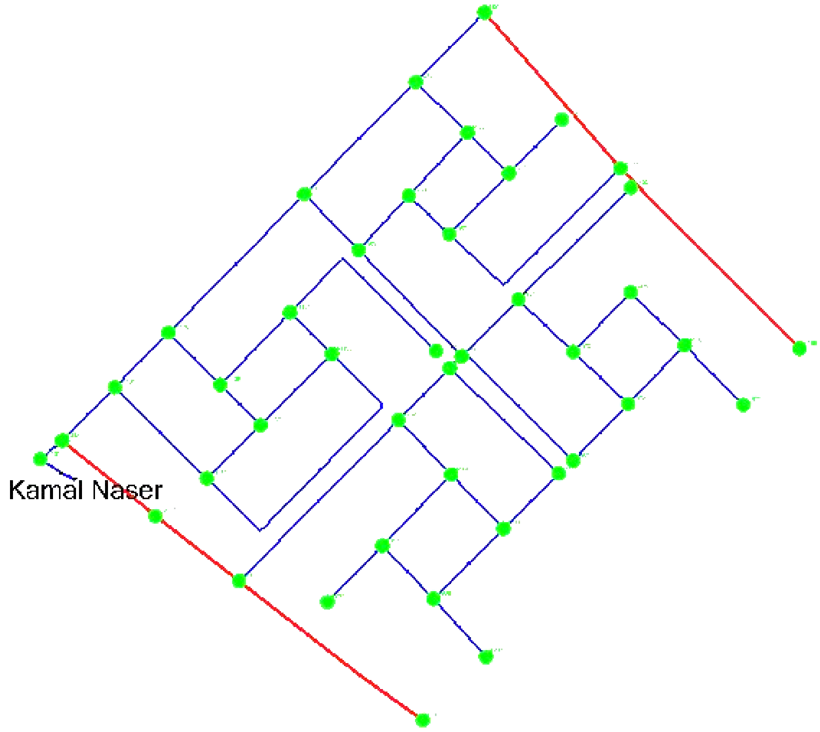


Figure 4.8 Zone 1B modeling network at WaterCAD

For zone 1A, the flow rate was 58 m^3/h, the average daily consumption for capita was160 l/day. The pressure head was between 1-2 bars and operating hours 18 hr. For zone 1B the flow rate was 63 m^3/h, the average daily consumption for capita was 90 l/day. The pressure head was between 1-3 bars and operating hours 18 hr.

These zones were made as case study for calibration the hydraulic modeling and proposing spatial decision support system as shown at the next chapter.

4.8 Performance Indicator

Performance indicator is one of the most important issue in analyzing the network. The used indicators for water modeling are: pressure head at network's nodes (5-70m) and flow velocity in pipes (0.5-2 m/s) (Hirner, et al., 1997).

Performance indicator (supply component): for population density, delivery flow rate and supply coverage. These indicators control the hydraulic system at modeling so that it must be more accurately to get realistic results.

4.9 Summary

This chapter focused on network analysis modeling, demand pattern, network evaluation, operating system, network zones and performance indicators. A demand pattern identified accurately to put a criteria for evaluation, after that operating system was worked in two cycles, finally performance indicator identified a range for acceptance in analysis results.

Chapter 5: Model Calibration and Spatial Decision Support System

Analysis stage was made a theoretical results not similar to the real situation, for that a pilot study is made to collect data by data logger at stations for each two zones (Zone A and B). Data logger results were used to calibrate the hydraulic modeling. These measurements were aimed to providing field measurements for the pressure and flows at selected stations on network and Kamal Nasser well. Pressure measurements on various tapping points "stations" were distributed on water network (Zone A and B). Flow measurements are recorded manually due to non-availability of specified flow-meters with pulses heads that can be used in data loggers reading system.

Six data loggers are set-up and uploaded using Radcom software to be installed in case study zones. Two data loggers were installed in Zone A , three of them were installed in Zone B , one data logger was installed at Kamal Nasser well as a reference for other stations.

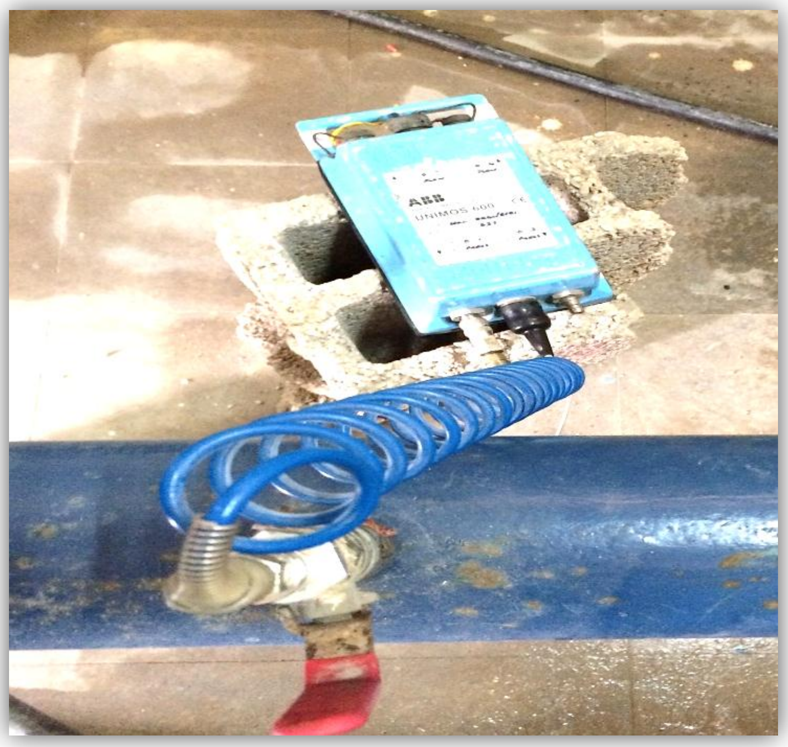


Figure 5.1 Data logger connected at Kamal Nasser Well

Figure 5.1 shows data logger connected in manifold of Kamal Nasser well during operating hours to supply zone 1A and 1B.

The analysis of the field measurements covers: results coherence with current intermittent supply schemes, observation on the water distribution status at zone in term of working pressure, pressure pattern analysis in term of supplying period and uniformity. For 13 days from 22-2-2015 till 6-3-2015 we made a record for pressure at every time to identify the operating hours, flow amount and pressure value. Figure 5.2 shows the location of the data loggers in Zone A and B.

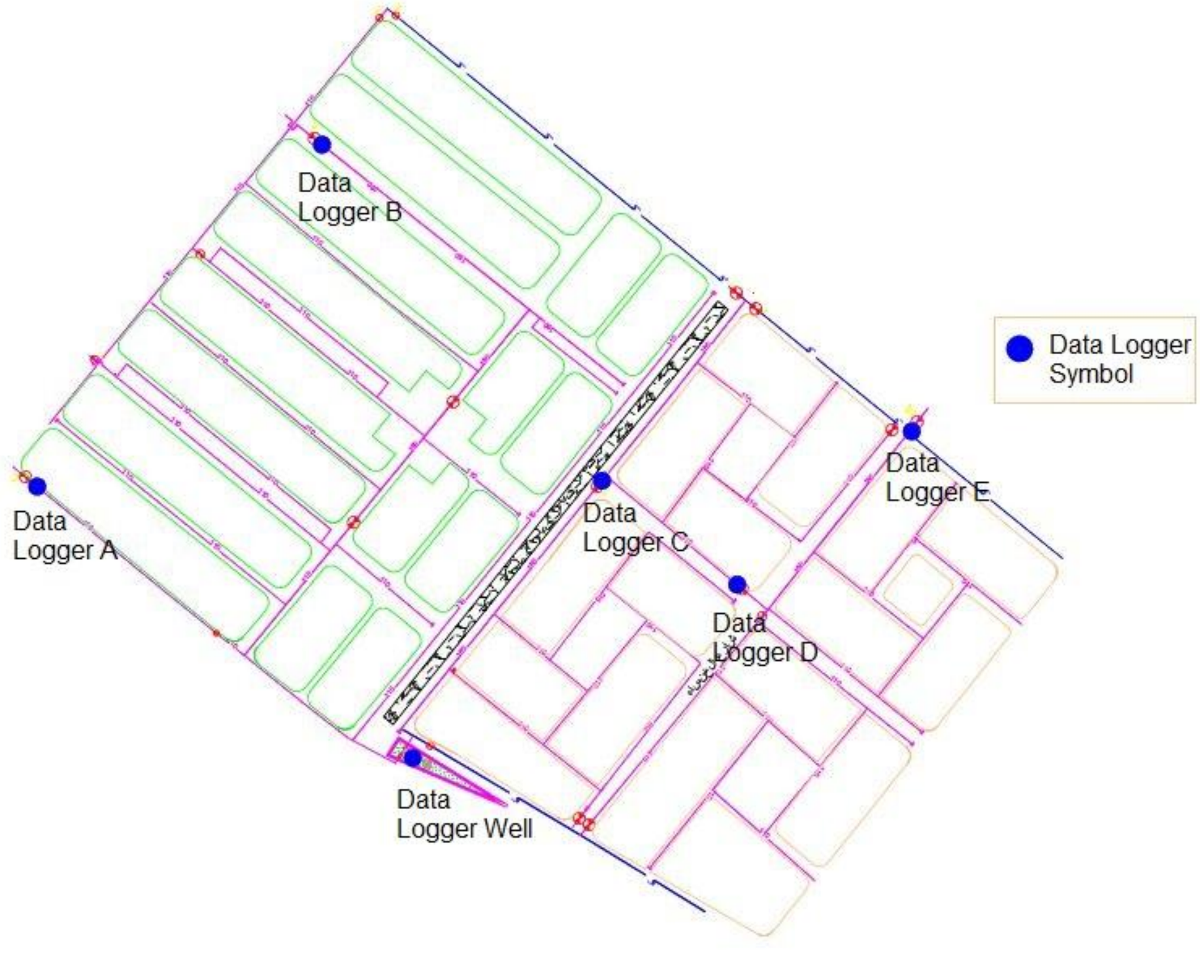


Figure 5.2 Distribution of data logger in the pilot study area.

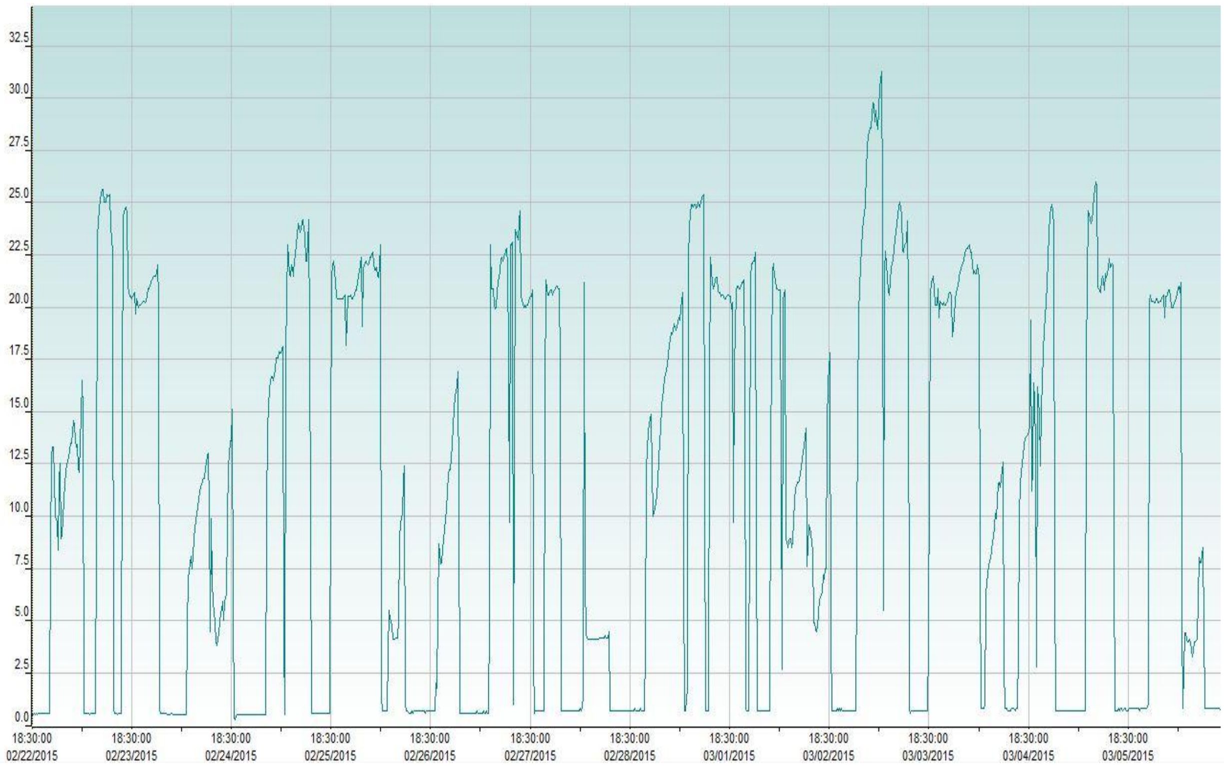


Figure 5.3 Pressure records curve at Kamal Nasser well

Figure 5.3 shows the pressure values were increased and decreased gradually at normal situation for well with range 5 to 32 meters head and average 11 meters head.

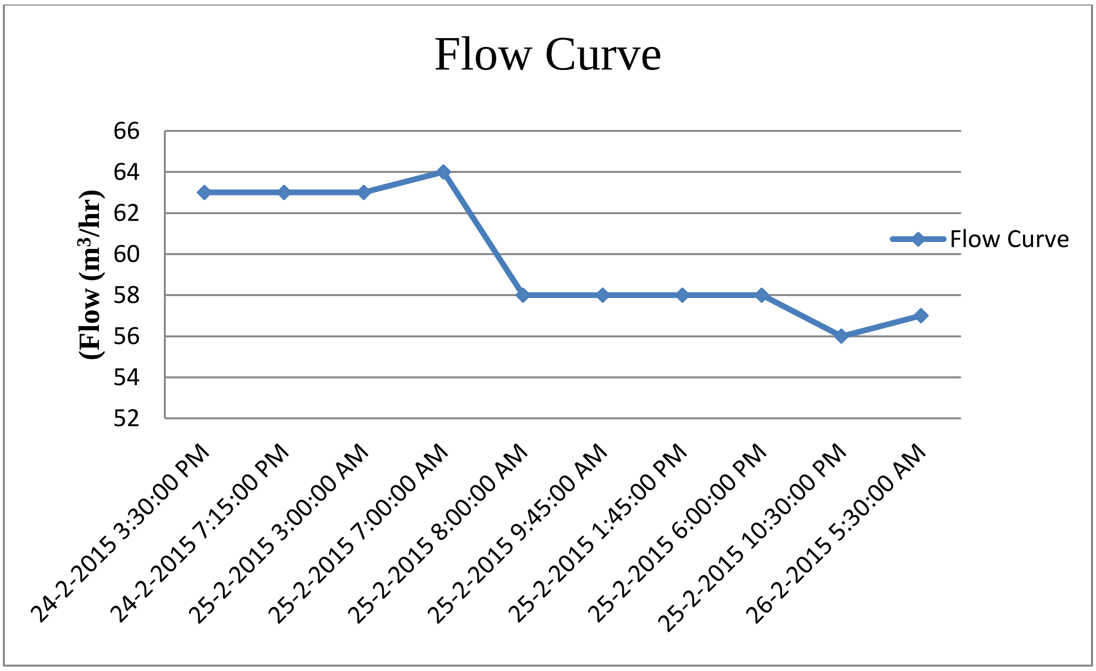


Figure 5.4 Flow records curve at Kamal Nasser well

Figure 5.4 shows the operating distribution results for cycle one, the flow rate recorded between 63 to 64 m^3/hr . For cycle two, the flow rate recorded between 56-59 m^3/hr . All data logger results were used to calibrate Zone 1A and 1B with accuracy near 90% which is a minimum to accept calibration process.

5.1 Calibration

To calibrate different consumption patterns used and pressure data measured along the network and defined as critical points. The criteria underlying the choice of critical points were the size of the DMA and land topography

The accuracy of a computer model is highly dependent on its degree of calibration. To determine if a computer model is calibrated, actual field conditions are simulated using the model. System operating parameters (e.g. system pressures, etc.) generated by the model are compared with the parameters measured in the field.

To calibrate the sample reclaimed water model, field pressure data for static and flowing conditions were collected from data logger on February 2015. Data for two flow tests and a static pressure reading near the highest system elevation was collected for Zone 1 reclaimed water system. The system demands, operating conditions, and blow off flow rates observed during the field tests were then simulated in the hydraulic model, and the modeled and field pressures were compared at each location.

5.2 Calibration procedures

Any calibration study needs a quantitative data, for that Zone A and B were measured independently by additional pressure loggers including inflows/outflows. Data loggers were installed in the field after modeling analysis and measurements are transferred to use at calibration step, but before calibration all valves at modeling were installed and all data was checked to be insure accurately to start calibration procedure.

Table 5.1: Pressure readings from data logger at zone 1A

Station	Actual reading (m)	Model reading (Before calibration) (m)	Watercad reading (After calibration) (m)	Percentage of error (%)
Well	23	23.56	23.57	2.42
A	11.5	13.71	12.34	6.81
B	12.7	17.9	13.73	7.50

Table 5.2: Pressure readings from data logger at zone 1B

Station	Actual reading (m)	Model reading (Before calibration) (m)	Watercad reading (After calibration) (m)	Percentage of error (%)
Well	16.9	17.39	17.4	2.87
C	16.8	26.01	16.85	0.30
D	21.8	31.89	21.88	0.37
E	17.6	35.82	17.89	1.62

Table 5.1 and 5.2 showed the readings of pressure head at stations where data logger installed and the percentage of error at each station. The degree of accuracy varies depending on the size of the system and the amount of field data and testing available to the modeler. Calibration is achieved through a trial and error process of adjusting the variables of nodal demand and pipe coefficients.

The acceptance value for percentage of error equal to ±10% according (Walski, et al., 2013) So that All percentage is accepted (under 10%) .

$$h_m = k_m \frac{V^2}{2g} = k_m \frac{Q^2}{2gA^2}$$ ………………………..…………………………….Eq. 5.1

Where, h_m : minor losses , k_m: closed conduits energy loss coefficient, V: velocity (m/s), Q: flow rate (m^3/s), A: Pipe area (m^2) and g: acceleration of gravity(m/s^2).

Equation 5.1 is minor loss equation for valves, (minor) compared to friction losses in long pipelines but, can be the dominant cause of head loss in shorter pipelines.

Final results from calibration showed at Annex I for Zone 1A and 1B with accurate near to 90% from data logger measurements.

5.3 Spatial Decision Making

ArcGIS is operated this stage by export all elements at WaterCAD as shape files and import it at ArcGIS. Quires and statically analysis made indication for Decision support from many indicators: Pressure, demand, diameter, pipes material, flow and velocity.

Pressure, flow and demand played a primary role of the critical components for decision support.

Histogram made by ArcGIS for decision support, display the output from this study procedures, made a realistic indication about the results and how it can be useful to apply at each zone to be used for further studies.

Spatial decision support system components are consisted of: Pipes and junctions. Pipe indicators are divided to diameter, flow rate and velocity but for junctions the indicators are divided to demand and pressure.

Diameters vary according to pipe types UPVC and steel. Flow rates are transferred at pipes from the well to every junction. Velocity of flow is depended on the diameter. Demand is identified according to the population density. Pressure is an important reference at the system for evaluation.

5.3.1 Components of SDSS in Zone 1A:

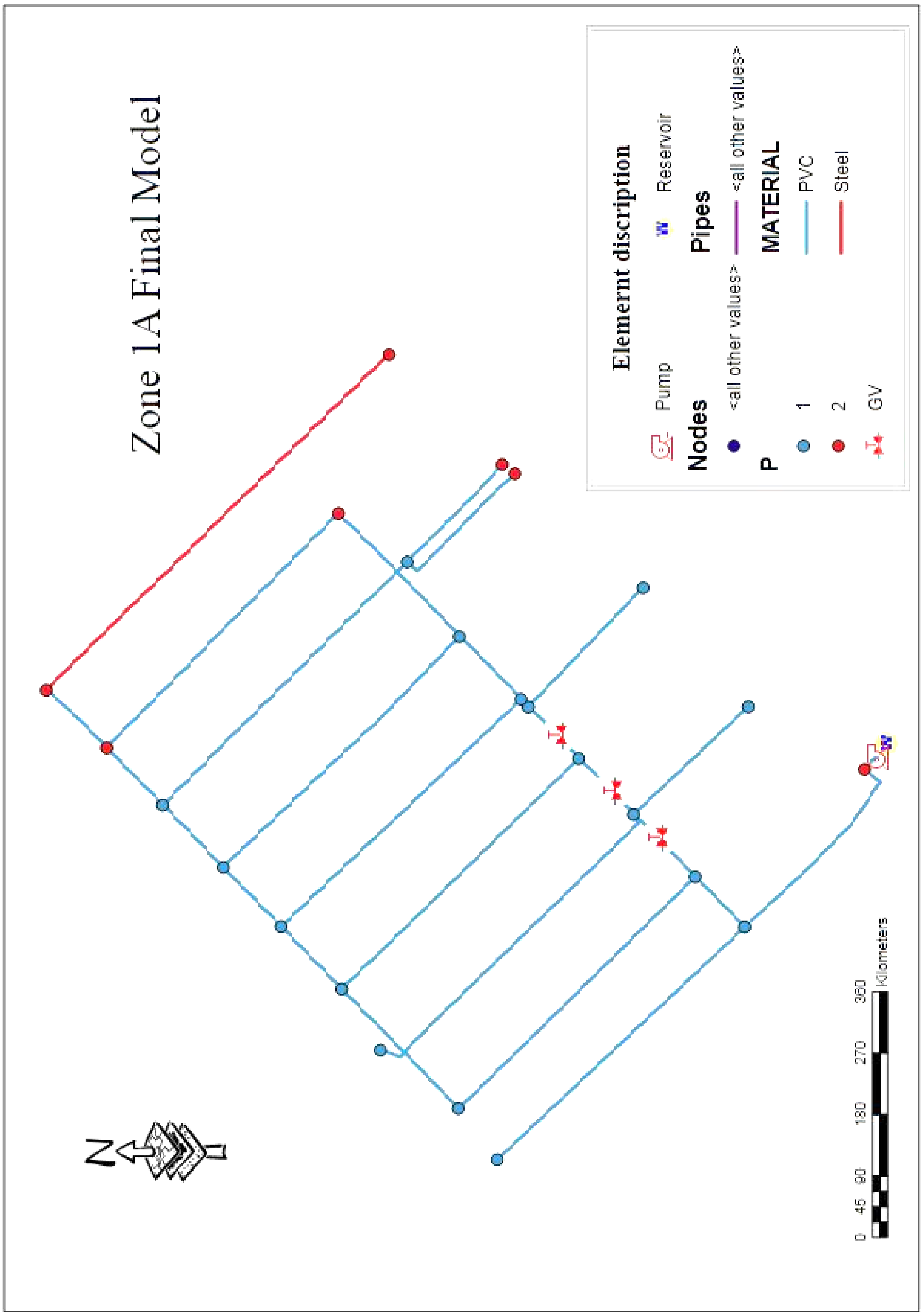


Figure 5.5 Zone 1A layout of model components.

Figure 5.5 shows a general layout to the components of zone1A for the south part from Kamal Nasser well supplied at operation cycle 2 which explained the pipe types and pressure values at junctions from 1 to 2 bar by ArcGIS.

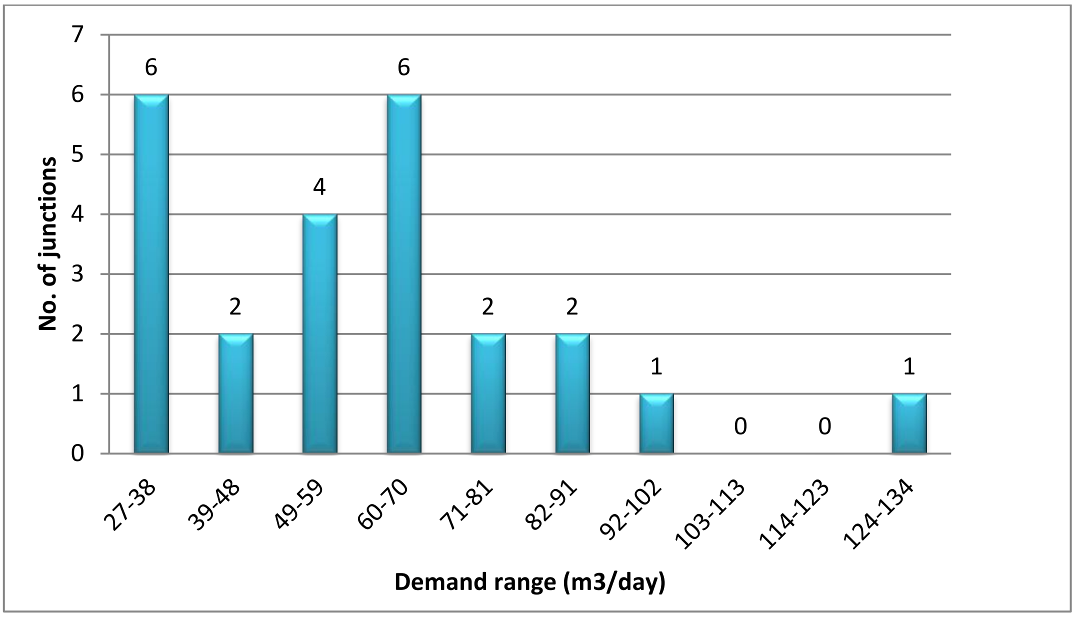


Figure 5.6 Zone 1A histogram demand at junctions.

Figure 5.6 shows a histogram for demand at each of 24 junctions with minimum value 27 m^3/day, maximum 134 m^3/day, the concentration for values between 27 – 102 m^3/day with a mean 58.46 and standard deviation 25.628 according population distribution.

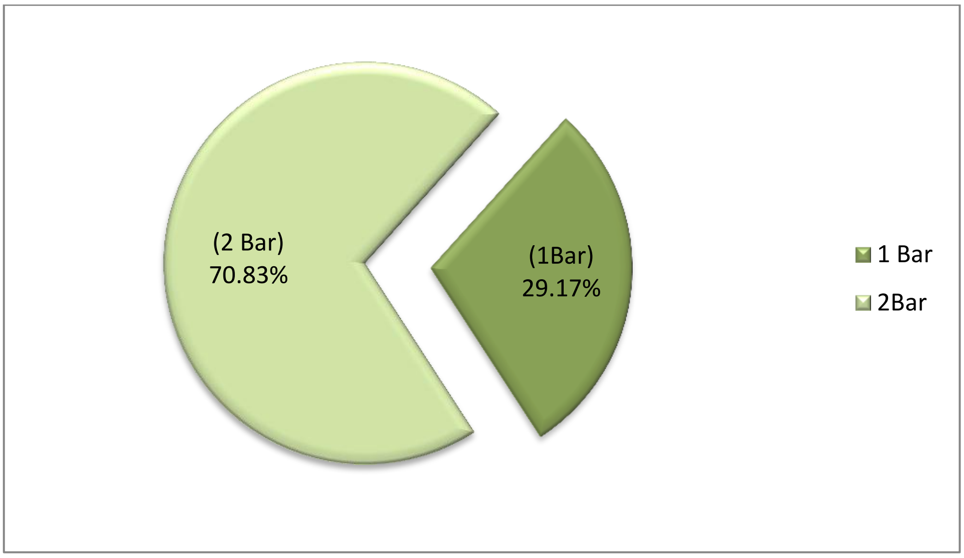


Figure 5.7 Zone 1A pressure percentage at junctions.

Figure 5.7 represented Zone 1A pressure values, at 24 junctions were resulted between 1-2 bar near 70% at 1 bar with a mean of 1.29 bar and standard deviation 0.464 bar.

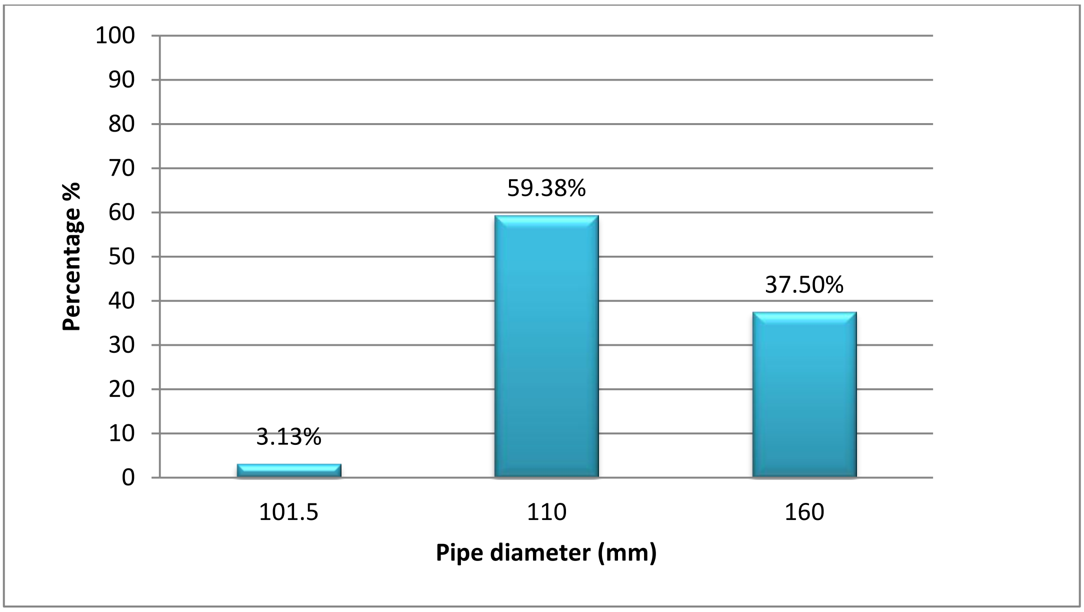


Figure 5.8 Zone 1A pipes diameter histogram.

Figure 5.8 shows 32 Pipes at zone 1A, is recorded between 101.5 mm (Steel) to 160 mm (UPVC) but the most pipes diameter at 110 mm and UPVC material.

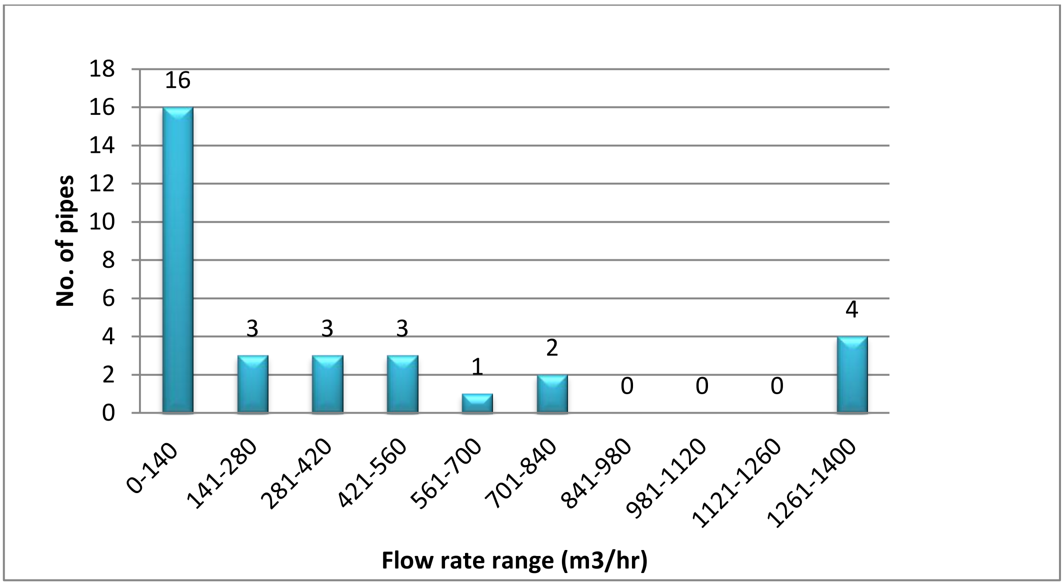


Figure 5.9 Zone 1A pipes flow rate histogram.

Figure 5.9 shows that zone 1A has flow rate at the range from 0 to 1401 m^3/day with a mean of 366.13 m^3/hr and standard deviation 442.75 m^3/hr which resulted from 18 hr from operating at Kamal Nasser well.

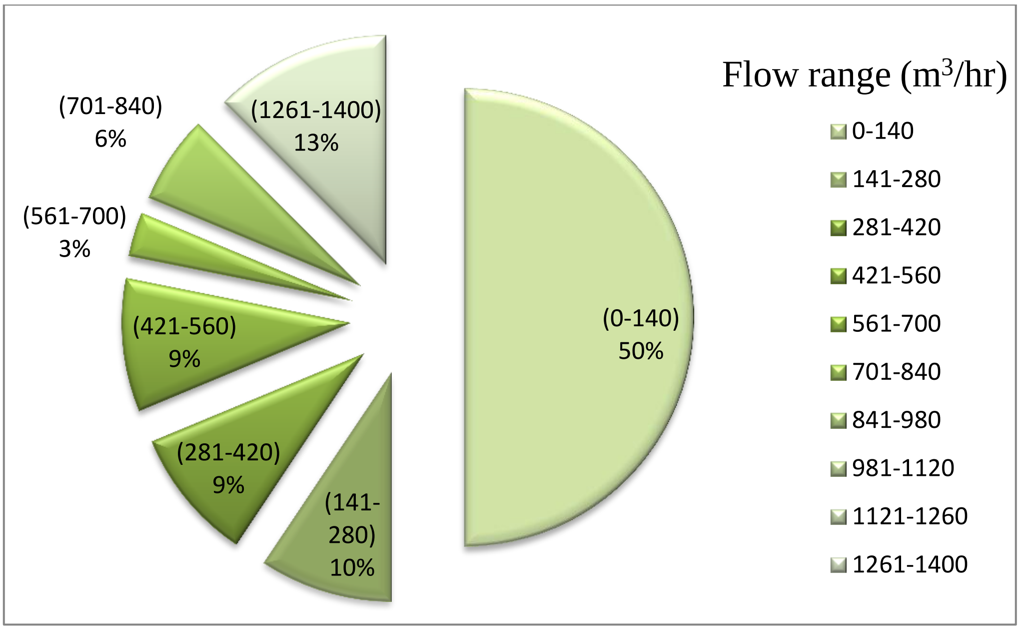


Figure 5.10 Zone 1A pipes flow rate percentage.

Figure 5.10 shows Zone 1A flow rate percentage for pipes, distributed for ten intervals from 0 – 1400 m^3/day.

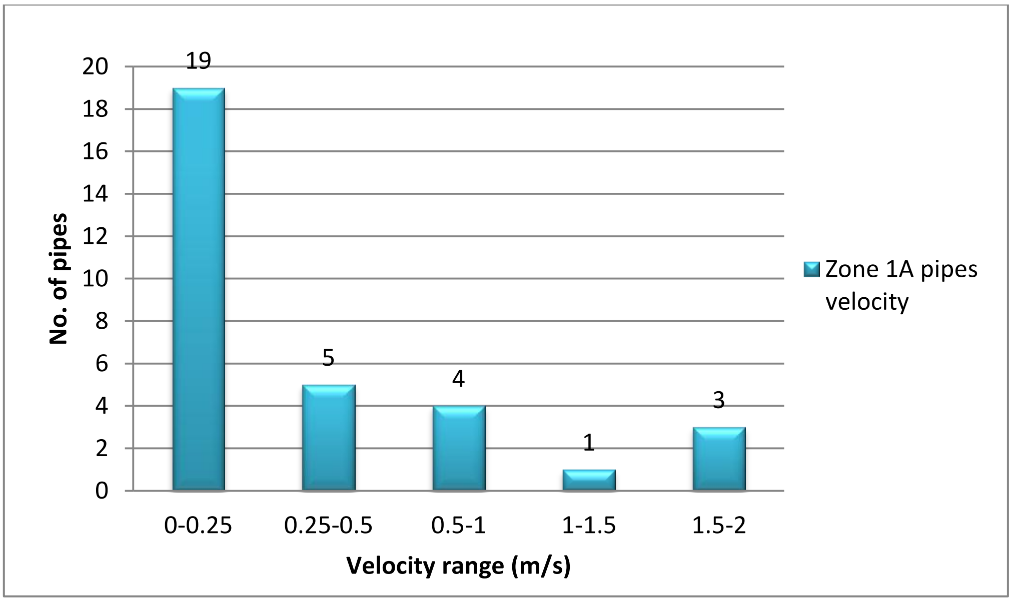


Figure 5.11 Zone 1A pipes velocity histogram.

Figure 5.11 shows velocity results at zone 1A between 0 to 1.71 m/s with a mean of 0.37 m/s and standard deviation 0.51 at operating hours.

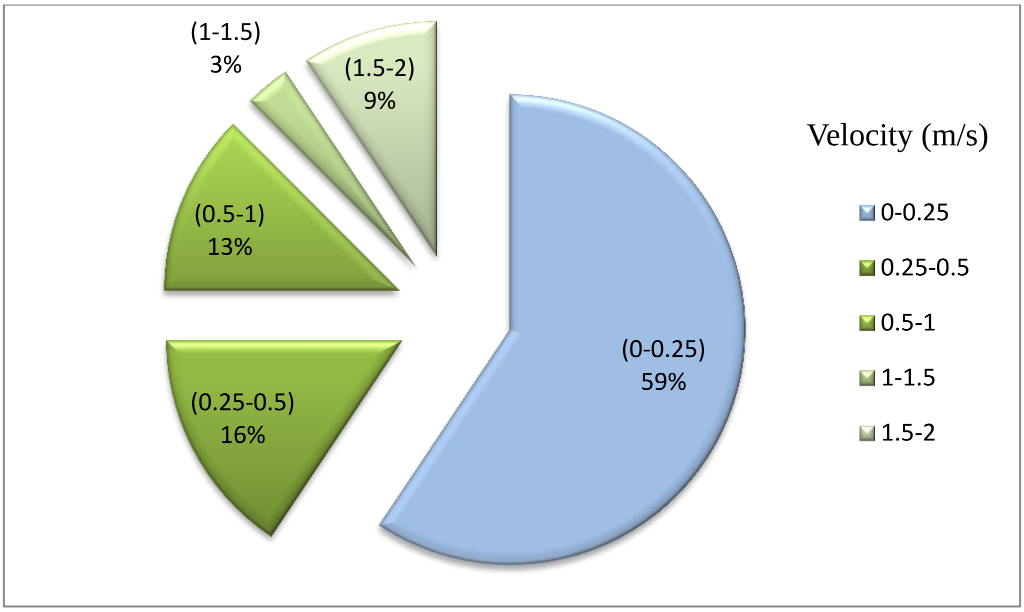


Figure 5.12 Zone 1A pipes velocity percentage.

Figure 5.12 shows Zone 1A velocity percentage between pipes divided into five intervals. The interval from 0 – 0.25 m/s takes the maximum value of 59% and the minimum percentage is for interval 1 – 1.5 m/s.

5.3.2 Components of SDSS in Zone 1B:

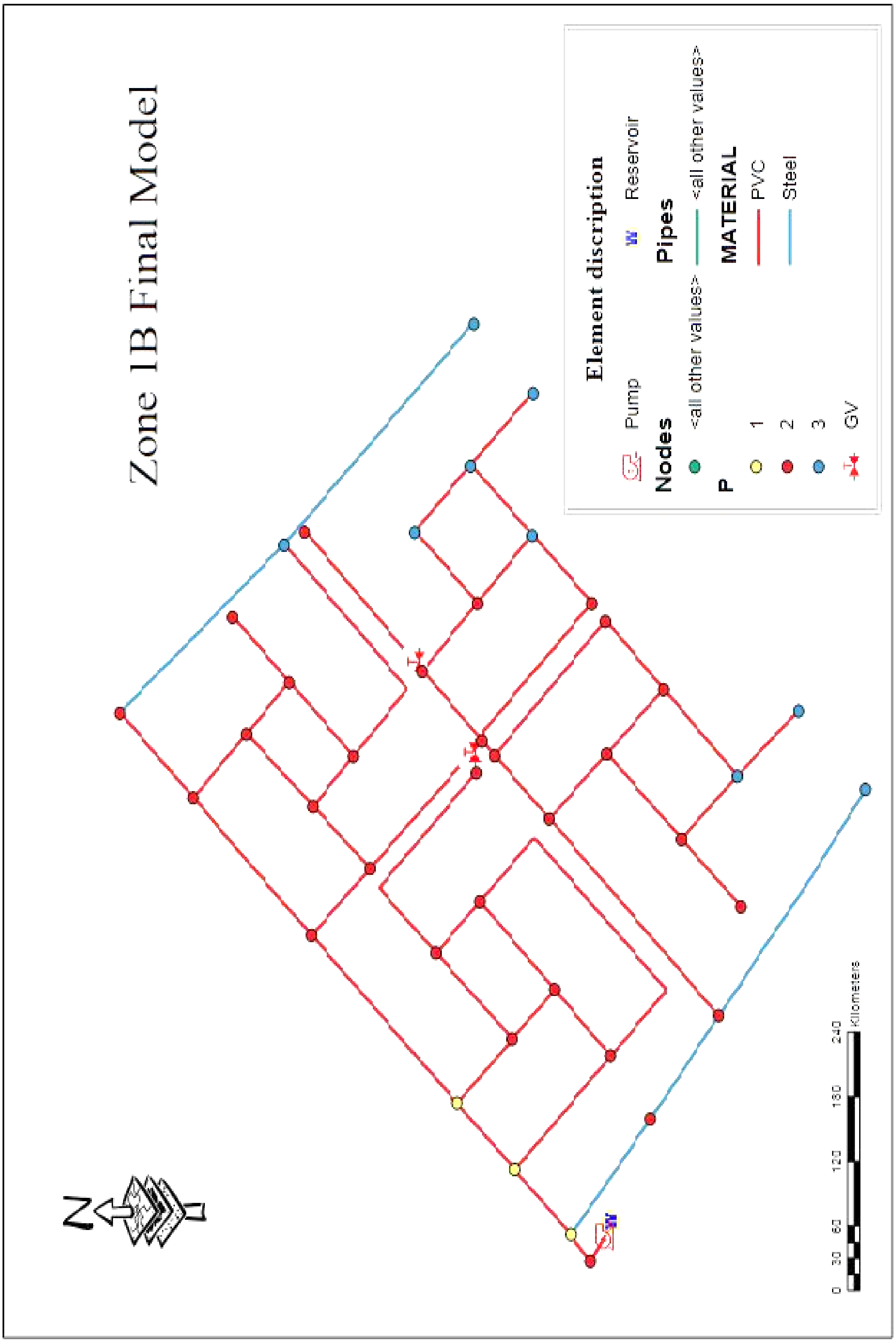


Figure 5.13 Zone 1B layout of model components.

Figure 5.13 shows a general layout to the components of zone1B for the north part from Kamal Nasser well supplied at operation cycle 1 which explained the pipe types and pressure values at junctions from 1 to 3 bar by ArcGIS.

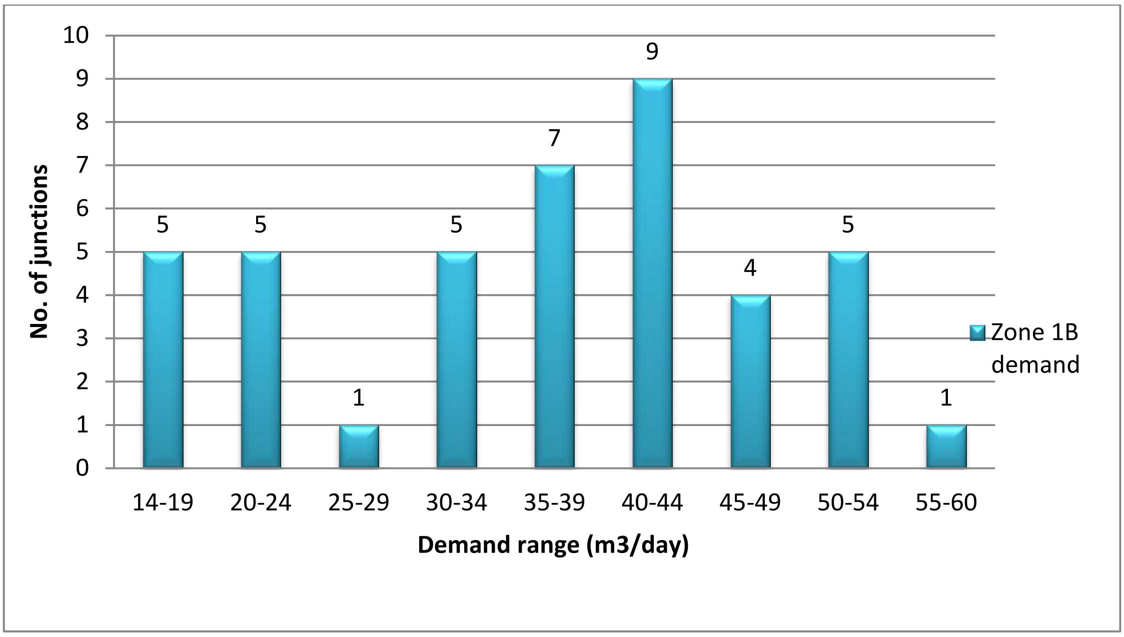


Figure 5.14 Zone 1B histogram demand at junctions.

Figure 5.14 shows a histogram for demand at each of 42 junctions with minimum value 14 m^3/day and maximum 59 m^3/day with a mean of 36.024 and standard deviation 11.57 the values verified according population distribution.

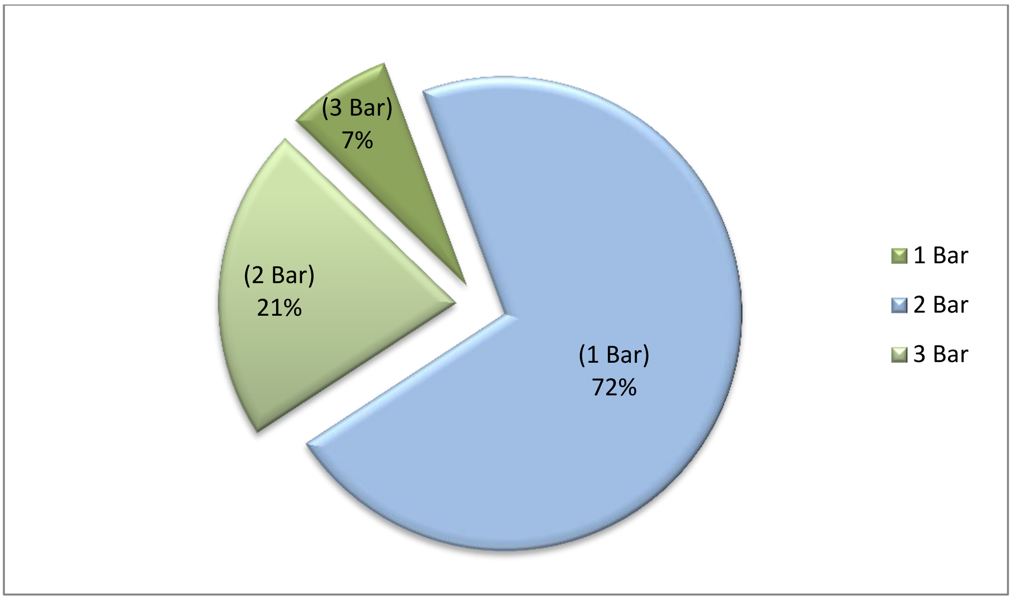


Figure 5.15 Zone 1B pressure at junctions.

Figure 5.15 represented Zone 1B pressure values, at 42 junctions between 1-3 bar near 72% at 2 bar with a mean of 2.14 bar and standard deviation 0.521.

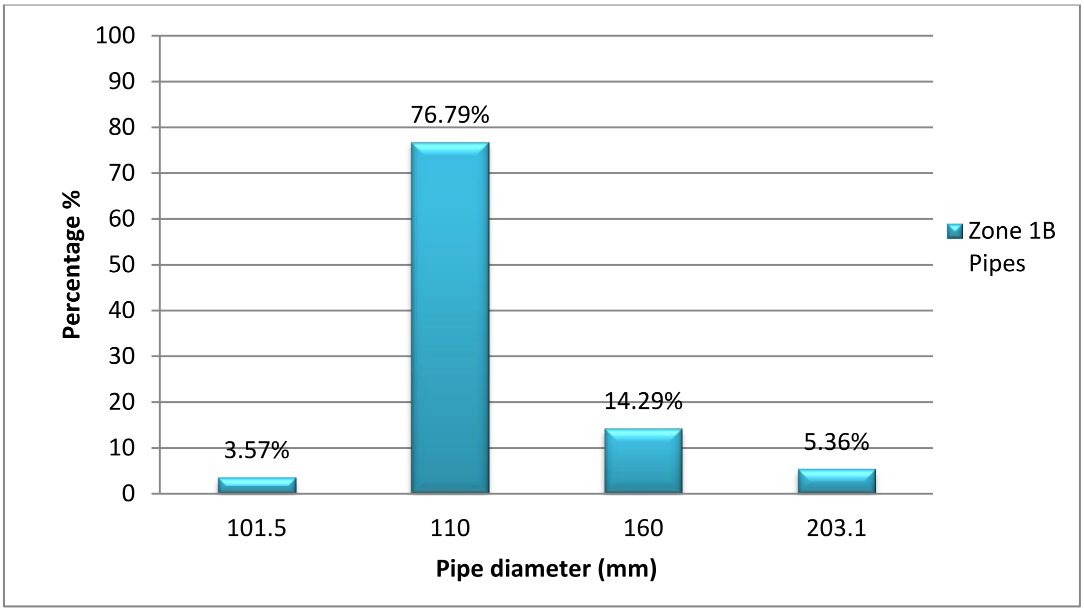


Figure 5.16 Zone 1B pipes diameter histogram.

Figure 5.16 shows 56 Pipes at zone 1B, is recorded between 101.5 to 203.1 mm (Steel and UPVC) but the most pipes diameter at 110 mm and UPVC material.

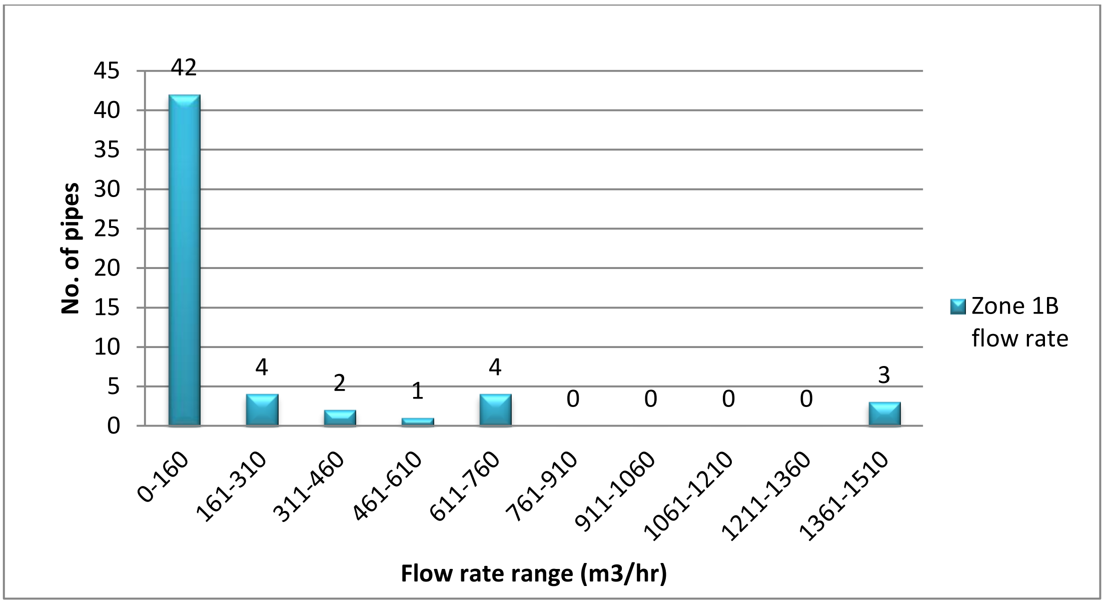


Figure 5.17 Zone 1B pipes flow rate histogram.

Figure 5.17 shows that zone 1B had flow rate at the range from 7 to 1513 m^3/day, mean 213.45 m^3/day and standard deviation 364.83 m^3/day which resulted from 18 hr from operating at Kamal Nasser well.

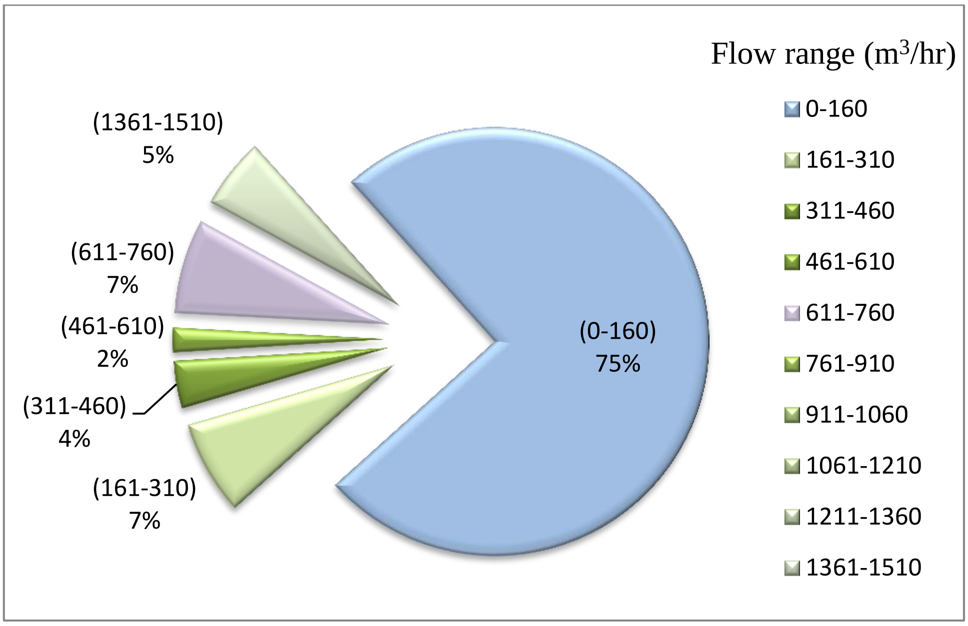


Figure 5.18 Zone 1B pipes flow rate percentage.

Figure 5.18 shows Zone 1B flow rate percentage for pipes, distributed for ten intervals from 0 – 1510 m^3/day.

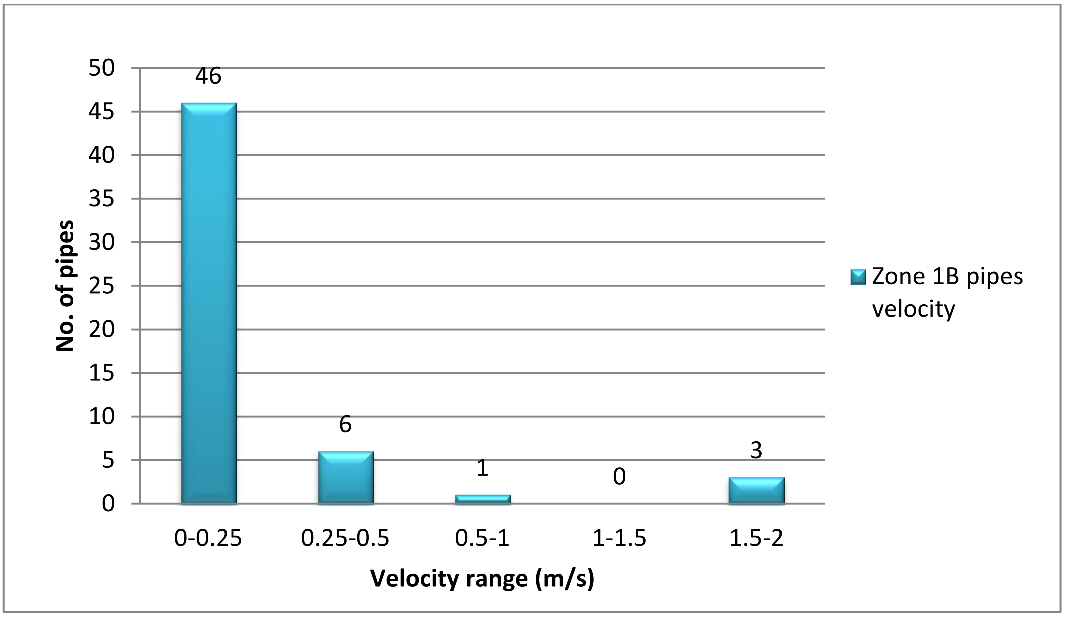


Figure5.19 Zone 1B pipes velocity histogram.

Figure 5.19 shows velocity results at zone 1B between 0.01 to 1.84 m/s with a mean of 0.21 m/s and standard deviation 0.413 m/s at operating hours.

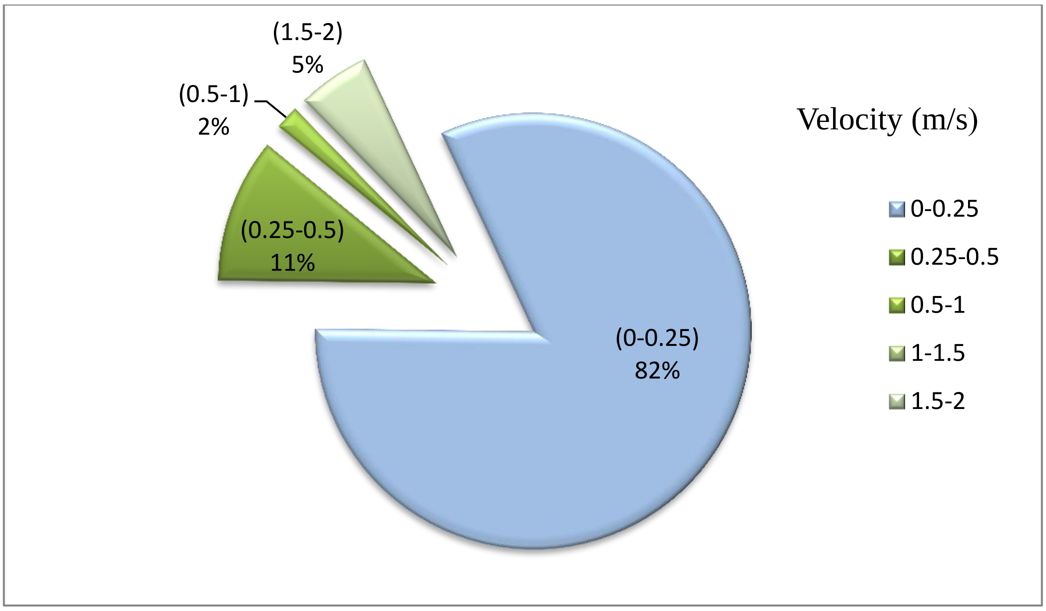


Figure 5.20 Zone 1B pipes velocity percentage.

Figure 5.20 shows Zone 1B velocity percentage between pipes divided into five intervals. The interval from 0 – 0.25 m/s take the maximum value of 82% and the minimum percentage is for interval 1 – 1.5 m/s.

Chapter 6: Results and Discussion

This chapter represents all available results from Gaza city network analysis and for pilot study zone (Zone 1A and 1B) accurately and expand as a prototype for further study to make zones more effectively.

6.1 Modeling results Gaza city network

This stage displayed the results from modeling analysis stage, Table 6.1 shows the average daily consumption and operating hours as an input for modeling and flow rate, total consumption, flow range and pressure at each zone for output.

Table 6.1 Results zones analysis at water distribution system

Zone No.	Flow Rate (m^3/hr)	Average daily consumption (L/day/cap.)	total consumption (m^3/day)	Flow range (m^3/hr)	Pressure (Bar)	Operating hours (hr)
Zone 2	39	120	950	1-39	1-2	14
Zone 3	75	120	1805	1-54	3-4	16
Zone 4	69	120	1654	1-45	2-3	14
Zone 5	64	110	1530	1-64	1-3	14
Zone 6	158	110	3796	1-158	4-5	18
Zone 7	264	160	2346	1-181	2-7	5
Zone 8	336	150	3055	1-127	1-7	5
Zone 9	80	120	1931	1-80	2-5	5
Zone 10	85	120	2040	1-49	4-6	16
Zone 11	202	120	484	1-80	2-4	16
Zone 12	95	120	2269	1-64	4-6	14
Zone 13	60	140	1434	1-32	3-4	14
Zone 14	47	110	1106	1-47	1-2	16
Zone 15	48	160	790	1-48	1-4	16
Zone 16	220	120	5288	1-79	1-3	20
Zone 17	33	160	1140	1-33	2-3	18

Zone 18	50	120	1200	1-22	3-5	8
Zone 19	39	120	980	1-39	2-5	14
Zone 20	93	105	2240	1-47	2-4	8
Zone 21	57	160	997	1-36	4-9	8
Zone 22	67	150	1596	1-55	2-6	8
Zone 23	7	160	166	1-7	3	14
Zone 24+31	1003	120	24073	1-417	1-6	16
Zone 25	442	140	10597	1-247	2-6	6
Zone 26	66	90	1595	1-66	1-3	18
Zone 27	39	120	945	1-39	4-5	16
Zone 28	49	120	1183	1-49	3-4	10
Zone 29	56	90	1333	1-56	1-2	16
Zone 30	24	120	583	1-24	2-3	10
Zone 32	36	120	875	1-36	1-3	14
Zone 33	68	120	1620	1-68	2-3	14
Zone 34	50	120	1202	1-50	1-2	14
Zone 35	58	120	1396	1-57	2-5	8
Zone 36	63	120	1512	2-31	3-4	10
Zone 37	17	120	398	1-17	4-5	8
Zone 38	40	150	933	1-24	3-5	8
Zone 39	18	120	413	1-18	4-5	8
Zone 40	732	115	13562	1-302	2-5	10
Zone 41	52	100	1258	1-52	1-3	10
Zone 42	23	100	546	1-23	2-3	8
Zone 43	38	90	913	1-38	1-6	12
Zone 44	23	80	558	2-23	3-5	8
Zone 45	31	110	751	1-31	1-3	10
Zone 46	71	120	1670	1-71	1-7	5
Zone 47	88	100	2101	1-88	1-6	8
Zone 48	40	120	962	2-40	4-5	10
Zone 49	73	110	1750	1-73	1-6	8

Zone 50	57	90	1370	1-57	1-2	8
Zone 51	15	170	363	2-15	4-5	8
Zone 52	34	90	827	1-34	4-6	8
Zone 53	30	90	710	1-30	3-5	8
Zone 55	111	80	2673	1-111	1-5	16
Zone 56	79	80	1886	1-79	4-5	10
Zone 57	71	110	1692	1-71	2-5	5
Zone 58	51	90	1232	1-51	3-6	3
Zone 59	70	100	1684	2-53	3-5	14

From Table 6.1 Pressure readings were between 1 to 7 bars and operating hours between 3 to 20 hr according to operation cycle and distribution zone.

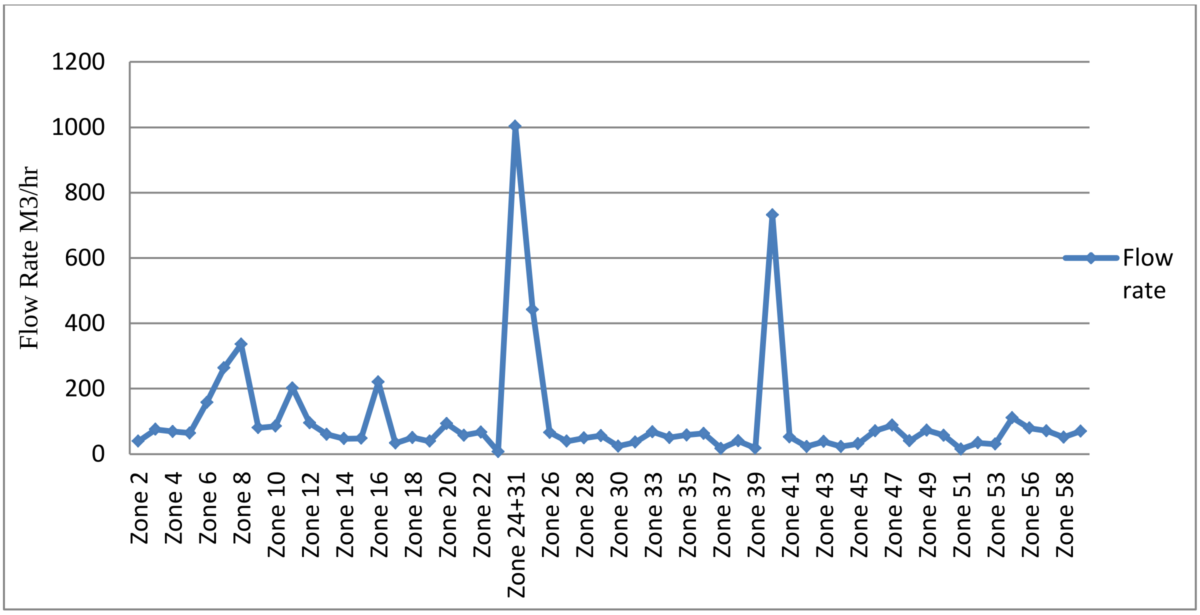


Figure 6.1 Zones Flow rate curve.

Figure 6.1 shows a description curve for flow rate at each zone to identify which zone had a high percentage of water consumption at operating hours. Low amount of flow rate resulted at zones 23, 30, 37, 39, 42, 44 and 51, but it meant that there are leakage at previous zones from illegal connections or losses from fittings.

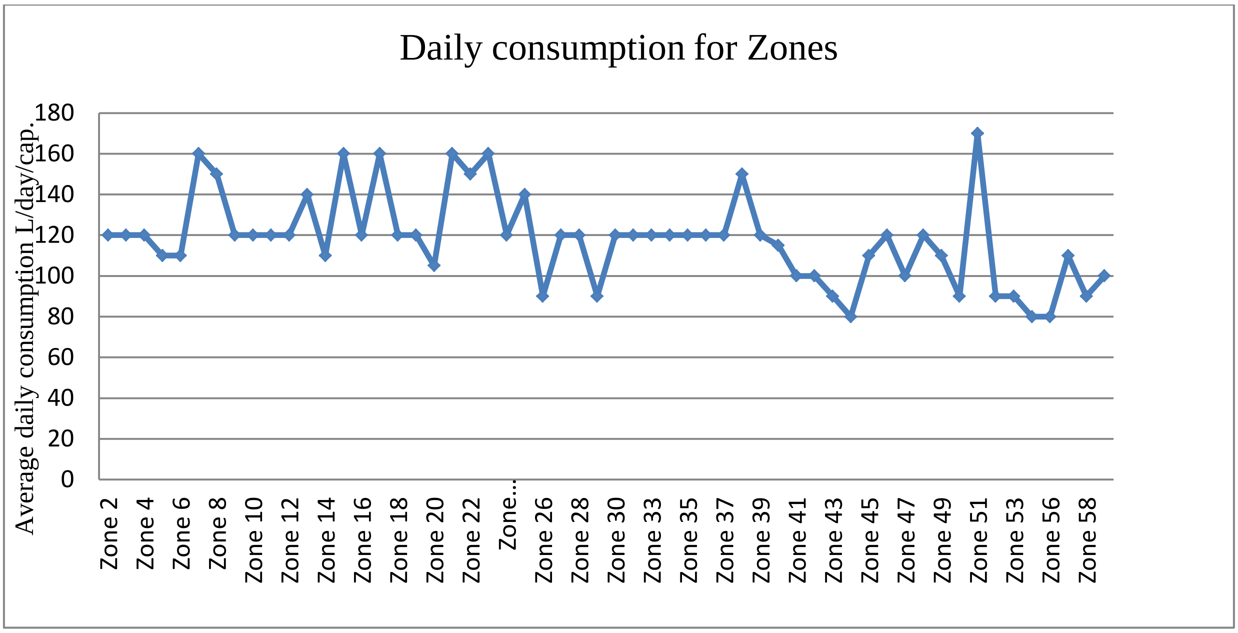


Figure 6.2 Average daily consumption for zones

Figure 6.2 shows the daily consumption for each zone and made it by curve.

Almost the pressure accepted but at some junctions have negative pressure specially at zone 24+31 and high pressure at zone 46 (7 bars), Total consumption was resulted at range from 166 to 24073 m^3/day according average daily consumption for inhabitants.

6.2 Pilot study results:

Table6.2: Pilot study area results (Zone 1A and 1B)

Zone No.	Flow Rate (m^3/hr)	Average daily consumption (L/day)	total consumption (m^3/day)	Flow range (m^3/hr)	Pressure (Bar)	Operating hours (hr)
Zone 1A	58	160	1401	1-58	1-2	18
Zone1B	63	90	1513	1-63	1-3	18

Table 6.2 shows a high accurately results of pilot study area after calibration stage with equal in operating hours 18 hr.

6.3 Discussion:

6.3.1 Gaza city network:

- The average daily consumption per capita was used between 80 to 160 L/day but according Palestinian water authority (PWA) 2014 study got near to 125 L/day for supply and 80 L/day for consumption so that this number is not accurate because varies between zones and the well sources.
- At the same study for PWA, the efficiency was near 63% but from hydraulic modeling was resulted 65% without neglected the losses at North wells and 85% with neglected.
- Gaza city needs a booster pumps to solve the low level from flow.
- A high range of pressure was resulted from 1 to 7 bars, needed to review to be realistic as zone 1A and 1B pressure value were resulted at the range of 1-3 bars.

6.3.2 A pilot study (Zone 1A and 1B):

- Total population at zone 1A equal 4380 capita but at zone 1B 8408 capital, it mean Concentration at zone 1B twice 1A because area for two zones near the same value.
- The Average daily consumption per capita was 90 L/day at zone 1B but zone 1A was got 160 L/day with review for total population is shown that zone 1A have a clear leakage near 70 L/day for each capita, but model and calibration stages was defined the point of leakage and it is targeted junction (from Annex I) no. 991 with pressure head 13.78m at the end of this point there was a valve normally close but from this study we discover all this valve fault of made a high percentage from leakage.
- Valves are controlled the situation of operating and made it perfectly specially at zone 1A the new three valves are solved a critical problem because the area at this valves had negative pressure before installed valves and low value at the best case pressure head reach to 1m.
- SCADA system for Kamal Nasser well wasn't installed so it affected at well control and operated manually.

- The differences at pressure head after calibration were resulted from fittings at zones and k coefficient (at station A before calibration 2.6 bar but after calibration 1.7 bar).
- The system can be improved by change flow value to increase velocity value and diameter stay constant.

6.4 Summary:

Modeling and pilot study analysis results viewed at this chapter to transfer for discussion part at points to use at developing the system.

Chapter 7: Conclusion and Recommendations

This chapter is divided for two parts. The first part specified for conclusions and to focus at pilot study area. The second is explained the recommendations from this research.

7.1 <u>Conclusions:</u>

The results of our study concluded that:

- Demand allocation depends on water quantities produced by wells, it distributed according population concentration at each zone which take from GIS department at MOG.
- The pressure values were accepted with exception for junctions have negative pressure specially at zone 24+31 and high pressure at zone 46 (7 bars). Total consumption was resulted at range from 166 to 24073 m^3/day.
- Calibration accuracy (the difference between modeling and data logger values) is reached to near 96%. A pilot scale study provided a sample to apply at all zones of Gaza city to improve the network efficiency and effectiveness of operation.
- Zone 1A was resulted 71% pressure value for 1 bar and 29% for 2 bar. The pipe diameters were distributed for 3 inch with percentage 3.13%, 110 mm with percentage 59.38% and 160 mm with percentage 37.5%. 59% of zone 1A water velocity ranged between 0-0.25 m/s. Zone 1B was resulted 72% pressure value for 1 bar, 21% for 2 bar and 7% for 3 bar. The pipe diameters were distributed for 3 in with percentage 3.57%, 110 mm with percentage 76.79%, 160 mm with percentage 14.29% and 8 in with percentage 5.36%. 82% of zone 1B water velocity ranged between 0-0.25 m/s.

7.2 Recommendations

From this study, the following recommendations should be considered to improve and to make the network in Gaza city work with high efficiency and effectiveness:

7.2.1 Gaza city network:

1. Re-planning study for water distribution system to work with new technology and make system more automation.
2. Performance evaluation studies and rehabilitation for wells to improve the efficiency.
3. Permanently update for network and analyze it. So, it is very important to take any sources change (desalination plants or water carrier) to make future studies more effective.
4. Make historical data of the system (pipes, valves and wells) with high accurate for evaluation and development studies and try to relate it with GIS.
5. Activate SCADA System to make the system more automation and specify any sudden problem at the system and to give more accurate data.
6. Tanks are one of critical components at the system, must suggest for strategic vision to avoid the system drop at emergency cases like electricity crisis and wars.
7. Fire flow demand was neglected and not valid for the design criteria to use at emergency crisis.
8. Fittings were affected on the hydraulic system efficiency and the percentage of losses because it is needed to more efforts from preventive maintenance.

7.2.2 A pilot study:

1. Try to apply this study results as a prototype to make isolate zones to make control more easily specially at zone 1 and identify the benefits from calibration and decision support system.
2. Operating hours for Zone 1 was resulted that enough for supply capitals zone with high quantity at pressure values.

3. This study made explore problems and weakness points more easily, at zone 1A demand high values (160 L/day/cap.).
4. Preventative maintenance for valves avoid the high percentage of losses.
5. Automation approach for valves and well control through SCADA make two important points: historical data as reference and future development planning.
6. Pipes type was affected by the quality of zone operation so at this zone UPVC take the maximum percentage and all zones need to be the same.
7. The low values for velocity at zone 1A and 1B need more solutions which explained at chapter 6 to avoid this problem because the maximum percentage at 0 – 0.25 m/s velocity.
8. Losses are one of many defects at the system it resulted from illegal connections, fittings and network situation.
9. Reduce valves as possible to avoid the high drop at pressure as results after calibration.

References:

- Abdul Rahman N, Kuhail Z and El-Jamal K Performance Improvement of the Water Distribution System [Book]. - Gaza, Palestine : [s.n.], 2005.

- Adenso-Diaz B, Tuya J and Goitia M EDSS for the evaluation of alternatives in waste water collecting systems design [Article] // Environmental Modelling & Software 20. - Spain : [s.n.], 2005. - p. 640.

- Al-Omari A and Abdulla F A model for the determination of residential water demand by the use of tracers [Article] // Advances in Engineering Software 40. - Jordan : [s.n.], 2009. - p. 93.

- Alves Z [et al.] Water distribution network's modeling and calibration.A case study based on scarce inventory data [Article] // Procedia Engineering 70. - Portugal : [s.n.], 2014. - pp. 1-2.

- Badwan A GIS Based System for Evaluating Groundwater Quality in the Gaza Strip [Book]. - Gaza : [s.n.], 2010. - p. 22.

- Bentley [Online] // www.bentley.com. - 2012. - 10 9, 2014.

- Bentley Systems, Inc Bentley WaterCAD V8i Help [Book]. - [s.l.] : Haestad Methods Solution Center, 2013.

- BFG Decision Support Systems (DSS) for River Basin Management. [Article] // Bundesanstalt fu¨r Gewa¨sserkunde (German Federal Institute of Hydrology). - Koblenz, Germany. : [s.n.], 2000.

- Bice L [et al.] Source Water Assessment Using Geographic Information Systems [Report] / U.S. Environmental Protection Agency. - USA : [s.n.], 2000. - p. 5.

- Cembrano G [et al.] Optimal control of a water distribution network in a supervisory control system [Article] // Control Engineering Practice. - Spain : [s.n.], 2000. - 8. - p. 1178.

- Cesario L. Modeling, Analysis, and Design of Water Distribution Systems [Report]. - Denver, USA. : American Water Works Association, 1995.

- Chatterjee A Water Disposal, Waste Disposal and Environmental Engneering [Book]. - Delhi, India : Seventeen Edition. Khanna Publisher, 2001.
- Chung G, Hoon Kim J and Woong Kim T System Dynamics Modeling Approach to Water Supply System [Article] // KSCE Journal of Civil Engineering. - 2008. - p. 1.
- Clark, A. Increasing Efficiency with Permanent Leakage Monitoring. In: Water Loss Reduction - Proceedings of the 7th IWA Specialist Conference [Article]. - 2012. - pp. 26-29.
- Coelho B and Andrade-Campos A Efficiency achievement in water supply systems—A review [Article] // Renewable and Sustainable Energy Reviews. - 2013. - pp. 59-72.
- Crossland M, Wynne B and Perrkins W Spatial decision support systems: An overview of technology and a test of efficacy [Article] // Decision Support Systems 14. - USA : [s.n.], 1995. - pp. 219-235.
- Darvini, G. Model discrimination in water distribution systems [Article] // Procedia Engineering 70. - Italy : [s.n.], 2014. - p. 1.
- Dasic T and Djordjevic B Method for water distribution systems reliability evaluation [Article]. - 2004. - p. 1.
- De Paola F [et al.] Optimal design of district metered areas in water distribution networks [Article] // Procedia Engineering 70. - 2014.
- Debiasi S [et al.] Influence of hourly water consumption in model calibration for leakage detection in a WDS [Article] // Procedia Engineering 70. - 2014. - p. 468.
- Denzer R Generic integration of environmental decision support systems – state-of-the-art [Article] // Environmental Informatics Group. - Germany : [s.n.], 2004.
- Ennis J [et al.] Improver water distribution system modeling and management using map objects [Report] / MW Soft, Inc.. - USA : [s.n.], 2014. - p. 1.
- ESRI ArcGIS Solutions for Civil Engineering [Report]. - USA : [s.n.], 2006.

- Fassio A [et al.] A decision support tool for simulating the effects of alternative policies affecting water resources: an application at the European scale [Article] // Journal of Hydrology 304. - 2005. - p. 464.
- Feick R and Hall G Consensus-building in a multi-participant spatial decision support system. [Article] // URISA Journal 11 (2). - 1999. - pp. 17-23.
- Feldman M. Aspects of energy efficiency in wate rsupply systems. In:Proceedings of the 5th IWA Water Loss Reduction Specialist Conference [Conference]. - South Africa : [s.n.], 2009.
- Gellings C. et al Program on technology innovation: electric efficiency through water supply technologies—a roadmap.technical report. [Report] / Electric Power Research Institute(EPRI). - PaloAlto,Califórnia : [s.n.], 2009.
- Giunti A [et al.] Contribution of numerical modeling to a drinking water production plan [Article] // Procedia Engineering 70. - Spaim : [s.n.], 2014. - p. 727.
- Goldenberg N and Wool A Accurate modeling of Modbus/TCPfo rintrusion detection in SCADA systems [Article] // international journal of critical infrastructure protection 6. - 2013. - p. 63.
- Hamilton, S. Technology-How far can we go? Pipelines [Article]. - 2012. - pp. 523-530.
- Hirner W and Mayr H Performance indicators for an efficient distribution management [Article]. - Germany : Blackwell Science Ltd, 1997.
- Hwang N and Houghtalen R Fundamentals of Hydraulic Engineering System [Book]. - [s.l.] : Prentice Hall, 1996. - Vol. 3 : p. 103.
- Jankowski P and Nyerges T Geographic Information Systems for Group Decision Making, Taylor & Francis [Article]. - London : [s.n.], 2001.
- Keen, P. “Decision Support Systems: The Next Decade.” Decision Support Systems: a decade in persepective [Book] / ed. McLean E and Sol, H.G., NorthHolland. - 1986.

- Kiselychnyk O, Bodson M and Werner H Overview of energy efficient control solutions for water supply system [Report] / Transactions of Kremenchuk State Polytechnic University . - 2009.
- Machell J, Mounce S and Boxall J Online modelling of water distribution systems :UK case study [Article] // Drinking Water Engineering and Science;3:21-7.. - 2010.
- Malczewski J GIS-based land-use suitability analysis: a critical overview [Article] // Progress in Planning. - Canada : [s.n.], 2004. - p. 15.
- Matthies M, Giupponi C and Ostendorf B Environmental decision support systems: Current issues, methods and tools [Article] // Environmental Modelling & Software. - November 8, 2005. - pp. 123-124.
- Matthies M, Giupponi C and Ostendorf B Environmental decision support systems: Current issues,methods and tools [Article] // Environmental Modelling & Software 22. - 2007. - p. 123.
- Meseguer J, Mirats-Tur J and Cembr G A decision support system for on-line leakage localization [Article] // Environmental Modelling & Software. - Spain : [s.n.], 2014. - p. 334.
- Orange Water and Sewer Authority (OWASA) Water Distribution Hydraulic Model Selection [Report]. - 1999. - pp. 8-9.
- Ormsbee, L. and Lingireddy, S. Calibrating Hydraulic Network Models [Article] // journal of the American Water Works Association. - 1997.
- Perez R.et al [et al.] Methodology for leakage isolation using pressure sensitivity analysis in water distribution networks. Control Eng. Pract. 19 [Article]. - 2011. - pp. 1157-1167.
- Rezai A, Kashavarzi P and Moravej Z Secure SCADA communication by using a modified key management scheme [Article] // ISA Transactions. - Iran : [s.n.], 2013. - 52. - p. 517.

- Schaetzen W and Boulos P Optimal Water Distribution System Management Using Esri MapObjects Technology [Report] / MWH Soft, Inc.. - 2014. - p. 1.
- Scholten L [et al.] Combining expert knowledge and local data for improved service life modeling of water supply networks [Article] // Environmental Modelling & Software 42. - Switzerland : [s.n.], 2013. - p. 1.
- Shaker, A. Prospects of Private Sector Participation for Sustainable Water and Sanitation Services in The Gaza Strip [Book]. - Gaza : The Islamic University, 2007.
- Shamir U and Howard C Engineering Analysis of Water-Distribution Systems. [Article] // Journal of the American Water Works Association 69.. - 1977.
- Temido J, Sousa J and Malheiroa R SCADA and Smart Metering systems in water companies.A perspective based on the value creation analysis [Conference] // 12th International Conference on Computing and Control for the Water Industry, CCWI2013. - Portugal : Procedia Engineering 70, 2014. - pp. 1632-1634.
- U.S. Fire Administration Water Supply Systems and Evaluation Methods [Book]. - USA : [s.n.], 2008. - p. 121.
- U.S. Fire Administration Water Supply Systems and Evaluation Methods [Book]. - USA : [s.n.], 2008. - p. 160.
- Vassiljev, A. and Koppel, T. Calibration of the model of an operational water distribution system. In: Topping BHV, Montero G, Montenegro R, editors Proceedings of the fifth international conference on engineering computational technology. [Article]. - Stirlingshire, United Kingdom : Civil-Comp Press, 2006. - p. 155.
- Viessman W [et al.] Water supply and pollution control [Article]. - New Jersey : [s.n.], 2009. - Vol. 8th ed.Person Education.
- Volk M [et al.] How can we make progress with Decision Support Systems in Landscape and River Basin Management? Lessons learnt from a comparative

analysis of four different decision support systems. Environmental Management(46) [Article]. - 2010. - pp. 834-849.

- Vuta L and Piraianu V INFOWORKS WS and EPANET v2 - Modeling the water distribution networks [Article] // U.P.B. Sci. Bull., Series D, Vol. 70, Iss. 4. - 2008.
- Walski T [et al.] Advanced water distribution modeling and management [Book]. - [s.l.] : Bentley Institute Press, 2013. - Vol. 8th.
- Walski T [et al.] Advanced Water Distribution Modelling and Managment [Article] // Heasted Press. - USA : [s.n.], 2003..
- Walski T, Chase D and Savic D Water Distribution Modeling [Book]. - Waterbury, USA : Haested Press, 2001.
- Wu Z, Sage P and Turtle D Pressure-Dependent Leak Detection Model and Its Application to a District Water System, J. Water Resour. [Conference]. - 2010.
- Xu Y and Zhang X Research on pressure optimization effect of high level water tank by drinking water network hydraulic model [Article] // Procedia Engineering 31. - China : [s.n.], 2012. - pp. 955-966.
- Yingchun G and Zhuotong N A Decision Support System for irrigation water allocation along the middle reaches of the Heihe River Basin, Northwest China [Article] // Environmental Modelling & Software. - China : [s.n.], June 17, 2013. - p. 9.
- Zheng Yi Wu Innovative Optimization Model for Water Distribution Leakage Detectionv [Article]. - USA : Haestad Methods Solution Center, Bentley Systems, Incorporated, 2007.

Annex I

Table 1.:Zone A consumption distribution according density and service area at each node

Junction No.	ID	Label	Elevation (m)	Element ID	Area*(m^2)	Density	Cap. For Junction	Consumption(L/d)	Consumption(M^3/d)
1	1211	J-465	44.84	1211	2654	0.03341	88.67	28374.445	28.374
2	1212	J-466	47.27	1212	5891	0.03341	196.82	62981.859	62.982
3	1214	J-467	55.04	1214	4733	0.03341	158.13	50601.450	50.601
4	1215	J-468	43.93	1215	12524	0.03341	418.43	133896.589	133.897
5	1217	J-469	52.61	1217	5720	0.03341	191.11	61153.664	61.154
6	1224	J-472	53.45	1224	3418	0.03341	114.20	36542.522	36.543
7	2525	J-978	47.13	2525	6357	0.03341	212.39	67963.958	67.964
8	2528	J-979	45.2	2528	2607	0.03341	87.10	27871.958	27.872
9	2530	J-980	53.87	2530	3901	0.03341	130.33	41706.371	41.706
10	2533	J-981	49.73	2533	4820	0.03341	161.04	51531.584	51.532
11	2535	J-982	58.29	2535	7792	0.03341	260.33	83305.830	83.306
12	2538	J-983	53.39	2538	5170	0.03341	172.73	55273.504	55.274
13	2540	J-984	53.23	2540	6768	0.03341	226.12	72358.042	72.358
14	2541	J-985	57.01	2541	7740	0.03341	258.59	82749.888	82.750
15	2545	J-986	53.82	2545	6424	0.03341	214.63	68680.269	68.680
16	2546	J-987	56.91	2546	7254	0.03341	242.36	77553.965	77.554
17	2550	J-988	53.41	2550	4594	0.03341	153.49	49115.373	49.115
18	2554	J-989	50.03	2554	9286	0.03341	310.25	99278.483	99.278
19	2557	J-990	50.33	2557	5742	0.03341	191.84	61388.870	61.389
20	2559	J-991	45.36	2559	5852	0.03341	195.52	62564.902	62.565
21	2898	J-1139	46.37	2898	2585	0.03341	86.36	27636.752	27.637
22	2902	J-1140	52.09	2902	2562	0.03341	85.60	27390.854	27.391

23	3000	J-1173	44.9	3000	3644	0.03341	121.75	38958.733	38.959
24	5010	J-1979	39.35	5010	3046	0.03341	101.77	32565.395	32.565
Total Area					131084.0m^2	Total Population	4379.52	Total consumption	1401.445

*: area take by ArcMap use shape file export from watercad for each junction

Table 2.:Zone A demand for each junction and pressure by bars

ID	Label	Elevation (m)	Demand (m³/day)	Hydraulic Grade (m)	Pressure (bars)
1211	J-465	44.84	28	60.99	2
1212	J-466	47.27	63	61	1
1214	J-467	55.04	51	64.44	1
1215	J-468	43.93	134	61	2
1217	J-469	52.61	61	61.3	1
1224	J-472	53.45	37	63.45	1
2525	J-978	47.13	68	60.99	1
2528	J-979	45.2	28	60.99	2
2530	J-980	53.87	42	61.01	1
2533	J-981	49.73	52	61	1
2535	J-982	58.29	83	63.46	1
2538	J-983	53.39	55	63.45	1
2540	J-984	53.23	72	62.57	1
2541	J-985	57.01	83	64.26	1
2545	J-986	53.82	69	61.87	1
2546	J-987	56.91	78	62.12	1
2550	J-988	53.41	49	61.01	1
2554	J-989	50.03	99	61.01	1

2557	J-990	50.33	61	61.09	1
2559	J-991	45.36	63	60.99	2
2898	J-1139	46.37	28	68.24	2
2902	J-1140	52.09	27	64.43	1
3000	J-1173	44.9	39	60.99	2
5010	J-1979	39.35	33	60.97	2

Table 3.:Zone A pipes data at water cad

ID	Label	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (m^3/day)	Velocity (m/s)	Headloss Gradient (m/m)
2526	P-1030	84	J-978	J-465	160	PVC	130	28	0.02	0
2527	P-1031	212	J-466	J-978	160	PVC	130	124	0.07	0
2529	P-1032	94	J-978	J-979	110	PVC	130	28	0.03	0
2534	P-1033	102	J-980	J-981	110	PVC	130	52	0.06	0
2539	P-1034	96	J-982	J-983	110	PVC	130	55	0.07	0
2542	P-1035	43	J-467	J-985	160	PVC	130	1296	0.75	0.004
2544	P-1037	203	J-985	J-984	110	PVC	130	709	0.86	0.008
2549	P-1040	203	J-987	J-986	110	PVC	130	252	0.31	0.001
2551	P-1041	6	J-988	J-980	160	PVC	130	93	0.05	0
2553	P-1042	203	J-469	J-988	110	PVC	130	272	0.33	0.001
2555	P-1043	54	J-988	J-989	160	PVC	130	130	0.07	0
2556	P-1044	106	J-989	J-468	160	PVC	130	167	0.1	0
2558	P-1045	203	J-990	J-989	110	PVC	130	136	0.17	0

2560	P-1046	49	J-466	J-991	110	PVC	130	101	0.12	0
2561	P-1047	202	J-468	J-991	110	PVC	130	33	0.04	0
2562	P-1048	53	J-990	J-466	110	PVC	130	288	0.35	0.002
2563	P-1049	51	J-469	J-990	110	PVC	130	486	0.59	0.004
2564	P-1050	53	J-986	J-469	110	PVC	130	819	1	0.011
2565	P-1051	103	J-984	J-986	110	PVC	130	636	0.77	0.007
2899	P-1216	12	Kamal Naser	J-1139	110	PVC	130	1401	1.71	0.029
2901	P-1218	135	J-1139	J-467	110	PVC	130	1374	1.67	0.028
2905	P-1220	208	J-467	J-1140	110	PVC	130	27	0.03	0
2906	P-1221	224	J-982	J-472	110	PVC	130	37	0.04	0
3001	P-1261	51	J-991	J-1173	110	PVC	130	72	0.09	0
6232	P-3653	9	R-1	Kamal Naser	110	PVC	130	1401	1.71	0.029
6288	P-3682	19	J-982	GPV-15	160	PVC	130	329	0.19	0
6289	P-3683	29	GPV-15	J-987	160	PVC	130	329	0.19	0
6292	P-3684	19	J-987	GPV-16	160	PVC	130	0	0	0
6293	P-3685	25	GPV-16	J-980	160	PVC	130	0	0	0
6295	P-3686	33	J-985	GPV-17	160	PVC	130	504	0.29	0.001
6296	P-3687	21	GPV-17	J-982	160	PVC	130	504	0.29	0.001
5011	P-2303	294	J-1173	J-1979	101.5	Steel	110	33	0.05	0

Table 4.:Zone A pump characteristic and operating data

ID	Label	Elevation (m)	Pump Definition	Status (Initial)	Hydraulic Grade (Suction) (m)	Hydraulic Grade (Discharge) (m)	Flow (Total) (m^3/day)	Pump Head (m)
2897	Kamal Naser	45.3	PMP18	On	45.03	68.6	1401	23.57

Table 5.:Zone A reservoir data

ID	Label	Elevation (m)	Flow (Out net) (m^3/day)	Hydraulic Grade (m)
6231	R-1	45.3	1401	45.3

Table 6.:Zone A gate valve data

ID	Label	Elevation (m)	Diameter (Valve) (mm)	Flow (m^3/day)	Hydraulic Grade (From) (m)	Hydraulic Grade (To) (m)	Headloss (m)
6287	GPV-15	57.73	160	329	63.45	62.13	1.32
6291	GPV-16	55.6	160	0	62.12	61.01	0
6294	GPV-17	57.8	160	504	64.24	63.47	0.76

Table 7.:Zone B consumption distribution according density and service area at each node

Junction No.	ID	Label	Elevation (m)	ELEMENTID	Area(m2)	Density	Cap. For Junction	Consumption(L/d)	Consumption(M3/d)
1	614	J-218	46.15	614	1458	0.07329	106.85	19232.915	19.233
2	615	J-219	30.45	615	1759	0.07329	128.91	23203.497	23.203
3	1189	J-455	34.24	1189	2650	0.07329	194.21	34956.945	34.957
4	1191	J-456	38.31	1191	1308	0.07329	95.86	17254.220	17.254
5	1209	J-464	40.18	1209	2546	0.07329	186.58	33585.050	33.585
6	2459	J-952	38.64	2459	1544	0.07329	113.15	20367.367	20.367
7	2463	J-953	38.96	2463	2561	0.07329	187.68	33782.919	33.783
8	2465	J-954	37.73	2465	2937	0.07329	215.24	38742.848	38.743
9	2467	J-955	36.53	2467	2238	0.07329	164.01	29522.129	29.522
10	2469	J-956	35.31	2469	1171	0.07329	85.82	15447.012	15.447
11	2470	J-957	39.27	2470	2817	0.07329	206.44	37159.892	37.160
12	2473	J-958	40.47	2473	3029	0.07329	221.98	39956.448	39.956
13	2475	J-959	42.07	2475	3045	0.07329	223.15	40167.509	40.168
14	2477	J-960	44.24	2477	2815	0.07329	206.30	37133.510	37.134
15	2481	J-961	38.18	2481	1711	0.07329	125.39	22570.314	22.570
16	2486	J-962	38.59	2486	3490	0.07329	255.76	46037.637	46.038
17	2488	J-963	38.33	2488	3107	0.07329	227.70	40985.369	40.985
18	2492	J-964	37	2492	3197	0.07329	234.29	42172.586	42.173
19	2494	J-965	35.22	2494	3932	0.07329	288.16	51868.192	51.868
20	2496	J-966	34.82	2496	2726	0.07329	199.77	35959.484	35.959
21	2499	J-967	36.83	2499	4016	0.07329	294.31	52976.261	52.976
22	2500	J-968	34.07	2500	3296	0.07329	241.55	43478.525	43.479

23	2502	J-969	31	2502	1767	0.07329	129.49	23309.027	23.309
24	2506	J-970	36.34	2506	4437	0.07329	325.17	58529.798	58.530
25	2508	J-971	34.62	2508	2775	0.07329	203.37	36605.858	36.606
26	2510	J-972	34.07	2510	3453	0.07329	253.05	45549.559	45.550
27	2512	J-973	35.53	2512	3007	0.07329	220.37	39666.239	39.666
28	2514	J-974	37.35	2514	3489	0.07329	255.69	46024.446	46.024
29	2518	J-975	34.31	2518	3891	0.07329	285.15	51327.348	51.327
30	2520	J-976	33	2520	3785	0.07329	277.38	49929.071	49.929
31	2522	J-977	31.99	2522	1677	0.07329	122.90	22121.810	22.122
32	2876	J-1131	46.31	2876	2396	0.07329	175.59	31606.355	31.606
33	2879	J-1132	41.28	2879	3264	0.07329	239.20	43056.403	43.056
34	2881	J-1133	40.27	2881	3080	0.07329	225.72	40629.204	40.629
35	2883	J-1134	42.55	2883	3970	0.07329	290.94	52369.461	52.369
36	2885	J-1135	42.97	2885	2640	0.07329	193.47	34825.032	34.825
37	2887	J-1136	45.86	2887	2358	0.07329	172.81	31105.085	31.105
38	2891	J-1137	41.77	2891	3728	0.07329	273.21	49177.166	49.177
39	2895	J-1138	38.52	2895	2149	0.07329	157.49	28348.104	28.348
40	2898	J-1139	46.37	2898	1067	0.07329	78.20	14075.117	14.075
41	5016	J-1981	31.79	5016	1390	0.07329	101.87	18335.907	18.336
42	5383	J-2112	41.66	5383	3054	0.07329	223.81	40286.230	40.286
43					114730.0	M2	8407.99	Cap.	1513.438

*: area take by ArcMap use shape file export from watercad for each junction

Table 8.:Zone B demand for each junction and pressure by bars

ID	Label	Elevation (m)	Demand (m^3/day)	Hydraulic Grade (m)	Pressure (bars)
614	J-218	46.15	19	61.25	1
615	J-219	30.45	23	61.16	3
1189	J-455	34.24	35	52.13	2
1191	J-456	38.31	17	60.05	2
1209	J-464	40.18	34	61.07	2
2459	J-952	38.64	20	61.07	2
2463	J-953	38.96	34	61.06	2
2465	J-954	37.73	39	61.06	2
2467	J-955	36.53	30	61.06	2
2469	J-956	35.31	15	61.06	3
2470	J-957	39.27	37	61.06	2
2473	J-958	40.47	40	61.06	2
2475	J-959	42.07	40	61.06	2
2477	J-960	44.24	37	61.09	2
2481	J-961	38.18	23	60.05	2
2486	J-962	38.59	46	60.14	2
2488	J-963	38.33	41	61.16	2
2492	J-964	37	42	60.07	2
2494	J-965	35.22	52	60.05	2
2496	J-966	34.82	36	60.05	2
2499	J-967	36.83	53	60.05	2
2500	J-968	34.07	43	60.05	3

2502	J-969	31	23	60.05	3
2506	J-970	36.34	59	60.04	2
2508	J-971	34.62	37	60.03	2
2510	J-972	34.07	46	60.02	3
2512	J-973	35.53	40	60.02	2
2514	J-974	37.35	46	60.04	2
2518	J-975	34.31	51	60.02	3
2520	J-976	33	50	60.02	3
2522	J-977	31.99	22	60.02	3
2876	J-1131	46.31	32	61.19	1
2879	J-1132	41.28	43	61.15	2
2881	J-1133	40.27	41	61.14	2
2883	J-1134	42.55	52	61.14	2
2885	J-1135	42.97	35	61.14	2
2887	J-1136	45.86	31	61.15	1
2891	J-1137	41.77	49	61.14	2
2895	J-1138	38.52	28	61.13	2
2898	J-1139	46.37	14	61.85	2
5016	J-1981	31.79	18	61.06	3
5383	J-2112	41.66	40	61.2	2

Table 9.:Zone B pipes data at water cad

ID	Label	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (m³/day)	Velocity (m/s)	Headloss Gradient (m/m)
2462	P-995	62	J-464	J-952	110	PVC	130	61	0.07	0
2464	P-996	46	J-464	J-953	110	PVC	130	118	0.14	0
2466	P-997	37	J-953	J-954	110	PVC	130	57	0.07	0
2468	P-998	48	J-954	J-955	110	PVC	130	30	0.04	0
2471	P-999	151	J-956	J-957	110	PVC	130	7	0.01	0
2472	P-1000	54	J-957	J-954	110	PVC	130	11	0.01	0
2474	P-1001	54	J-953	J-958	110	PVC	130	28	0.03	0
2476	P-1002	47	J-959	J-958	110	PVC	130	54	0.07	0
2479	P-1003	100	J-960	J-464	160	PVC	130	213	0.12	0
2480	P-1004	49	J-960	J-959	110	PVC	130	160	0.2	0.001
2483	P-1005	11	J-456	J-961	160	PVC	130	283	0.16	0
2485	P-1007	35	J-958	J-957	110	PVC	130	42	0.05	0
2487	P-1008	46	J-962	J-456	110	PVC	130	322	0.39	0.002
2491	P-1010	143	J-963	J-962	110	PVC	130	654	0.8	0.007
2493	P-1011	48	J-962	J-964	110	PVC	130	287	0.35	0.002
2495	P-1012	47	J-964	J-965	110	PVC	130	123	0.15	0
2497	P-1013	49	J-965	J-966	110	PVC	130	14	0.02	0
2498	P-1014	96	J-456	J-966	110	PVC	130	22	0.03	0
2501	P-1015	47	J-967	J-968	110	PVC	130	10	0.01	0
2503	P-1016	50	J-968	J-969	110	PVC	130	23	0.03	0
2504	P-1017	62	J-964	J-967	110	PVC	130	122	0.15	0
2505	P-1018	62	J-965	J-968	110	PVC	130	56	0.07	0

2507	P-1019	50	J-967	J-970	110	PVC	130	59	0.07	0
2509	P-1020	97	J-961	J-971	110	PVC	130	105	0.13	0
2511	P-1021	50	J-971	J-972	110	PVC	130	69	0.08	0
2513	P-1022	48	J-973	J-972	110	PVC	130	35	0.04	0
2516	P-1024	50	J-961	J-974	160	PVC	130	221	0.13	0
2517	P-1025	48	J-974	J-973	110	PVC	130	140	0.17	0
2519	P-1026	52	J-973	J-975	110	PVC	130	66	0.08	0
2521	P-1027	48	J-975	J-976	110	PVC	130	14	0.02	0
2523	P-1028	53	J-976	J-977	110	PVC	130	22	0.03	0
2524	P-1029	51	J-972	J-976	110	PVC	130	58	0.07	0
2877	P-1204	47	J-218	J-1131	160	PVC	130	721	0.42	0.001
2880	P-1205	82	J-1131	J-1132	110	PVC	130	156	0.19	0.001
2882	P-1206	203	J-1132	J-1133	110	PVC	130	40	0.05	0
2884	P-1207	37	J-1133	J-1134	110	PVC	130	35	0.04	0
2886	P-1208	63	J-1135	J-1134	110	PVC	130	46	0.06	0
2888	P-1209	48	J-1131	J-1136	160	PVC	130	533	0.31	0.001
2889	P-1210	122	J-1136	J-960	160	PVC	130	410	0.24	0
2890	P-1211	46	J-1136	J-1135	110	PVC	130	92	0.11	0
2892	P-1212	36	J-1135	J-1137	110	PVC	130	11	0.01	0
2893	P-1213	64	J-1137	J-1133	110	PVC	130	36	0.04	0
2894	P-1214	48	J-1132	J-1137	110	PVC	130	74	0.09	0
2896	P-1215	130	J-1134	J-1138	110	PVC	130	28	0.03	0
2899	P-1216	16	Kamal Naser	J-1139	110	PVC	130	1513	1.84	0.034
2900	P-1217	18	J-1139	J-218	110	PVC	130	1499	1.83	0.033
6232	P-3653	9	R-1	Kamal Naser	110	PVC	130	1513	1.84	0.034

6410	P-3749	84	J-959	GPV-1	110	PVC	130	66	0.08	0
6411	P-3750	9	GPV-1	J-961	110	PVC	130	66	0.08	0
6414	P-3751	6	J-974	GPV-2	160	PVC	130	35	0.02	0
6415	P-3752	94	GPV-2	J-455	160	PVC	130	35	0.02	0
2490	P-1009	145	J-963	J-219	203.1	Steel	110	23	0.01	0
5384	P-2496	76	J-218	J-2112	203.1	Steel	110	759	0.27	0.001
5385	P-2497	67	J-2112	J-963	203.1	Steel	110	718	0.26	0.001
6220	P-2971	160	J-956	J-1981	101.5	Steel	110	18	0.03	0
6316	P-3698	131	J-952	J-956	101.5	Steel	110	40	0.06	0

Table 10.:Zone B pump characteristic and operating data

ID	Label	Elevation (m)	Pump Definition	Status (Initial)	Hydraulic Grade (Suction) (m)	Hydraulic Grade (Discharge) (m)	Flow (Total) (m³/day)	Pump Head (m)
2897	Kamal Naser	45.3	PMP18	On	44.99	62.39	1513	17.4

Table 11.:Zone B reservoir data

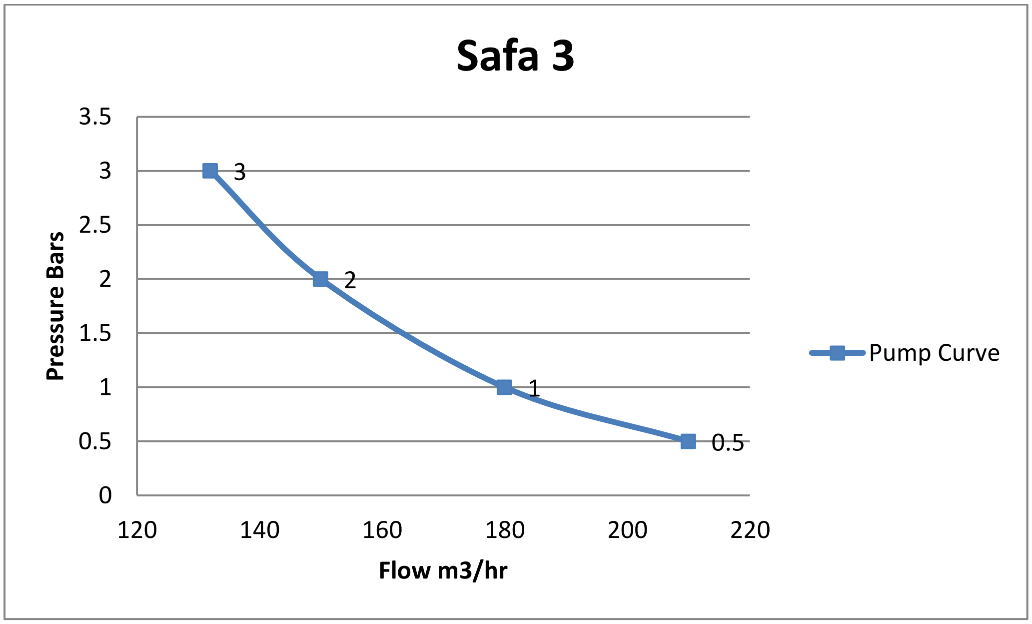
ID	Label	Elevation (m)	Flow (Out net) (m³/day)	Hydraulic Grade (m)
6231	R-1	45.3	1513	45.3

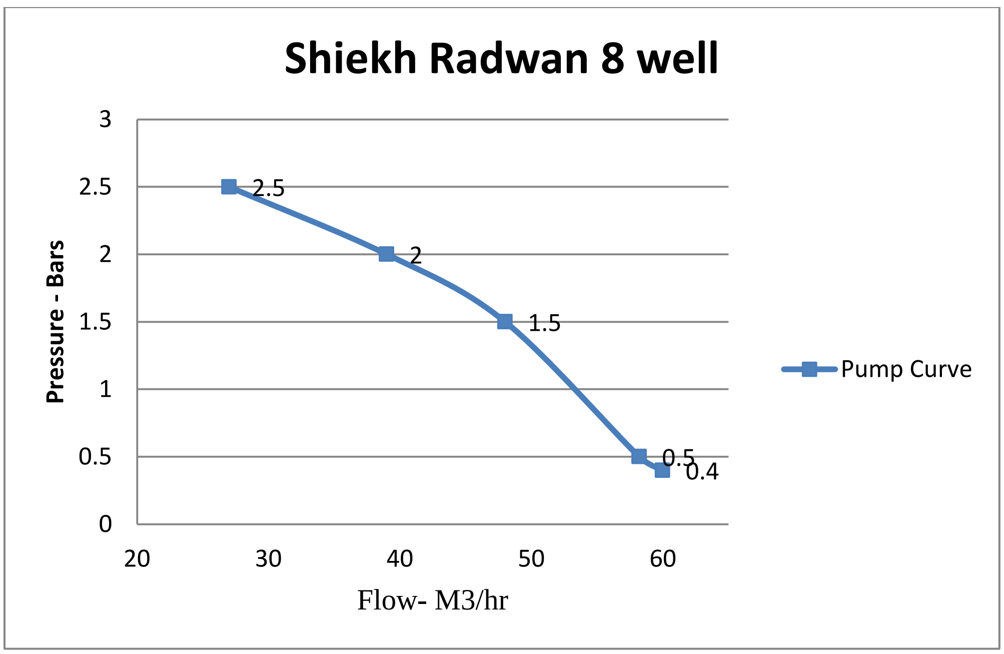
Table 12.:Zone B gate valve data

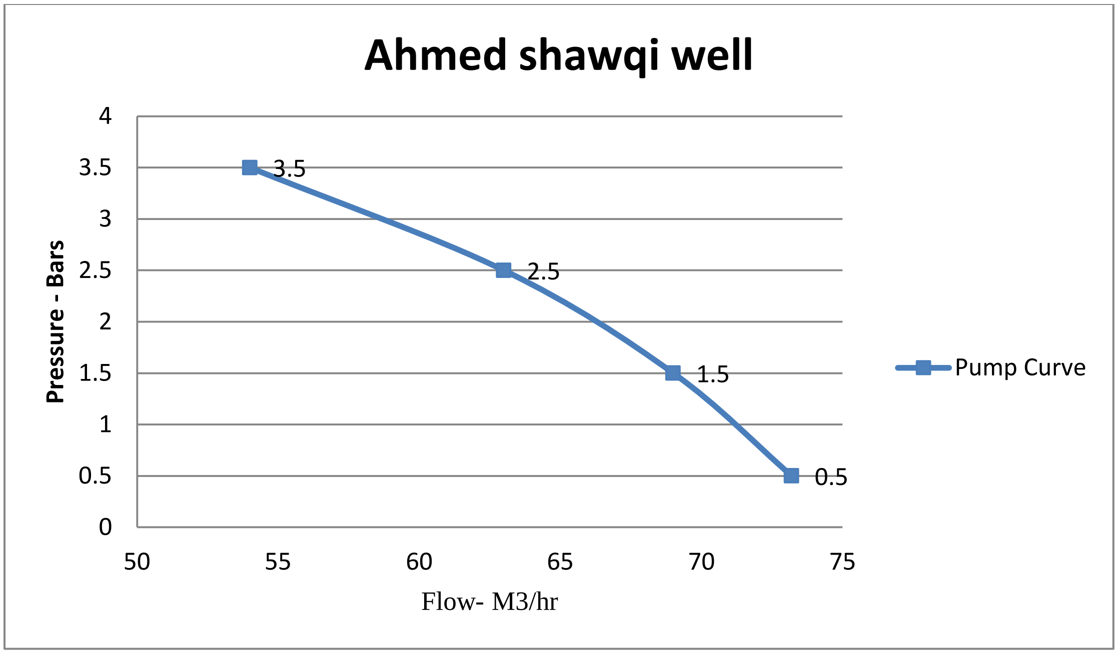
ID	Label	Elevation (m)	Diameter (Valve) (mm)	Flow (m^3/day)	Hydraulic Grade (From) (m)	Hydraulic Grade (To) (m)	Headloss (m)
6409	GPV-1	38.56	110	66	61.05	60.05	1
6413	GPV-2	37.16	160	35	60.04	52.13	7.91

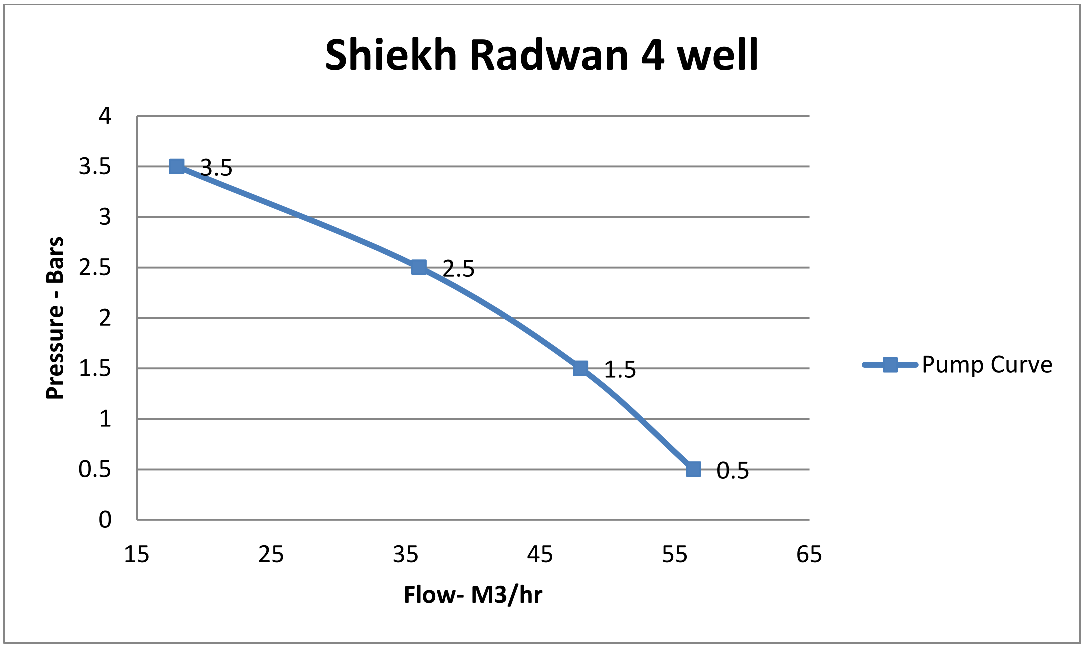
Annex II

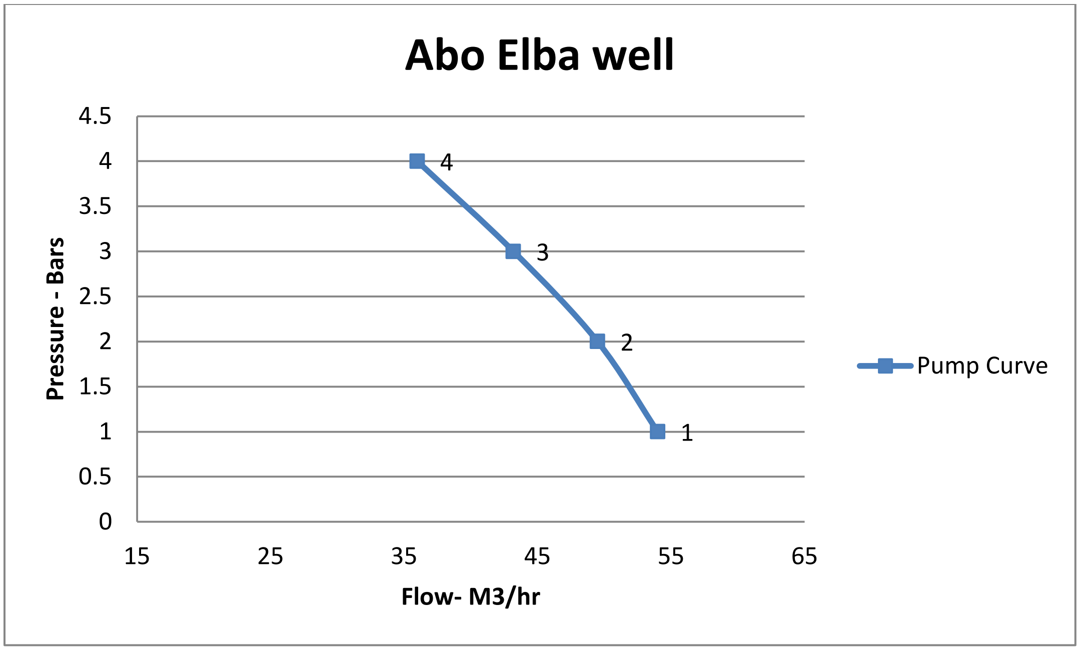
Pump Curves

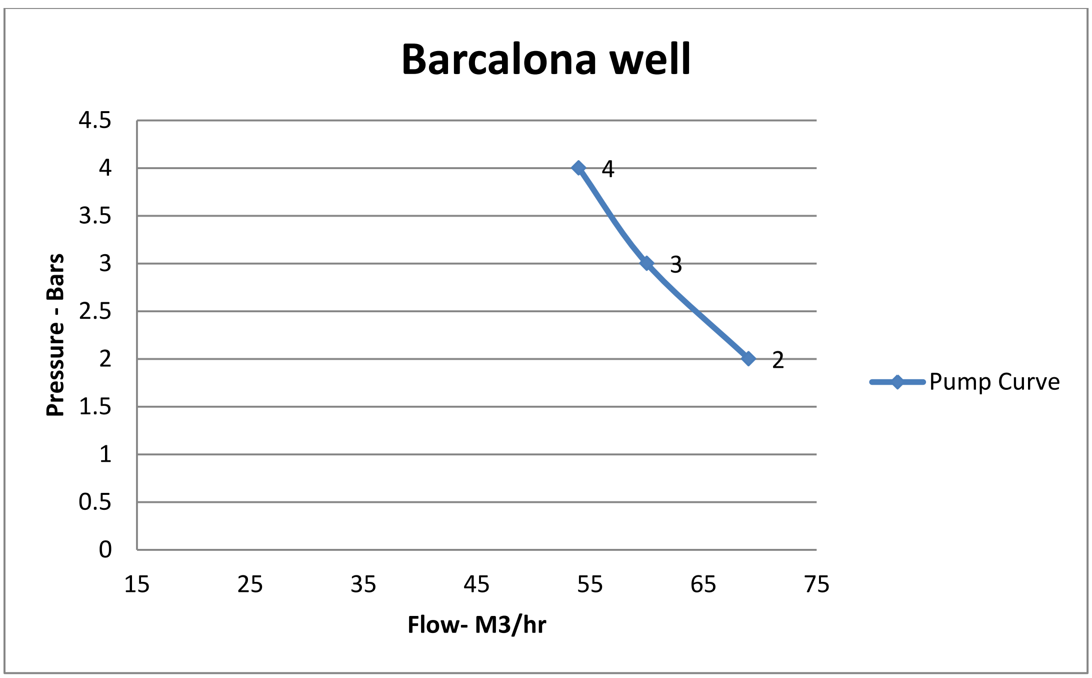

Safa 3
Pressure Bars
3.5
3
2.5
2
1.5
1
0.5
0
120
140
160
180
200
220
Flow m3/hr
3
2
1
0.5
Pump Curve

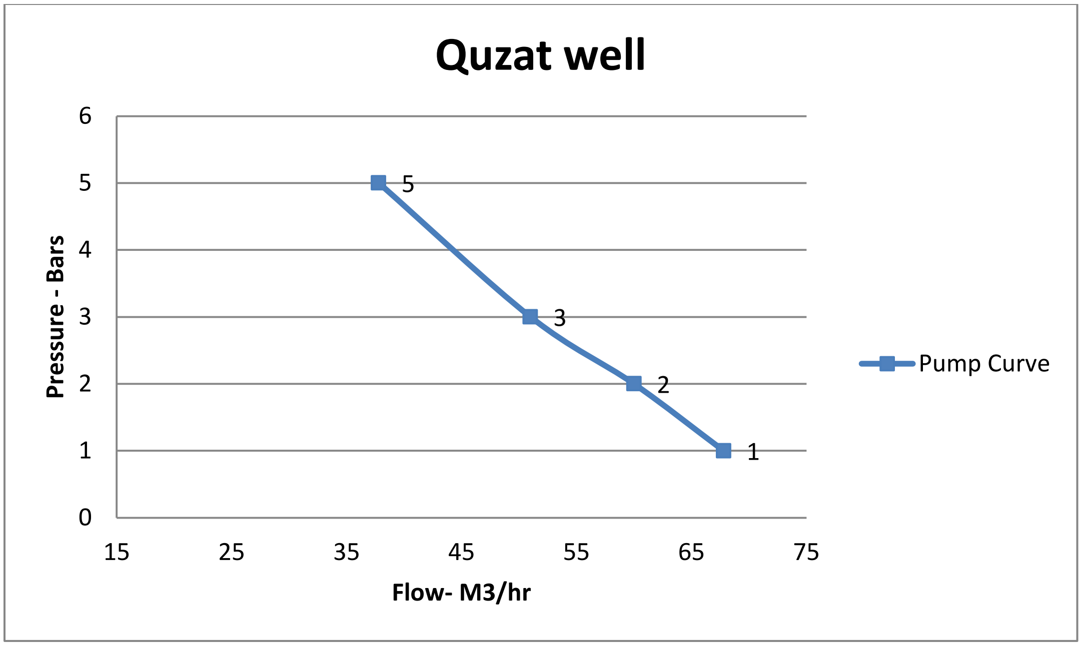

Shiekh Radwan 8 well
Pressure - Bars
3
2.5
2
1.5
1
0.5
0
20
30
40
50
60
Flow- M3/hr
2.5
2
1.5
0.5
0.4
Pump Curve


Ahmed shawqi well
Pressure - Bars
4
3.5
3
2.5
2
1.5
1
0.5
0
50
55
60
65
70
75
Flow- M3/hr
3.5
2.5
1.5
0.5
Pump Curve


Shiekh Radwan 4 well
Pressure - Bars
4
3.5
3
2.5
2
1.5
1
0.5
0
15
25
35
45
55
65
Flow- M3/hr
3.5
2.5
1.5
0.5
Pump Curve


Abo Elba well
Pressure - Bars
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
15
25
35
45
55
65
Flow- M3/hr
4
3
2
1
Pump Curve


Barcalona well
Pressure - Bars
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
15
25
35
45
55
65
75
Flow- M3/hr
4
3
2
Pump Curve


Quzat well
Pressure - Bars
6
5
4
3
2
1
0
15
25
35
45
55
65
75
Flow- M3/hr
5
3
2
1
Pump Curve