BAZOUN WATER DISTRIBUTION SYSTEM

by

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LIST OF ACRONYMS

WDS	Water Distribution System
SWN	Smart Water Network
IWA	International Water Association
AWWA	American Water Works Association
GIS	Geographical Information System
WHO	World Health Organization
ARV	Air-Relief Valve
GV	Gate Valve
PRV	Pressure-Reducing Valves
WO	Washout Valves
SS	Steady State
EPS	Extended Period Simulation
DMA	District Meter Area
SCADA	Supervisory Control and Data Acquisition
AMR	Automated Meter Reading
AMI	Advanced Meter Infrastructure
MNF	Minimum Night Flow

CHAPTER 1. GENERAL INTRODUCTION

1.1.Overview

Water constitutes one of the basic necessities for life. Research has shown that people can go weeks without food, but can't take a couple of days without water. We use water on a daily basis; for drinking, cooking, cleaning, for irrigation, for agriculture and many others, it constitutes the human's basic and most important source of life.

During ancient times, people would have access to potable water from collecting it naturally from streams, rivers, from the ground or from harvesting rain in big containers. Then collected water would be transported in containers such as baskets back to their homes. With time, humans began developing ways to have access to it, to be able to consume it easily and satisfy their needs. They invented systems to transport directly water into their communities and households and to dispose wastewater more conveniently. Over the years, technology has drastically improved and increased and was introduced to the water distributions network. Nowadays, water systems have gotten significant developments and is able to be delivered immediately to the consumers.

By definition, a water distribution system is the part of the water network that has the role of carrying **potable** water from the water source (treatment plants, wells, reservoirs, tanks etc…) to the consumers to satisfy all their need; residential, commercial, industrial and firefighting requirements. According to International Water Association (IWA) "water distribution systems comprise, essentially reservoirs, pipes, pumps and valves. These need to be properly designed and optimized so that they can function adequately, delivering the required water volumes to consumers". The American Water Works Association (AWWA) defines the water distribution system as the system that includes "all water utility components for the distribution of finished or potable water by means of gravity storage feed or pumps through distribution pumping networks to customers, including distribution equalizing storage."

Therefore, WDSs play crucial importance in today's societies to provide potable water to the population. WDSs includes a series of components such as pipes, valves, tanks, pumps etc. that should be properly designed and maintained to be able to transport potable water to the consumers, through all conditions or hazards.

A good WDS should be adequate to provide the following:

- Supply potable water, at required standards given by global, local and federal institutions.
- Deliver water without interruption, to all consumers.
- Supply water to all intended locations with sufficient pressure.
- Satisfy emergency needs such as firefighting purposes.

However, the water sector has been lacking worldwide and water constitutes a major problem in the world. WDSs have become more and more difficult to manage due to urbanization, increase of the population leading to increase in consumer's demand, ageing infrastructure and lack of maintenance due to high operational costs etc.

In Lebanon, WDSs are on the verge of collapse. It is the result of years of under-investment in neglect of the water sector as well as the socio-economic crisis in the country. The outdated infrastructure and the bad maintenance of WDSs in the country, the local population growth these problems lead to drastic consequences such as water cuts throughout the day leaving people with no other choice than to search for potable water from private distributors in order to meet their daily water needs. Not to mention the huge water losses leading to drastic financial costs on the public institutions. An article by UNICEF in 2011 states that *"Lebanon's critical water infrastructure is reaching a breaking point. Unless immediate action is taken, the public water supply networks will collapse and, directly or indirectly, eliminate access to safe water to more than four million people" (UNICEF-supported assessment based on data collected by the country's public Water Establishment, 2021).*

Nowadays, the design of the WDS (Water distribution systems) aim not only to deliver safely potable water, but also to solve water distribution systems management problems such as costs, losses etc. The amount of water lost in the world WDSs goes from 15% to 50% of the overall water produced (Kingdom et al. 2006). Water losses have negative socio-economic impacts, wasting large amount of water instead of being consumed, increasing costs and pressure on governments. as well as environmental damage, as large amount of water is being wasted. Causes of losses is mainly due to leaks in the water supply system.

1.2.Objective of the project

1.2.1. Main objective

Our project revolves around this topic. How can we improve the water network in Lebanon? What can be done to limit water losses in WDSs?

This project aims to design a water distribution system to a region in Lebanon, improving the water supply network, both in quality and quantity.

1.2.2. Specific objectives

The specific objectives of this project are as follow:

- Design a water distribution system that includes the design of all its components; pipes, tank, valve etc., test the system on all scenarios.
- Transform the system into a GIS model which is the system that will be used for capturing, storing and displaying the data of the model.

1.2.3. Software used

The software used during this project are:

- Bentley v8i WaterCAD
- Autodesk AutoCAD
- ArcGIS

1.3.Summary of the Project

This project is divided into 5 main parts.

The first chapter includes a general introduction of the project, with its main objectives.

The second chapter presents a literature review of the project about the details of Water Distribution System and about ArcGIS.

The third chapter presents the study area, details about the with an analysis of the population growth and existing water sources.

The fourth chapter is dedicated for the design and analysis of the WDS.

The fifth chapter talks about the GIS modelling.

The sixth chapter presents a cost estimation of the project.

And finally, chapter 7 consists the General Conclusion.

CHAPTER 2. RELATED LITERATURE REVIEW

2.1. Overview of the Water supply network

A water supply network represents the set of all engineered hydrological and hydraulic components used to provide water supply.

The water supply system should mainly include:

- **Phase 1 - Water abstraction:** which includes the collection of raw water (also called untreated water) from water sources. This water is then transferred to purification facilities through aqueducts, covered tunnels or water pipes.
- **Phase 2 - Water Treatment:** it's the process done on raw water to improve its quality and make it appropriate to use for the consumers. The water is regulated by global, state and federal institutions (World Health Organization (WHO) for example). Water treatment is done before distribution to the consumers and is usually before delivery to reduce the risk of the water getting contaminated again and also reducing pump costs.
  Water treatment mainly consists of 3 phases; the clarification of the water which is separating all heavy particles from the water stream (dirt, etc.). filtrating the water to removed dissolved particles and disinfecting the water to kill all bacteria and viruses and protect it from contamination again.
- **Phase 3 - Water distribution:** once the water meets the standards and regulations required for consumption it's called potable water.
  This potable water will be transported and distributed to the consumers through a design network of pipes, pumps, valves etc. (to the consumers directly or to a reservoir that feeds the consumers).
- **Phase 4 - Wastewater treatment:** once the used water leaves the consumers, it becomes wastewater. Wastewater treatment is the process to collect and treat used water to remove all contaminants and convert it into water that can be discharged or reintroduced to the water cycle. The treatment process takes place in a wastewater treatment plant.

Our project will focus on the third phase of the water supply network, which is the design of the water distribution system.

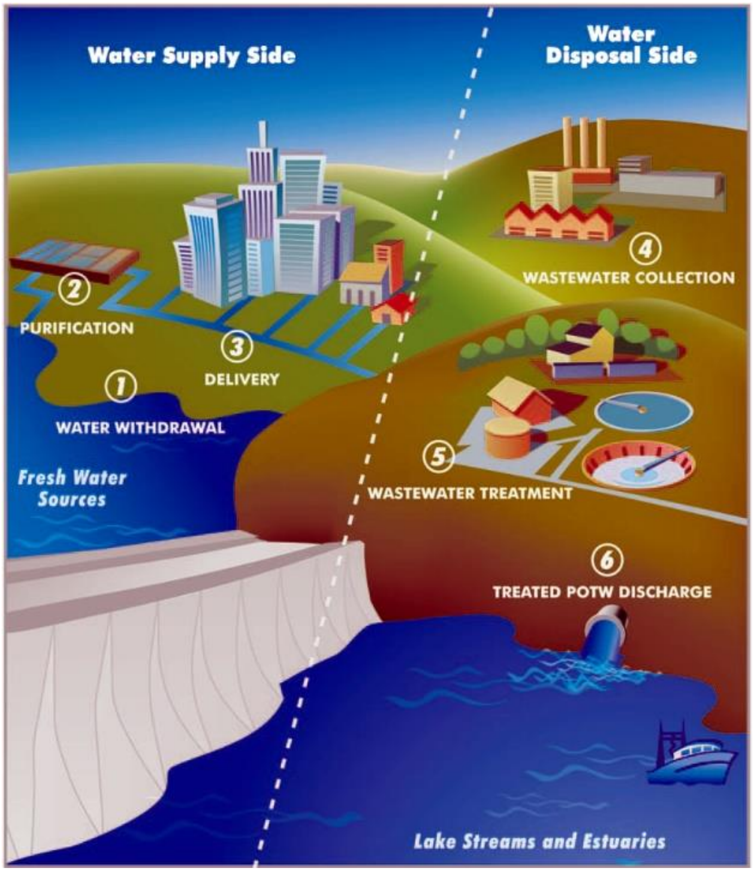

Figure 2.1 Water Supply Phases

2.2. Sources of water

Water can be withdrawn from multiples types of bodies of water in order to provide water to the network. Water sources include:

- Surface waters (lakes, rivers, etc.);
- Ground water (underground aquifer, water well etc.);
- Recycled wastewater.

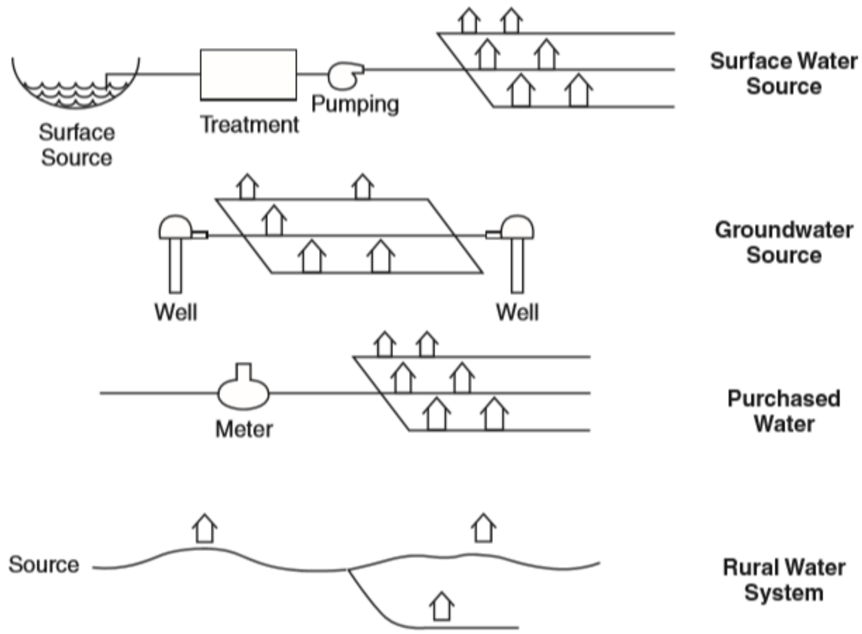

Figure 2.2 Type of Water Sources

2.3. Water distribution systems

2.3.1. Types of distribution systems

- **Gravity supply:** when the source of supply is at an elevation high enough that water can be distributed at required pressure to the consumers though gravity only. It is considered a cost-effective system as no need to supply energy to system to increase the pressure of the water from the source.

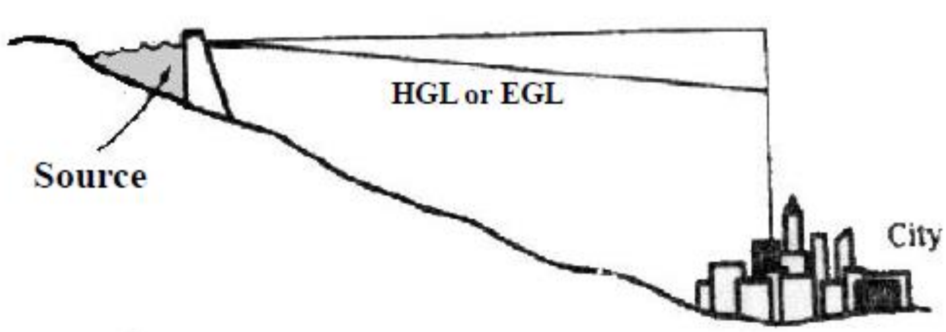

Figure 2.3 Gravity Supply System

- **Pumping supply:** Usually used when the source of supply is at a lower elevation than the distribution area or when the pressure is less than the required standards. The water is supplied using that gives the pressure required for the water to flow. This system is not commonly used as the pump is used 24/24, energy costs are high and the system requires constant maintenance.

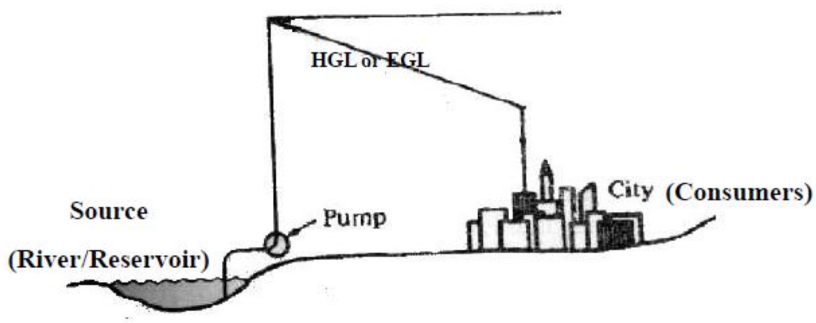

Figure 2.4 Pumping Supply System

- **Combined supply:** It is the most common system. Water is delivered by both pumping and gravity methods. This method allows water to be distributed at required parameters and be economical as the pump is used only during necessity. Some examples of the combined system are: Case 1: where 2 sources of water are supplied to the distribution area, each at different elevations; Case 2 where we install an elevated tank to supply water by gravity

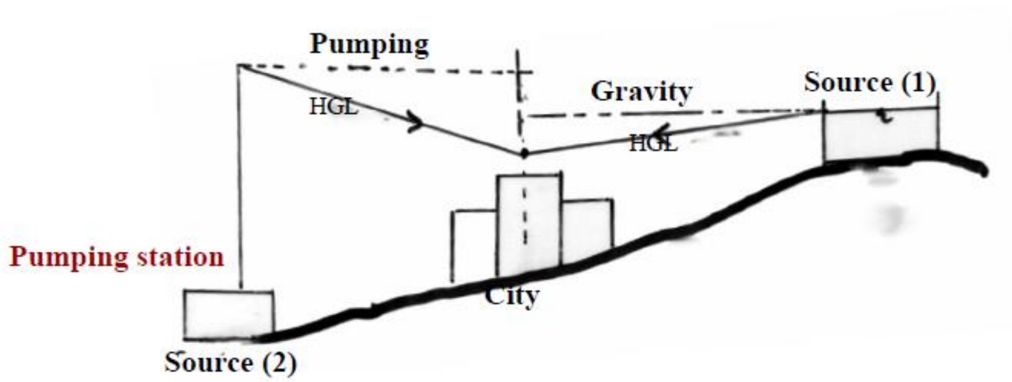

Figure 2.5 Combined System Example 1

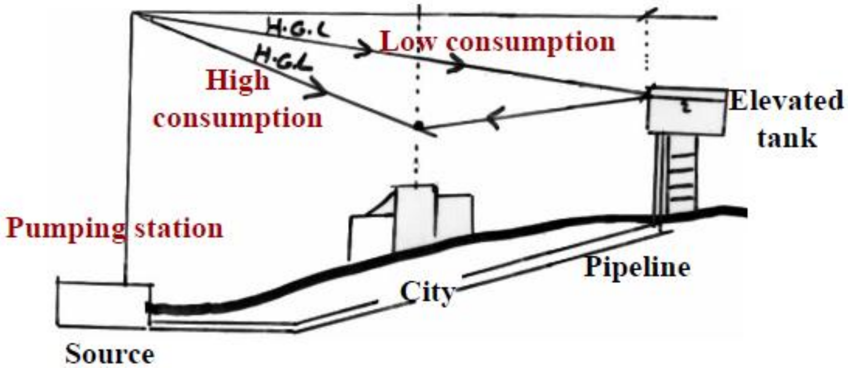

Figure 2.6 Combined System Example 2

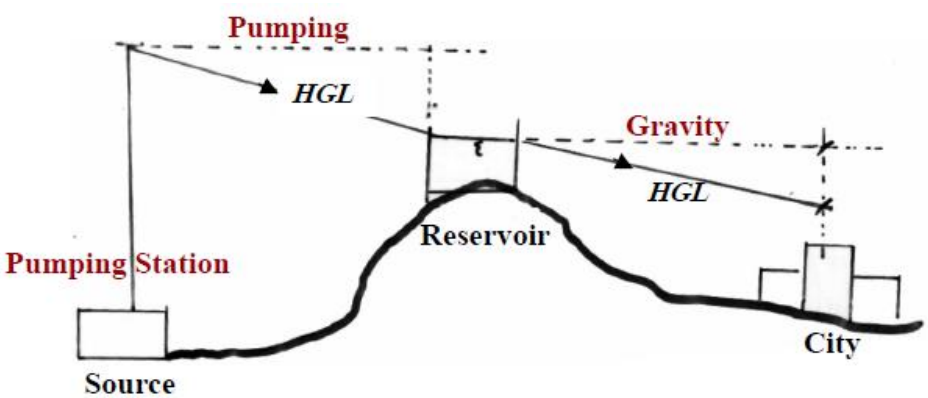

Figure 2.7 Combined System Example 3

2.3.2. Network configurations

- **Branched system:** It is a cost-effective system, where the main pipeline is divided into sub-main pipelines that are further divided into branches to deliver water to the households. Although being simple and economical, it is not usually favored nowadays due to its disadvantages; low pressure causing limitations for firefighting use, in case of damage the area can't receive water until repair, high head loss etc.

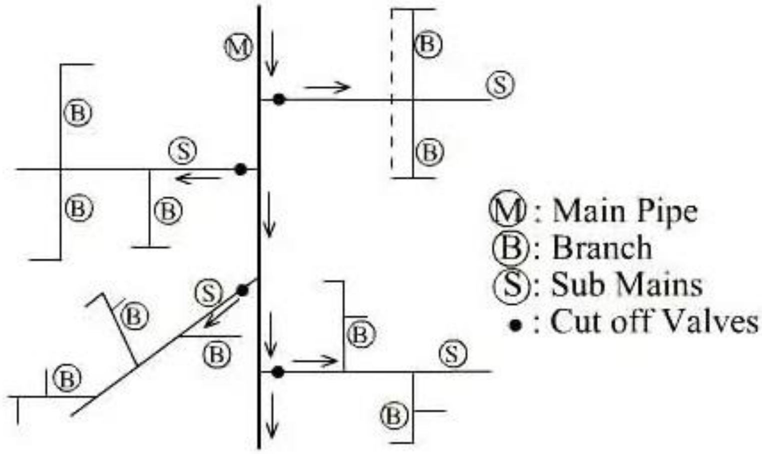

Figure 2.8 Branched Systems

- **Looped System:** The main pipeline, sub-main pipeline and branch pipelines are interconnected into loops so that water can move in the entire system. Then even with breaks, water can still be delivered through another loop. Although the need of more pipe lengths for laying (resulting in additional costs), this method delivers water with no disrupting even during maintenance and repair work.

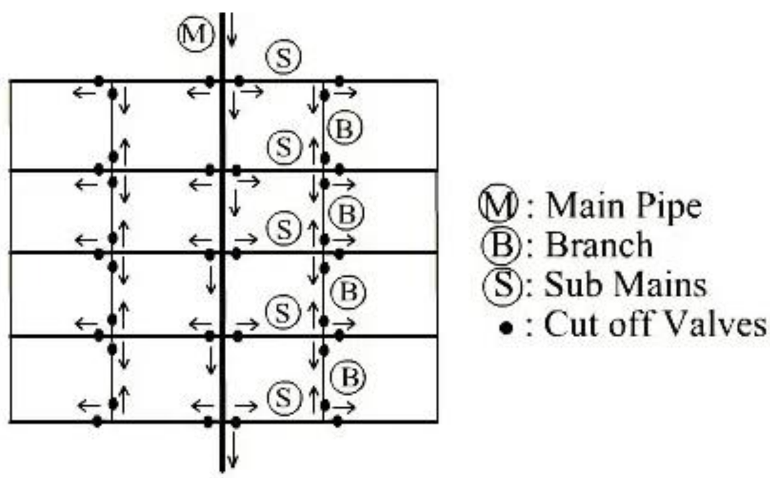

Figure 2.9 Looped Systems

- **Combined System:** Widely used worldwide, the whole system is a combination of both the looped and branched systems as the main pipes are looped and the smaller pipes branch off the main pipes into the households.

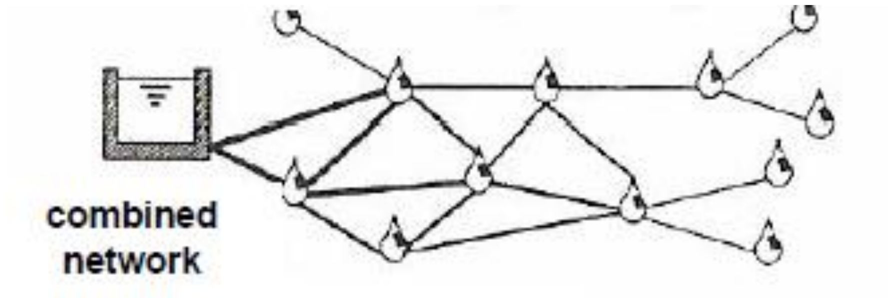

Figure 2.10 Combined Systems

2.3.3. Water supply types

Water is supplied in the system through 2 types:

- **Continuous System:** Where the water is available and supplied 24/7. It is used when there is sufficient quantity of water available from the source. It prevents negative pressure to occur in the system, water is always available for firefighting.
- **Intermittent System:** Where water is delivered to the consumers only during certain hours of the day. this system is applied when the available water is not enough coming from the source. It is not preferable to opt for this type as it leaves the consumers to have to store water for the non-supply hours.

2.4. Pipes

Most water distribution systems include of pipes and couplings that are linked through different configurations. Pipes in WDSs can differ in type, material used, jointing materials etc., depending on the requirements and need in the system.

2.4.1. Types of pipes

Pipes can be classified according to their diameter and function in the system:

- **Arterial or Main pipes:** The pipes that distribute water from the tank/water treatment plant to the different part of the system. They are usually large in diameter (350 mm/12 in or more).
- **Secondary pipes:** Smaller in diameter (250 mm to 300 mm) linked to the main pipes, deliver water from the main to the smaller pipes.
- **Local pipes/small distribution mains:** Usually 150 mm diameter, those pipes supply water from the bigger pipes to the consumers.

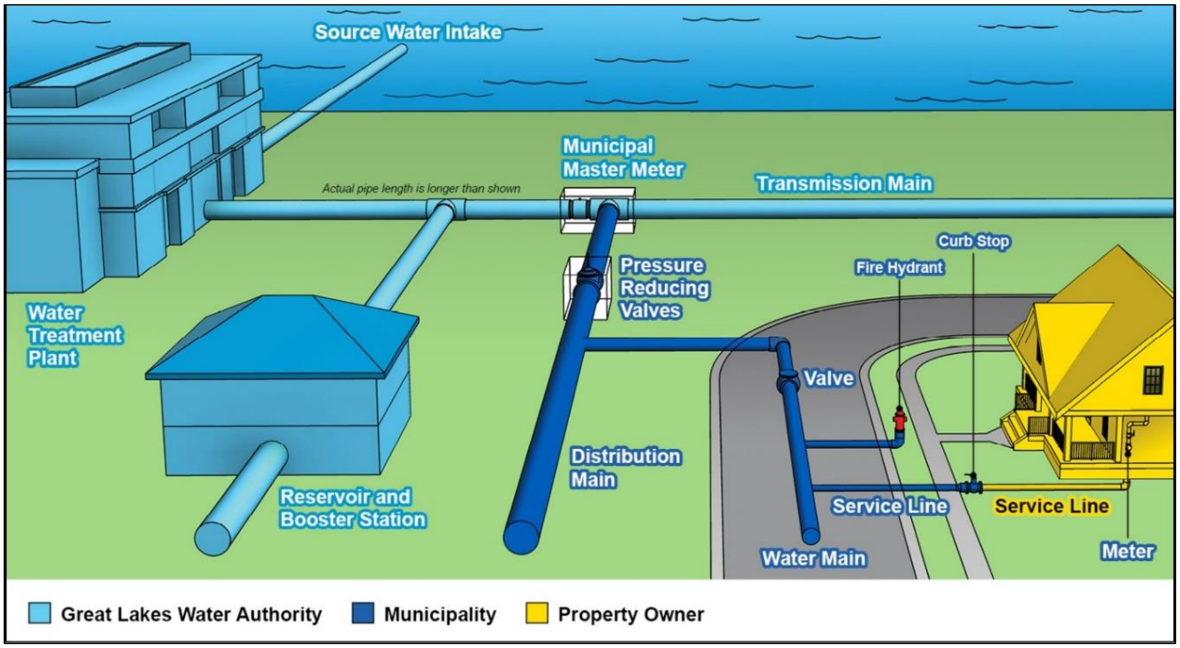

Figure 2.11 Types of pipes in a WDS

2.4.2. Types of pipe material

- **Cast Iron Pipes (CIP):** One of the oldest types of material used in the WDSs. They are still found in old WDSs. Cast iron pipes have the advantages to resist corrosion, are stable, heart resistant and durable and therefore resist high water pressure. However, they are heavy in weight and are quite expensive to install.
- **Ductile Iron Pipes (DIP):** Replaced CIP and are commonly used nowadays. DIP resembles CIP in many characteristics. The difference between both is that DIP is formed by injecting magnesium into the molten cast iron resulting in a change in carbon structure. DIP can handle high water pressure and heat although they are heavy too and expensive. They are of high strength and resist corrosion better than CIP. Bituminous external coatings and polyethylene wraps are commonly used to reduce external corrosion.
- **Steel pipes:** Usually used in large size water works where there is high pressure or pipes of large-diameter/long-distance. Steel pipe resist high pressure, are high strength and can resist shock loads. But they are susceptible to corrosion thus require a protective coating such as hot-dipped galvanizing, epoxy, bitumen etc.

- **Asbestos Cement (AC):** AC pipes were commonly used from the 60s to the 90s. however, they are not used anymore from fears for health risks due to asbestos, and also after the introduction of other more modern types of materials.
- **Polyvinyl Chloride (PVC):** The most commonly used pipe in the WDSs, especially used for small diameter water pipes. It is made of unplasticized polyvinyl chloride. It has the advantage of being lightweight, easy to install, with a very smooth interior and are generally lower cost. It is virtually corrosion-free. However, any damage of the soil, presence of gasoline, fuel or other organic compounds may damage the pipe wall.
- **Concrete pipes:** Concrete pipes are used mainly for large diameter lines. They provide a high tensile strength from the steel and high compressive strength from concrete. They usually range between 10 to 20 in. and can be found in multiple type: prestressed concrete pipes, reinforced concrete pipes and bar wrapped concrete pipes.
- **High density polyethylene pipes (HDPE):** This type of pipe id formed from a heat extrusion process of the polyethylene resins. They are used in main and services lines.

	Common Sizes—Diameter		Normal Maximum Working Pressure			
Material	*in.*	*(mm)*	*psi*	*(kPa)*	Advantages	Disadvantages
Ductile iron	3–64	(76–1,625)	350	(2,413)	Durable, strong, high flexural strength, good corrosion resistance, lighter weight than cast iron, greater carrying capacity for same external diameter, easily tapped	Subject to general corrosion if installed unprotected in a corrosive environment
Concrete (reinforced)	12–168	(305–4,267)	250	(1,724)	Durable with low maintenance, good corrosion resistance, good flow characteristics, O-ring joints are easy to install, high external load capacity, minimal bedding and backfill requirements	Requires heavy lifting equipment for installation, may require special external protection in high-chloride soils
Concrete (prestressed)	16–144	(406–3,658)	350	(2,413)	Same as for reinforced concrete	Same as for reinforced concrete
Steel	4–120	(100–3,048)	High		Lightweight, easy to install, high tensile strength, low cost, good hydraulically when lined, adapted to locations where some movement may occur	Subject to general corrosion if installed unprotected in a corrosive environment; poor corrosion resistance unless properly lined, coated, and wrapped
Polyvinyl chloride	4–36	(100–914)	200	(1,379)	Lightweight, easy to install, excellent resistance to corrosion, good flow characteristics, high tensile strength and impact strength	Difficult to locate underground so tracer tape can be used, requires special care during tapping, susceptible to damage during handling, requires special care in bedding
High-density Polyethylene	4-63	(100-6000)	250	(1750)	Lightweight, very durable, very smooth, liners and wrapping not required, can use ductile-iron fittings	Relatively new product, thermal butt-fusion joints, requires higher laborer skill

Figure 2.12 Comparison of pipeline materials (Source: Water Transmission and Distribution, American Water Works Association (AWWA))

2.4.3. Selections of pipe

While selecting the type of pipes to be used in a WDS, many considerations should be taken into account:

- State and Local regulations for the WDS design;
- The existing conditions of the area such as: local soil conditions, type of climate and weather conditions, earthquake activity, type of existing pipes etc.
- Whether the pipes are exposed to the sunlight, to the weather, to fire etc.

2.5. Valves

Valves are the components in water distribution system that helps better control the system overall. It is done by opening, partially or fully closing the pipes. We find in the system numerous types of valves, each with its unique function and should be used accordingly in the system. The designs of various types of valves are covered in several American Water Works Association (AWWA) standards.

Water utility valves are designed to perform several different functions. The principal uses are to

Valves are designed to perform several functions such as:

- Control the flow
- Prevent backflow
- Isolate the pipes
- Regulate the pressure and throttle flow
- Relieve pressure

2.5.1. Types of valves by their functions

2.5.1.1. Isolation Valves

Isolation valves are installed in WDS to be able to shut off a certain section of the system during repair or maintenance.

- **Hydrant auxiliary valves:** Isolation valves installed near fire hydrants to allow shutting down the flow leading to the fire hydrants without interrupting the flow to the customers.
- **Pump control valves:** Valves installed before and after pumps to prevent the water flowing back to the pump when it's not working or during maintenance/repair process.

- **Water service valves:** Valves located at water mains used when needed (during maintenance or repair), they can shut off the flow coming to a building or shutting off a certain section of the system.

2.5.1.2. Regulating pressure and throttling flow valves

- **Pressure-reducing valves (PRV):** Pressure in the system should be within an adequate range. Then at high-pressure zones in the WDS, PRVs can be installed at specific points to reduce the pressure downstream avoiding excessive pressure in the system. They protect the WDS from damage due to high pressure and maintain minimum and maximum values of pressure for the consumer.

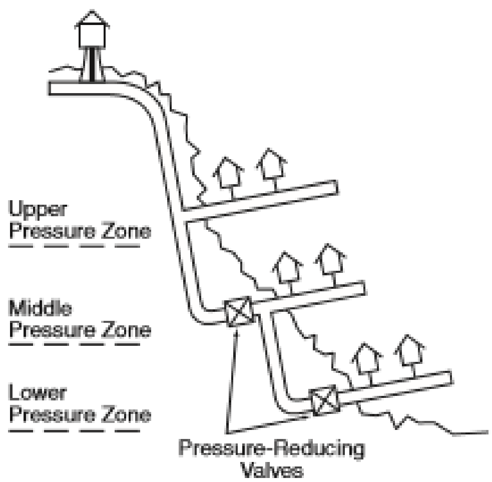

Figure 2.13 PRV installed in a system to reduce pressure

- **Altitude valves:** Valves used to fill ground-level reservoir or elevated tanks that are not high enough. They help filling it at a regulated flow and stop it when full, preventing overflowing.

2.5.1.3. Valves for relieving pressure

Special valves are necessary to protect water systems and plumbing from excessive pressure. They are designed to remain tightly shut under normal pressure but will open when excessive pressure occurs.

- **Pressure-relief valves:** Those valves are used to prevent water hammer. Water hammer is created when there is a rapid increase in pressure in the WDS, damaging the valves and pipes. Those valves release some of the energy created by water hammer.

Figure 2.14 Pressure relief valves (Watts Regulator Co.)

- **Air-relief valves (ARV):** Air-valves are located at high points in transmission pipelines. They relieve air that accumulates as air pockets in the pipes reduce the area of flow of the water in the pipes. This reduction will result in increased pumping costs and restricted flow to parts of the system.
- **Wash out valves:** Washout valves are installed in water main (usually at low points in the system), and used during maintenance works.

2.5.2. Types of valves by their configurations

Valves can be classified based on their configurations:

- **Gate valves:** The gate, or disk, of the valve is raised and lowered by a screw, which is operated by a handwheel or valve key.
- **Globe valves:** the valves have a circular disk that moves downward into the valve port to shut off flow.
- **Needle valves:** Needle valves are similar to globe valves except that a tapered metal shaft fits into a metal seat when the valve is closed.
- **Pressure-relief valves:** Pressure-relief valves are similar to globe valves, but their disks are normally maintained against the seat by a spring.

- **Air-and-vacuum relief valves:** air-and-vacuum relief valves consist of a float-operated valve that will allow air to escape as long as the float is down.
- **Diaphragm valves;**
- **Pinch Valves:** Pinch valves are closed by pinching shut a flexible interior liner.
- **Rotary valves:** The two principal types of rotary valves used in water systems are plug valves and ball valves.
- **Butterfly valves:** Butterfly valves consist of a body in which a disk rotates on a shaft to open or close the valve.
- **Check valves:** Check valves are designed to allow flow in only one direction.

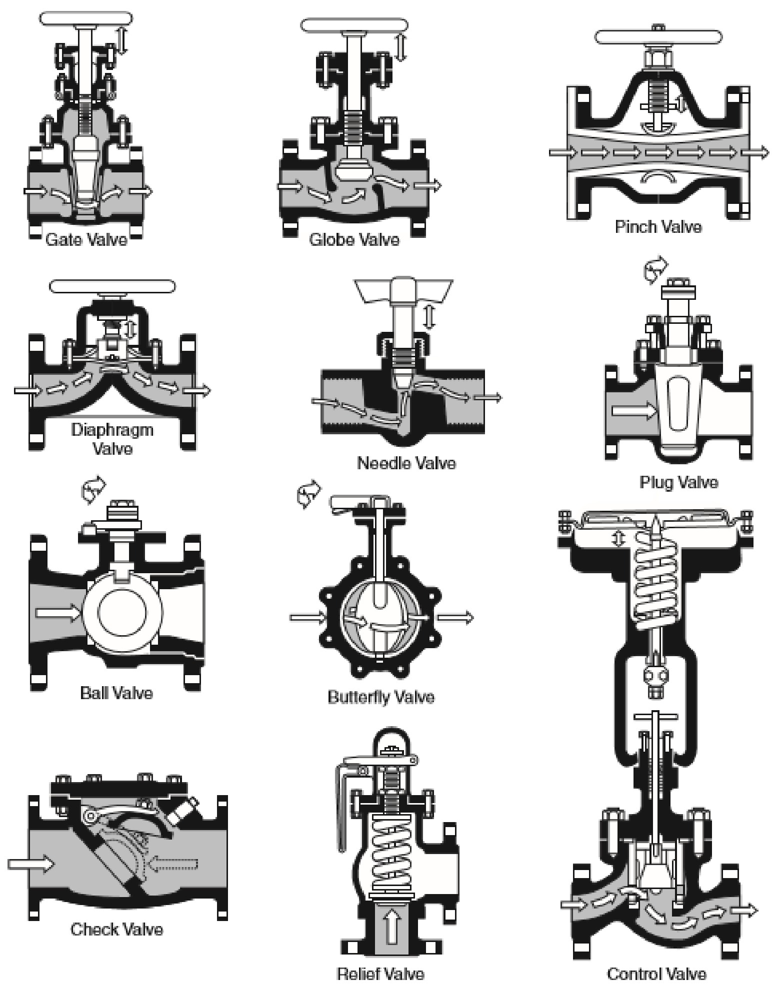

Figure 2.15 Different Configurations for valves

2.6. Fire Hydrants

A fire hydrant is the component of the WDS responsible of public fire protection in a municipal area. It is the outlet equipped with a valve that provides water to the fire pumps/jeeps engaged in firefighting. Hydrants should be located at an adequate distance to the buildings, allowing fire fighters to access it but not too close in case a building was to collapse during a fire. Also located at an adequate distance to the road, close to intersection to allow using it in multiple directions.

2.6.1. Types of Fire Hydrants

- **Dry-Barrel Hydrants:** Equipped with a valve and a drain, this hydrant fills with water only when the main valve is open. Then the hydrant is broken, no flow passes form the dry-barrel hydrant.

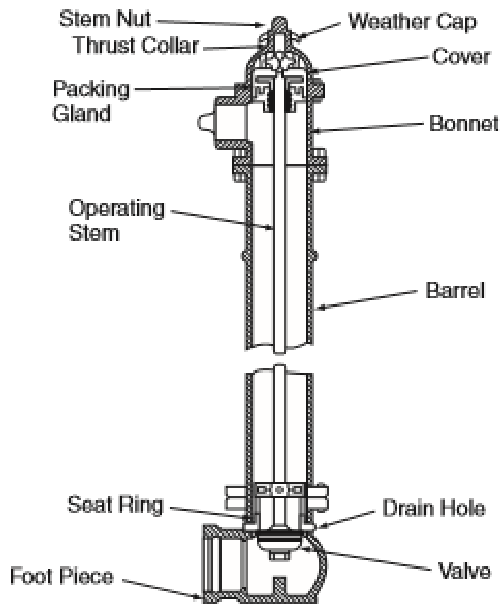

Figure 2.16 Dry-Barrel Hydrant

- **Wet barrel hydrants:** this hydrant is completely filled with water all the time. It has no main valve and water might flow if the hydrant is broken until repairing.

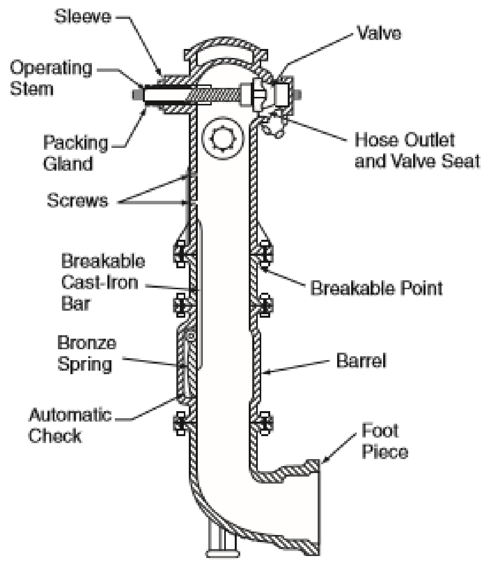

Figure 2.17 Wet-Barrel Hydrant

2.7. Water Storage

Treated water should be stored until distributed to the customers. Water storage in WDS is essential for multiple purposes such as equalizing demand and supply, providing fire demands.

2.7.1. Configuration of Water Storage

- **Elevated tanks:** Water tanks supported by a steel/concrete tower. They use the force of gravity to supply water to the distribution area providing water at sufficient pressure.

Figure 2.18 Elevated Tank

- **Standpipes:** water tank that rests on the ground with a height that is greater than its diameter. Standpipes have the ability to store a large quantity of water. However, a relatively large amount of water must regularly circulate through the tank to keep the water fresh and to prevent freezing.

Figure 2.19 Standpipes

- **Reservoirs:** The term reservoir can mean multiple things in the water supply field. For raw water, reservoirs refer to the ponds, lakes, or basins. They can also refer to a large aboveground or underground storage facility. If a reservoir is located at a high elevation comparing to the distribution area, then most of the water can be delivered to the system without the need for pumping.

Figure 2.20 Reservoirs

- **Hydropneumatics Systems:** this type of water storage is used usually for small water system. This hydropneumatics pressure tank will often provide adequate continuity of service for domestic use. It consists of a steel pressure tank, kept partially filled with water and partially filled with compressed air. The compressed air maintains water pressure when use exceeds the pump capacity.

Figure 2.21 Hydropneumatics Systems

2.7.2. Type of material in water tanks

Multiple types of materials can be used in the construction of the water tanks:

- Steel tanks;
- Concrete tanks;
- Wood tanks;

2.8. Pumps and pumping stations

Pumping facilities are required wherever gravity cannot be used to supply water to the distribution system under sufficient pressure to meet all service demands. Pumps are used to add energy to the system. When used, pumping accounts for most of the energy consumed in water supply operations.

Pumps are divided into 2 main categories: Velocity pumps (which includes vertical turbine pumps and Centrifugal pumps) and Positive-displacement pumps (mostly used in water treatment plants).

2.8.1. Centrifugal pumps

From all types of pumps, the centrifugal pump is the most used in the Water Distribution System. They're the devices used to transport water by converting the rotational kinetic energy to hydraulic energy transmitted to the water, resulting in an increase in velocity and pressure.

Water enters the pump axially while the impeller is rotating, transferring mechanical energy to the fluid (in the form of kinetic energy). The fluid exists radially the pump with its velocity increased and enters the volute where its cross-sectional area gradually increases. Based on the Bernoulli's principle, the kinetic energy is converted to pressure.

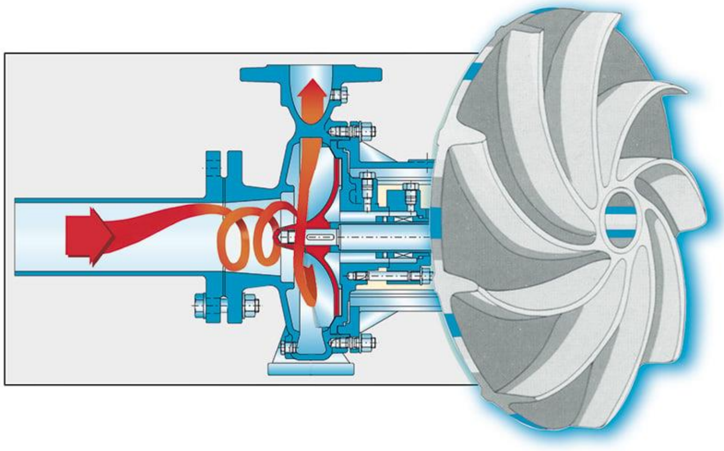

Figure 2.22 Centrifugal Pump

2.9. Water distribution system design

2.9.1. Overview

A proper design of the WDS is essential. The system should be built with the purpose to satisfy the consumers' demand while meeting minimum standards of pressure at nodes and of velocity in pipes. Other than that, a distribution system design should be done while also taking into account the least-cost solutions while still meeting the requirements. The design of the water distribution system passes by multiple phases; the preliminary studies, the network layout and the hydraulic analysis.

2.9.2. Design criteria

2.9.2.1. Flow rate

Defined as the volume of fluid that passes a point in the system per second

$$Q = \frac{V}{t} \text{ or } Q = v \times A$$

Where,

- V: the volume (m^3)
- T: is the time (s)
- v: the velocity (m/s)
- A: the cross-section area of the pipe (m^2)

2.9.2.2. Energy Conservation in the System

Calculations in the system are based on the Bernoulli equation representing the continuity of energy:

$$\frac{p}{\rho g}+\frac{v^2}{2g}+z+H_{Losses}=\frac{p'}{\rho g}+\frac{v'^2}{2g}+z'$$

Where,

- p and p': pressure at initial and final point (N/m^2)
- v and v': velocity at initial and final point (m/s)
- z and z' height above datum at initial and final point (m)
- ρ: density of water (kg/m^3)
- g: gravitational acceleration (m/s^2)

2.9.2.3. Pressure

Delivering water at an adequate pressure is one of the most important conditions while designing a water system.

For residential/commercial districts, the pressure is to range around hypothetically: 2 bars - 6 bars.

2.9.2.4. Velocity

a) Calculation of the velocity in the pipes.

Using Hazen-Williams equation:

$$V=0.849\ C_{HW}R_h^{0.63}S_0^{0.54}$$

Where,

- V: velocity of water flow in pipes (m/s).
- C_{HW}: roughness coefficient, depends on the type of material of the pipelines.
- R_h: hydraulic radius of the pipe (which is the flow section area/the wetted perimeter) (for circular pipes flowing full R_h = d/4).
- S_o: slope of the energy grade line, corresponding to the energy loss due to friction per unit of pipe length (= H_L / L).

b) A minimum velocity of 0.6 m/s should be generally maintained in the system. Values might differ depending on the pipe diameter and might range from 0.6 to 3 m/s.

2.9.2.5. Calculation of Energy Losses

Distribution systems don't deliver water at 100% efficiency. There are losses in the system due to conditions related to the pipelines type, age, materials and to the type of components in the system. Losses are in order of 20% of average total consumption and therefore should be taken into account during calculations.

We know:

$$H_{Losses} = H_{major} + H_{minor}$$

Major head losses are due to the friction in pipes. The Head losses (major Losses) can be calculated using multiple equations. On WaterCAD Software, we can choose one of those methods to analyze the system. Two of the most important equations are:

- Hazen-Williams
- Darcy-Weisbach

Darcy-Weisbach Equation:

$$H_L = f\frac{L}{D}\frac{V^2}{2g}$$

Where,

- H_L: head loss (m)
- f: friction coefficient
- L: pipe length (m)
- D: diameter of pipe (m)
- V: velocity of the flow (m/s)
- g: gravitational acceleration (m/s^2)

The coefficient of friction should be calculated depending on the type of flow:

- for laminar flow (Re<2300): $f = \frac{64}{Re}$

- for turbulent flow (Re>4000): using Moody chart where f = function (Re;ε)

Calculation of Reynolds Number Re:

$$Re = \frac{\rho V D}{\mu}$$

Where,

- ρ: density of the fluid (kg/m^3).
- V: average velocity (m/s).
- D: Diameter (m).
- μ: dynamic viscosity of the fluid ($N.s/m^2$).

	Equivalent Roughness, *e*	
Pipe	**Feet**	**Millimeters**
Riveted Steel	0.003 – 0.03	0.9 – 9.0
Concrete	0.001 – 0.01	0.3 – 3.0
Wood stave	0.0006 – 0.003	0.18 – 0.9
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Commercial steel or wrought iron	0.00015	0.045
Drawn tubing	0.000005	0.0015
Plastic, glass	0.0 (smooth)	0.0 (smooth)

Figure 2.23 Equivalent Roughness coefficient (Moody and Colebrook)

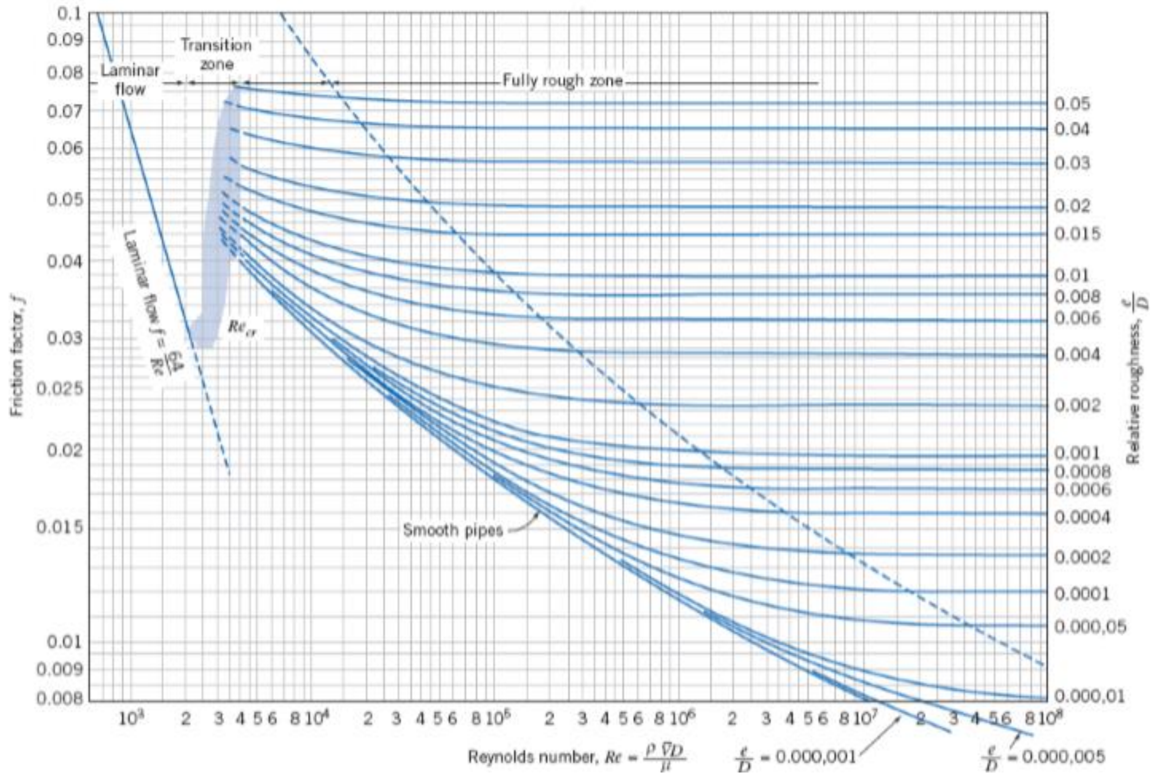

Figure 2.24 Moody chart

Hazen-Williams Equations:

Using Hazen Williams equation, we calculate the head loss:

$$HL = \frac{10.65L}{C_{HW}^{1.85} D^{4.87}} Q^{1.85}$$

Where,

- HL: head loss (m)
- Q: Flow rate (m/s)
- C_{HW}: roughness Coefficient
- L: Pipe Length (m)
- D: Diameter of pipe (m)

Materials	C_{HW}
Pipes	
Asbestos cement	140 – 150
Brick	100
Clay	110
Concrete, rough	100
Concrete, smooth	130
Copper and brass	130 – 140
Ductile iron, new	130
Ductile iron, old (55-75 years)	55 – 75
Ductile iron, very corroded	80
Ductile iron, + inside mortar cement coating	140
Glass, smooth (old)	150 (135)
Lead	130 – 140
Neoprene (fire hose)	150
Rubber hose	135
Steel, corrugated	60
Steel, galvanized, new (old)	120 – 130 (90)
Steel, riveted, new (old)	110 (80)
Steel, very corroded	80
Steel, welded, new	130 – 140
Thermoplastics, smooth (old)	150 (135)
Wood	120

Figure 2.25 Hazen-Williams roughness Coefficient for pipes

The minor losses are due to the fitted components in the system such as bends, valves, changes in area etc.

Minor losses are calculated as follow:

$$H_{minor} = \frac{K_L v^2}{2g}$$

Where,

- K_L: is the loss coefficient for pipe components.
- V: average velocity (m/s).
- g: gravitational acceleration (m/s^2)

Loss Coefficients for Pipe Components

Component	K_L
a. Elbows	
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
Long radius 90°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 45°, flanged	0.2
Regular 45°, threaded	0.4
b. 180° return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5
c. Tees	
Line flow, flanged	0.2
Line flow, threaded	0.9
Branch flow, flanged	1.0
Branch flow, threaded	2.0
d. Union, threaded	0.08

Component	K_L
e. Valves	
Globe, fully open	10
Angle, fully open	2
Gate, fully open	0.15
Gate, $\frac{1}{4}$ closed	0.26
Gate, $\frac{1}{2}$ closed	2.1
Gate, $\frac{3}{4}$ closed	17
Swing check, forward flow	2
Swing check, backward flow	∞
Ball valve, fully open	0.05
Ball valve, $\frac{1}{3}$ closed	5.5
Ball valve, $\frac{2}{3}$ closed	210

Figure 2.26 Loss Coefficients for WDS components

2.9.3. Water demand

By definition, Water demand is the water that is treated and delivered to residential, commercial, industrial and public institutions via water system network. It is defined as the "total volume of water necessary or needed to supply customers within a certain period of time" (Billings and Jones et al. 2008). Water demand can be calculated hourly, daily or monthly.

2.9.3.1. Types of water demand

The best solution to obtain a realistic calculation of the water demand is to define each type:

- **Residential Water Demand:** it includes the water demand required by residential consumers, mainly used for indoor and outdoor use such as drinking, washing, laundering, cooking and other household operations. The average residential water demand differs from population to another, as well as the size of the household.

- **Industrial or Commercial Water Demand**: that includes water used in industries such as offices, hotels, stores, restaurants, manufacturing facilities etc.
- **Agricultural Water Demand:** The Water used for irrigation/treatment of soil. This type is significant especially in rural area.
- **Fire Demand:** It is the amount of water required for firefighting purposes such as fire breaks.
- **Leakage and Losses:** It includes the amount of water that doesn't reach the consumers as it escapes from the system through leakage. It should be included in the calculations as it is inevitable to obtain losses in the system in real life. Losses constitutes the difference between what is produced and what is received to the consumers.

2.9.3.2. Factors affecting the Water Demand

Various factors affect the water demand:

- Climate: during hot weather, water demand increases as the water consumption increases;
- Size of the city: the bigger the city, the greater the water demand;
- Population Growth: and it is one of the most important factors that should be taken into account during the design;
- Quality of Water;
- Living standards;
- Cost of Water.

2.9.3.3. Calculation of the Water Demand

Calculation of the water demand includes all type of residential, commercial and industrial water demand.

Table 2.1 Unit consumption loads for different types of activities

Type of Consumer	Consumption per Unit (L/day)	Unit Description	Assumptions	Total Consumption (L/day)
Residential apartment	200	per person	5 persons/apartments	1000
Shops/store	40	per employee	5 employees/shop	200
Shopping center	40	per SQM of area	average area of 625 SQM	25000
Gas stations	40	per automobile served	10 automobiles served	400
Restaurants	150	per seat	150 seats (medium-sized restaurant)	22500
Hospitals/unit	600	per bed	60 beds	36800
	40	per employee	20 employees	
Schools	50	per person (student and teachers)	300 persons (student and teachers)	15000
hotels	300	per person	80 persons	24000
Office	55	per employee	5 employees/office	275
Farm	4	per dry sheep	20 dry sheep	2080
	100	per lactating cattle	20 lactating cattle	
Automobile service(garage)	50	per employee	5 employees	250
Church	50	-	-	50
Mosque	50	-	-	50
Factory	5000	per Hectare (10000 SQM)	average area of 2000 SQM	1000

(Source: Wastewater Engineering: Treatment, Disposal and Reuse, Metcalf and Eddy Inc. and WaterCAD Library)

The average daily water Demand is calculated as follow:

$$\text{Average Water Demand} = \text{Number of Units} \times \text{Daily Consumption per Unit}$$

2.9.3.4. Calculation of Fire Demand

For the fire demand, we estimated the consumption to be **60 m^3/h (Farah et al.)**. We estimate for fire demand that, in 24h, around 3h will be dedicated for firefighting. This number will be used to calculate the daily amount of water needed for fire demand.

2.10. System analysis

The system is to be analyzed in multiple states, changing each time the hydraulic parameters of the system and testing multiple scenarios:

2.10.1. Steady State Simulation

A steady state simulation is independent of time (also called instantaneous model, values obtained are for a particular instant). It is a model that shows values for input parameters that are constant with time. However, in real life distribution systems change (fluctuating energy consumption during the day).

2.10.2. Extended Period Simulation (EPS)

It is a model type analysis of the system where hydraulics parameter of a system varies over a specified period of time. It is basically a series of Steady state simulation that are performed successively. EPS analyses and gives results over a period of time.

2.10.3. Peak factors

At steady state, it is important to analyze the system at peak demand. It can be done using the peak factor (PF). We calculate the peak demand by multiplying the average water demand by a PF.

$$\text{Peak Water Demand} = \text{Average Water Demand} \times \text{Peak Factor}$$

The peak factor is dependent of the value of the interval of time. Usually, it is taken during analysis over a period of 1 day = 24h.

The peak factor should be taken into account based on the population density.

Population	Peak factors		
	Maximum daily of the year	Maximum hourly of the year	Minimum hourly of the year
under 500	3,00	4,50	0,40
500 – 1 000	2,75	4,13	0,40
1 001 – 2 000	2,50	3,75	0,45
2 001 – 3 000	2,25	3,38	0,45
3 001 – 10 000	2,00	3,00	0,50
10 001 – 25 000	1,90	2,85	0,60
25 001 – 50 000	1,80	2,70	0,65
50 001 – 75 000	1,75	2,62	0,65
75 001 – 150 000	1,65	2,48	0,70
over 150 000	1,50	2,25	0,80

Figure 2.27 Peak factors (Source: Ontario Environment Ministry, Guidelines for the Design of Water Storage Facilities, Water Distribution Systems)

2.10.4. Multipliers

Multipliers are the factors used to multiply the demand. In real life, the demand is not constant throughout the entire day. In steady state simulation, the demand is considered as constant over time. But in EPS, the demand varies throughout the specified period of time and thus should be multiplied by the multipliers. For example, during the evening, the demand increases as people tend to use water for showers, preparing food etc., where after midnight when most consumers would be asleep, the demand decreases. Multipliers gives us a water demand pattern showing the behavior of the demand during 24h.

Multipliers are determined at a specific time step (each 2 hours for example). And they differ from the type of demand (residential or commercial).

Table 2.2 EPS Values

EPS			
Residential		**Commercial**	
Time from Start (h)	**Multiplier**	**Time from start (h)**	**Multiplier**
3	0.4	3	0.6
6	1	6	0.8
9	1.3	9	1.6
12	1.2	12	1.6
15	1.2	15	1.2
18	1.6	18	0.8
21	0.8	21	0.6
24	0.5	24	0.4

2.11. ArcGIS

2.11.1. ArcGIS Overview

GIS refers to Geographic Information System. ArcGIS is a geospatial software used to work with maps and geographic information. GIS consists of a set of software, each with different functions:

- ArcMap
- ArcCatalog
- ArcGIS Pro
- ArcScene

- ArcGlobe

In our project, we will be using ArcMap. It is the main part of ArcGIS that is used mainly to view, edit, create and analyze geospatial data, add features to the maps etc. We will be modelling the WDS on GIS, adding all the features of the system (pipes, valves, reservoirs, tanks, etc.) as well as the relevant data to every component. We will obtain the model with all its features that are georeferenced on the map. We also will add the buildings and road of the region. We will be able to compare the WDS layout to the exiting map, making sure it matches. Finally, we will add the sensors and meters in the map.

Figure 2.28 Integration of a GIS database

2.11.2. Advantages of Building a GIS Model

Using ArcGIS presents many advantages:

- This software will allow us to map the region with all the features of the water network, creating a system of record that is georeferenced, able to locate and track easily each data. Water utility companies use GIS as their system of record, enabling to store fata of the WDS (pipes, valves, pumps, reservoirs, storage tanks etc.).
- Also from GIS, we will be able to do a feasibility study showing the costs of the system with all its components. It enables us to do and economic study of the system as all components are quantified and can be extracted for the calculation.
- It enables us to do the conceptual study of the Smart Water Network. Our project is based on the District Meter Area Method and can be studied on GIS.

2.12. Smart Water System

2.12.1. Overview

The WDS's main purpose is delivering potable water for consumers at sufficient pressure. However, nowadays, a typical water distribution system is not enough. Losses of water in distribution system due to leakage or any other damage present a far greater challenge that is very underestimated in the world. A smart water network (SWN) consists of providing the overall instruments and equipment to the WDS in order to monitor the system, detect changes and track any problems such as leakage. Implementing smart water grids is one of the most efficient method to help manage the water distribution networks and improve the system's performance. According to research commissioned by Sensus Inc., smart water systems can save up to 12.5 billion dollars a year in utilities and equipment (Sensus Inc. et al, 2012).

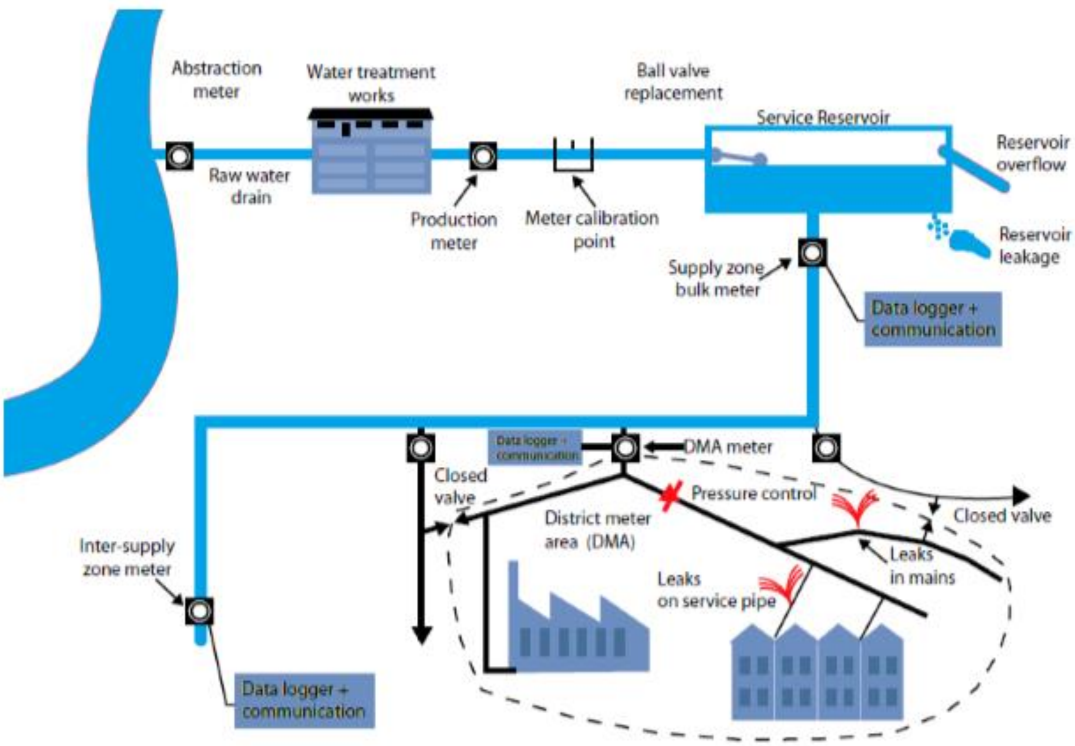

Figure 2.29 Typical Smart Water Network (Farley et al, 2008)

2.12.2. Real and Apparent Losses

According to the International Water Association (IWA), Losses (or the Non-Revenue Water) in the system are classified into 2 types:

- **Real Losses:** due to losses in energy from the system's components such as the joints, fittings, valves, pipes etc., as well as leakage from reservoirs and storage when they overflow.
- **Apparent Losses:** due to unauthorized consumption, inaccuracy in the meters or errors in data analysis of the system.

It has been reported that the losses and leakage from distribution system have reached 50% or higher in some cities around the world (Porwall et al, 2018).

2.12.3. Causes of Real losses in the WDS:

- **Corrosion:** It is the deterioration of the components in the WDS resulting of their interaction with the surrounding. The pipes in the WDS are submitted to a chemical reaction from the interaction between the pipe wall and the soil/water. With time the internal pipe diameter gradually decreases causing problems within the system.
- **Material:** As mentioned earlier, many types of material can be used for the pipes. However, each type of pipe used have different results when objected to the soil and water in the WDS.
- **Age:** The age of the pipes is an important factor as with time the leaks increase in the WDS.
- **Joints:** The unproper installation of pipe joints can cause increase of leakage.
- **Pressure:** The increase of pressure results in a higher flow rate, increasing the losses in the system.

2.12.4. Consequences of leakage:

The increase of leakage means the increase of water losses. These losses have negative impacts on the economic, Social, technical and environmental aspects:

- Increase in costs (maintenance and production, pump costs);
- Damage of the water system (pipes (from water hammer), water meters);
- Rick of attracting bacterial infection causing diseases;
- Customer dissatisfaction from the delivered water (low pressure, low quality).

2.12.5. Advantages of Smart water network

The real-time monitoring of the WDS has many advantages:

- Water and energy savings (cost saving);
- Early leak detection;
- Better decision making;
- Decrease on-site work;
- Improvement of quality of service for customers.

2.12.6. Basics of Smart Water Network

The objective of the Smart water network is based on the following:

- **Real-time pressure and water quality monitoring:** It is used for the detection of any change in the water quality (pH, chlorine, turbidity, conductivity etc.) and alert in case of any contamination of the water, it also helps monitor the hydraulic parameters of the water throughout the network. Leaks can be directly located in a fast way and actions can be directly taken to repair, minimizing water losses.
- **Real-time monitoring of asset condition for preventive maintenance:** With the use of smart water network technologies, it enables the location of outdated or damaged pipelines that might need change or repair. Then it helps to better plan the repairing schedules, as the system is automatically generating information when events occur, preventing the use of a maintenance plan of the whole system which can be costly and time-consuming.
- **Real-time water consumption information:** Help customers conserve water by providing real-time measurements of the consumption of the consumers. Then it helps tracking the consumption and helps with the choices made every day regarding water conservation.

2.12.7. The SWN framework

The SWN is layered into 5 layers listed below:

Figure 2.30 The five SWN layers (Source: SWAN Forum)

- The first layer "physical" includes all WDS components such as pipes, tanks, valves, pumps etc.
- The second layer "sensing and control" includes the hardware equipment and meters used to measure the hydraulics parameters (flow, pressure, water quality etc.), also includes the automatic meter reading (AMR) and automatic meter infrastructure (AMI) devices.
- The third layer "Collection and Communication" consists of the components responsible for the collection of the data, automatically and continuously.
- The fourth layer "Data management and display" build a database platform and then interface it for a human operator via a supervisory control and data acquisition (SCADA) system, geographic information system (GIS), or other network visualization tools.
- "Data Fusion and Analysis," provides tools to study data analytics and modeling software, test scenarios to apply predictive analytics for any event detection, leak detection, decision support etc. Therefore, utilities can conduct network management tasks remotely and automatically.

2.12.8. Smart Water Network Projects Examples

Many Smart Water Network Project were implemented worldwide and have showed promising results.

- **Scientific Campus of the University of Lille, France**

Research was done in 2017 presenting the results and feedback of the implementation of Smart Water technology at the Scientific Campus of the University of Lille. A water balance analysis was done in the campus and the results indicated a high percentage of water losses due to leaks in the system. The monitoring of the water network was done using AMR technology that used smart water meters to record each period of time at different locations in the system the water consumption and water supply. The records were then transmitted to the database and studied in order to locate and rapidly identify water leakage at said locations and be corrected (Farah et al, 2017).

- **Cape Town, South Africa**

Cape Town's program in water conservation has been internationally recognized as the city has managed to reduce water consumption by 30% over the past 15 years despite the population increase of 30% during this period. The city's plan consists of using smart water technology in the system, improving leak detection, carrying out extensive repairs and improving the management of water the meters.

This strategy has showed impressive results that it even enabled the city to put plans for a new dam on hold (Whitehead et al. 2016).

- **Dubai, KSA**

Dubai has as some of the highest water consumption rates in the world, driven by the climate, increase in population and the rapid urbanization (Sawe et al, 2019). A Smart Water Distribution Project was launched in Dubai in 2018 by Dubai Electricity and Water Authority (DEWA). The project consists of the implementation of Smart Meter and Grids, in order to detect any leakage or possible defect, reducing water losses through leakage, as well as monitoring real-time water consumption. According to DEWA, the system helps enhance the efficiency and reliability of the water distribution network and ensures continuous and stable water supply in different parts of Dubai. (Water Technology News, 2018).

- **Mumbai, India**

Mumbai is India's largest city worldwide with a population of 13 million people. The city installed water meters in the system that provided tap water to half of the city's residents. By implementing this technology, the city was able to locate and eliminate leakage, decreasing 50 percent of water losses as well as promoting water conservation. This project exceeded the target's goals and provided a higher quality water network (Polson et al. 2013).

2.13. Monitoring Methods in SWN

WDS require operation, maintenance and personnel. Water utilities keep track of the consumption in the WDS through water meters. Traditionally, the method to obtain the data from those meters was to do it manually and required utility personnel to visit each meter to obtain the reading, usually located inside or outside the building. Nowadays, with the development of the communication technologies came new ways to monitor and to collect reading.

2.13.1. Automated Meter Reading (AMR)

Automated Meter Reading (AMR) is a monitoring method that consists of obtaining water meter reading from radio transmitted signals. It is a much faster method compared to the traditional data collection. With AMR technology, the utility personal can walk-by or drive-by to do the readings and collect the data. The collected information would include the volume of water consumption registered at each meter. Then the meter showing high consumption might indicate a presence of leak in the system, alert the required personnel and notify the residents, avoiding in that way high bills.

Figure 2.31 Automated Meter Reading (AMR)

2.13.2. Advanced Metering Infrastructure (AMI)

Advanced Metering Infrastructure (AMI) is a system that collects the data from the meters remotely and continuously and transmit them to the water utilities. It enables a two-way communication between meter endpoints and utilities. This method ensure data are collected securely and without interruption, and reduces the need of utility personnel to collect the data and therefore reduces the costs for the staff. Moreover, this method enables to collect the data at any required period as the system automatically transmits the data to the utility at any interval and any time of the day. This system is done by installing a fixed network to transmit the data. Some examples could be fixed radio frequency (RF), landline or cellular networks, power line communication (PLC), etc. This system can be incorporated with a water management system such as SCADA (Supervisory Control and Data Acquisition).

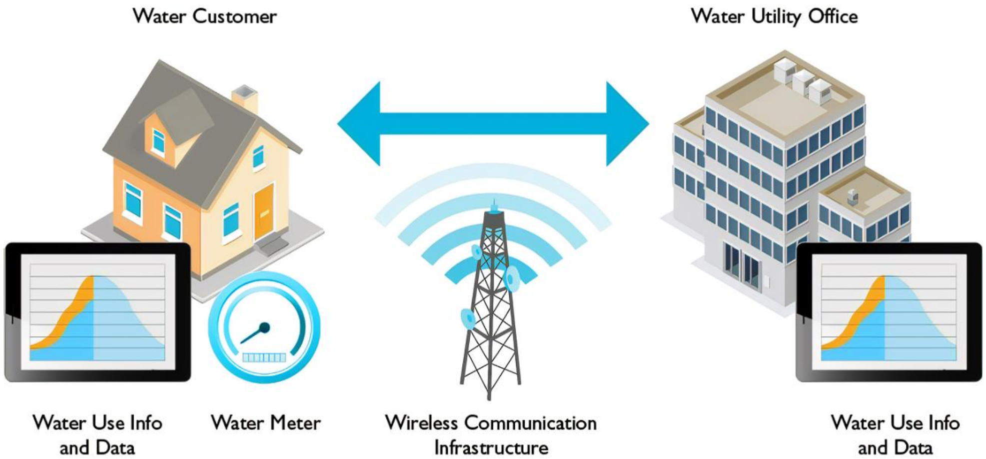

Figure 2.32 Advanced Metering Infrastructure

2.13.3. Supervisory Control and Data Acquisition (SCADA)

Supervisory Control and Data Acquisition (SCADA) consists of computer-controlled system used to monitor and control processes. SCADA systems acquire information from remote devices to the central system where the Host software system can communicate and control these devices remotely. SCADA systems require human interaction for the controlling and monitoring process. The system consists of 4 different components: the field instrumentation (automated or advanced instrumentation), PLCs/RTUs which are the devices connected to the field instruments responsible to control and activate the devices remotely, the type of remote communication to transmit the gathered information (examples of communication types are cellular or radio devices), and the last component of the SCADA system is the SCADA host software, which consists of graphical displays, alarms, and trends.

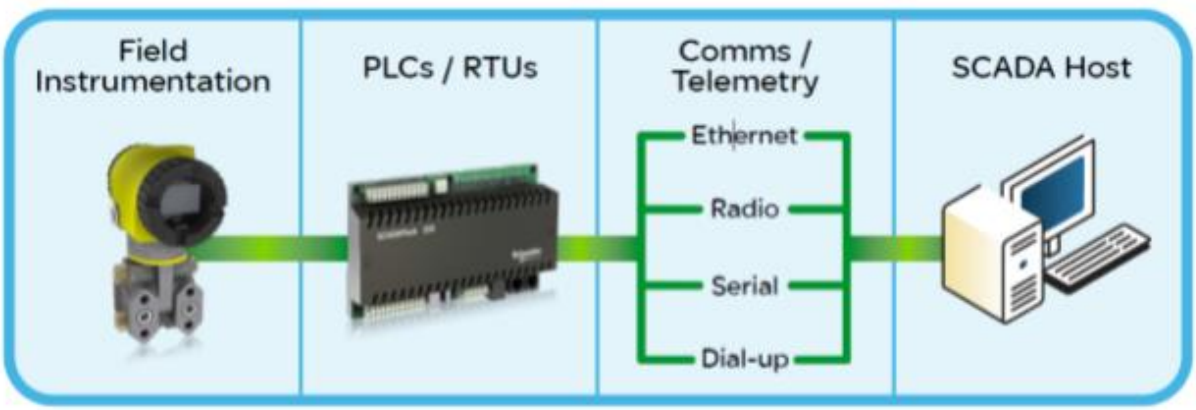

Figure 2.33 SCADA Components

2.14. The DMA Concept

DMA refers to "District Meter Area". It is a technique used by water utilities for the monitoring of the water consumption in the WDS. DMA method consists of dividing the water system into sections called District Meter Area (DMAs). DMAs are obtaining by dividing the areas into zones by closed isolation valves and by meters (flow and pressure meters). They are placed at the DMA boundary resulting in isolation of the DMA where the flow coming in and out is measured. Based on this inflow and outflow of each DMA, water utilities can analyze the data and identify any leakage within a certain DMA.

The DMA concept has many benefits as it allows to detect leakage and illegal connections to the system easily, decreasing the losses and resulting in cost (non-revenue water), water and energy savings. It also increases the quality of water and the efficiency of the system, and provides better customer satisfaction.

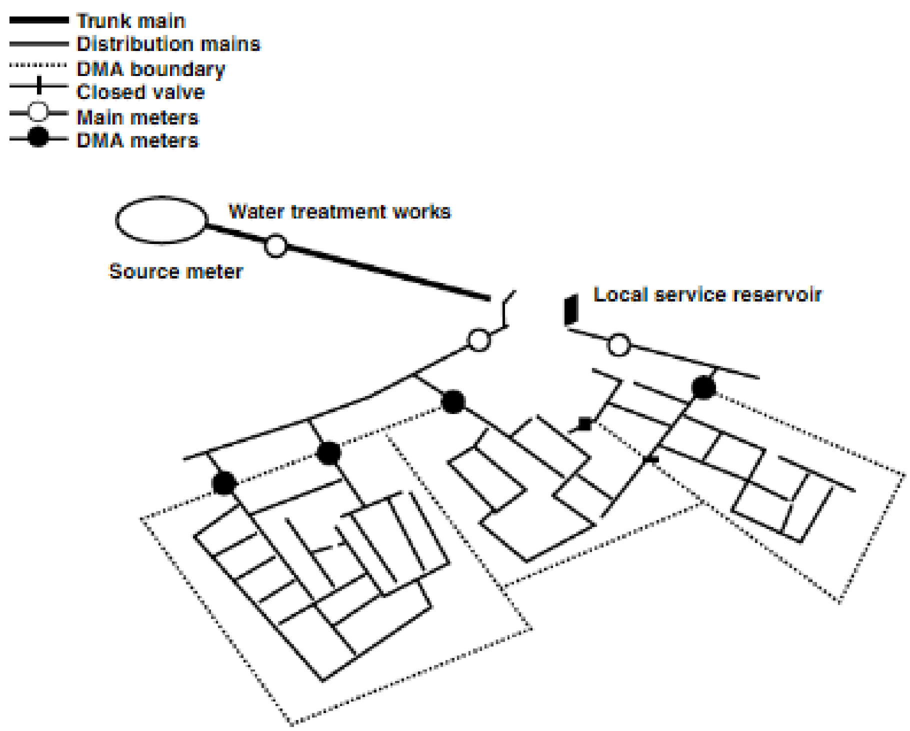

Figure 2.34 Division of a WDS into DMAs (Morrison et al,2004)

2.14.1. DMA Concept Criteria:

The size of a DMA depends on the geographic and demographic factors of the region (adequate number of customers in the section, type of consumers (residential, industrial etc.). The DMA should be of adequate size, not too big not too small. Designing the DMA of a WDS is not an easy process as it requires to analyze and determine where and how to divide the area in a way to choose strategically the places where the DMA boundary crosses a main, and also choose what pipes is to be closed and what pipe to remain open to put the flow meters.

Note that the system should be tested and checked once all valves and meters are installed in order to check if the pressure in the system is still within standards. The following figure shows the steps of the DMA concept.

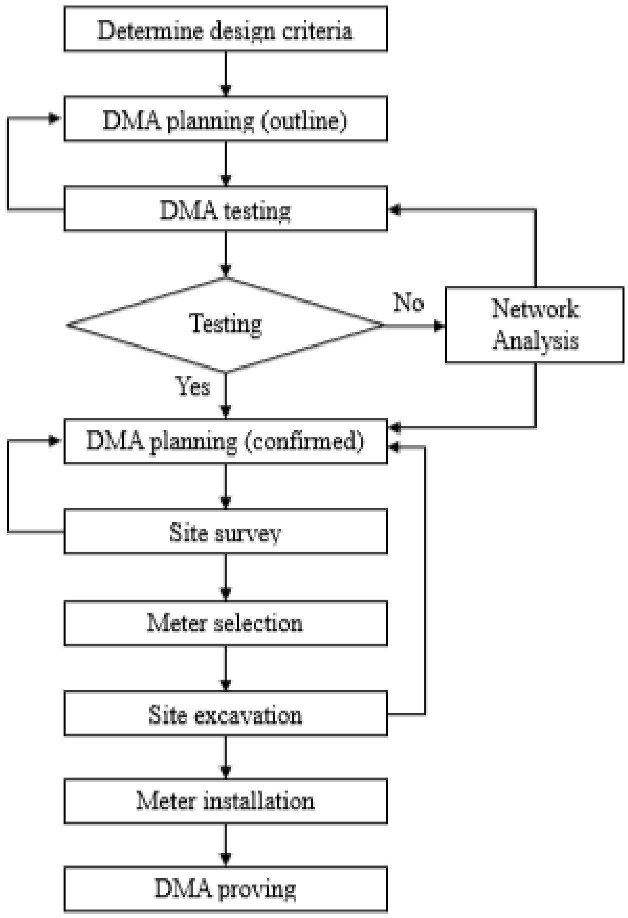

Figure 2.35 Stages in DMA process (Farley. 2001)

2.14.2. Water Balance

The Water Balance Method is based on the principle of conservation of mass. It consists of determining the volume of lost water in a DMA. The water balance method is based on the collection of the bulk meters and customer meters installed at each DMA during a defined period of time. Then, the volume of water lost can be measured in the WDS.

Table 2.3 - Summary of the water balance terminology by IWA

System input Volume W_i	Authorized Consumption W_C	Billed authorized consumption W_{BC}
		Unbilled authorized consumption W_{UC}
	Water Losses W_L	Apparent losses W_{AL}
		Real Losses W_{RL}

The bulk meters installed at the DMA boundaries measure the system input volume Wi, and the customer meters measure the billed authorized consumption W_{BC}. The unbilled authorized consumption W_{UC} includes the water consumed in the unmetered households, for firefighting as they can’t be exactly quantified, and withdrawals of water for operational purposes (for example main flushing, pipes construction and repair work, cleaning in waterworks etc.). We sum up both values to obtain the authorized consumption W_C and subtract it from W_i to obtain the water losses W_L. The apparent losses W_{AL} includes the unauthorized consumption, inaccuracies in the meters or errors in the data. This value is estimated around 0.25% of W_i. That way we can deduce the real losses W_{RL}.

2.14.3. Minimum Night Flow (MNF)

The analysis of the Minimum Night Flow (MNF) is the most common method worldwide to estimate real losses and evaluate leakage in a WDS. This method is considered a simple approach to evaluate leakage making it very useful as it requires a limited set of data within a limited period of time. The Minimum Night Flow (MNF) is based on the measurement of the flow at night, specifically between 2:00 am and 4:00 am. During this time the customer demand is at its lowest, hence the pressure in the network is at its highest and leakage at its peak in the DMAs. When the MNF in the DMA during this period of time exceeds a threshold already specified, a leak alarm is generated and is sent to the water utilities. A leak alarm is generated when the MNF in a DMA exceeds a threshold set by water utility companies. This threshold is specified by taking into account multiple factors such as the age and length of the pipes, the number of connections and the pressure (Alkasseh et al., 2013). The leakage is the difference between the MNF value registered and legitimate night consumption. The latter is calculated by taking into account residential and commercial consumption. Usually at night residential consumption might include toilet flashing, outdoor irrigation or automatic washing machine. Commercial consumption includes the machines programmed to be used at night. The following graph represent a typical demand pattern during the day 24h and where the minimum night flow is located.

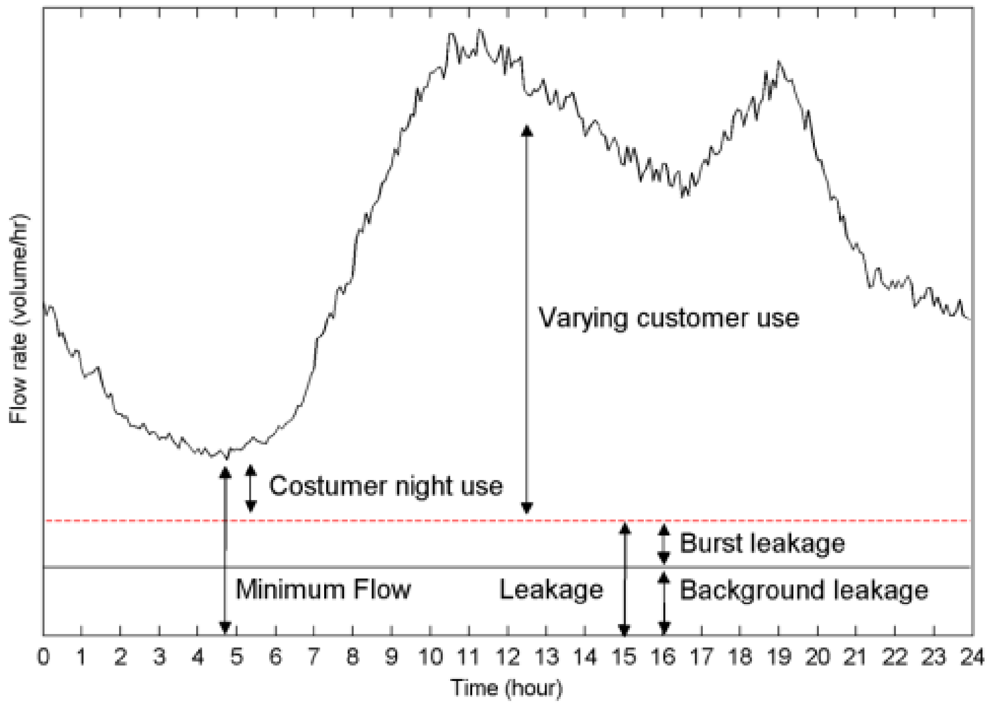

Figure 2.36 MNF location in a typical 24-hour flow profile (Farley et al., 2008)

2.15. Conclusion

This chapter went in details about the Water Distribution System, all its components, the basics for its Design, the importance of Using ArcGIS with the hydraulic modelling and a summary of the Smart Water System and how it is introduced into the WDS.

CHAPTER 3. PROJECT SITE ANALYSIS

3.1. Geography and topography of Bazoun

Bazoun is a Lebanese local authority which is located in Bcharre District, North Lebanon. Located at a distance of 103 km from Beirut, it has an altitude of 1 399 meters above sea level and covers an area of 0.268 km^2.

Figure 3.1 Bazoun Location on map

3.1.1. Longitude & Latitude of Bazoun

Table 3.1 Longitude and Latitude

Longitude (DMS)	Latitude (DMS)	Altitude (m)	Altitude (ft)
35.9872° E	34.2422° N	1 399	4756

The Latitude is the measurement of location north or south related to the Equator.

Longitude is the measurement of location east or west related to the prime meridian at Greenwich, the specially designated imaginary north-south line that passes through both geographic poles and Greenwich, London.

Altitude is the vertical elevation of an object above a surface (such as sea level or land) of a planet or natural satellite.

3.2. Land Occupation plan

This section presents the urban plan of the region, showing the various structures, buildings and installations in Bazoun, divided by type.

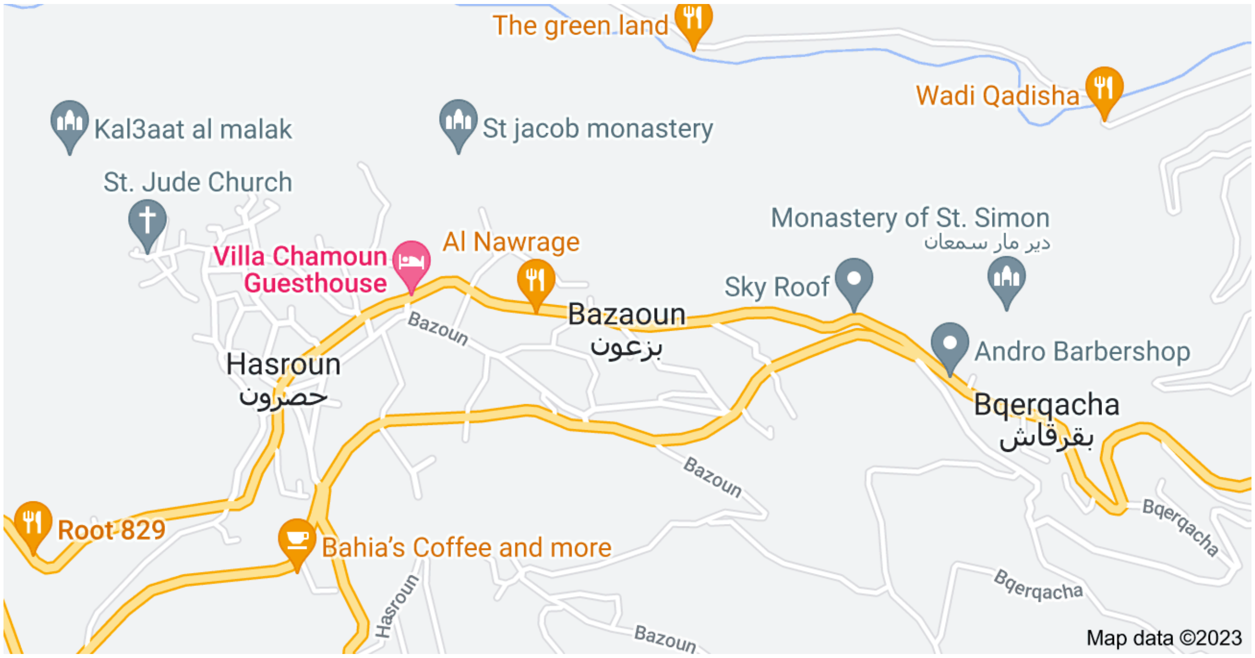

Figure 3.2 Bazoun map

The city of Bazoun includes the following:

Table 3.2 Ground occupation distribution (Source: Ministry of Energy and Water in Lebanon)

Type	Number
Residential Units	384
Villa	42
Shops and stores	20
Restaurants	1
Churches	3
Enterprise	1
municipality	1

3.3. Population Analysis

Research and statistical studies done by City-facts and JRC (European Commission's Joint Research Center) showed that Bazoun had a population of approx. 881 with a median age of 28.2 years old as of 2020. It is noted also that the population density was 3,209 / Km^2, with a population change of +81.1% from 2000 to 2020. The following table shows the population and population density in Bazoun.

Table 3.3 Population and population density in Bazoun (City-Facts, JRC (European Commission's Joint Research Center) et al. 2015)

Data	1975	1990	2000	2020
Population	347	426	514	881
Population Density	1,296 / km^2	1,591 / km^2	1,920 / km^2	3,209 / km^2

3.3.1. Population growth

The population growth was obtained every 1 decade (1 decade = 10 years). We observe that between 1990 and 2022 the average 10-year growth increased significantly due to the urban growth during this period. Then after 2022, it was estimated that the population growth decreases significantly.

Table 3.4 Population growth (City-Facts, JRC and CIESIN et al. 2017)

Year	Average 10 Year growth %
1970	23.2
1990	16.7
2000	20.7
2020	30.9
2030	4.1
2040	1.4
2050	-0.9

Figure 3.3 Average 10-year growth %

From the statistical studies above, we observe a significant increase in the population growth from years 2000 to 2020 in Bazoun to reach a peak point of 30.9%. However, from those studies it is predicted that the population growth significantly decreases after 2020 to reach around -0.9% in 2050.

3.3.2. Population forecasting calculation

Population forecasting consists of determining the estimated population after a certain period of time which is the design period of the WDS. Due to the population increase, the demand increases with time, thus it should be taken into consideration. The study of the population growth is essential to expect the future needs. In our project, it will be used in the design of the water distribution system in order to calculate the expected water needs in the upcoming years.

The design period of our WDS is **25 years**.

The calculation of the projected population in 25 years requires present and past values in order to be able to estimate as precise as possible. Multiple methods can be used in the population forecasting.

In our project, we will be using the **Geometric Increase Method**:

The estimated population P_t is given by:

$$P_t = P \times \left(1 + \frac{R}{100}\right)^n$$

Where,

- P_t : population after n years
- P: current population
- R: the average rate of growth
- N: number of 10-years.

But in our case, we have a different growth each 10 years then we will calculate the population growth each 10 years with the corresponding population growth value until we reached the required year. The following graph shows the estimated population in the upcoming years.

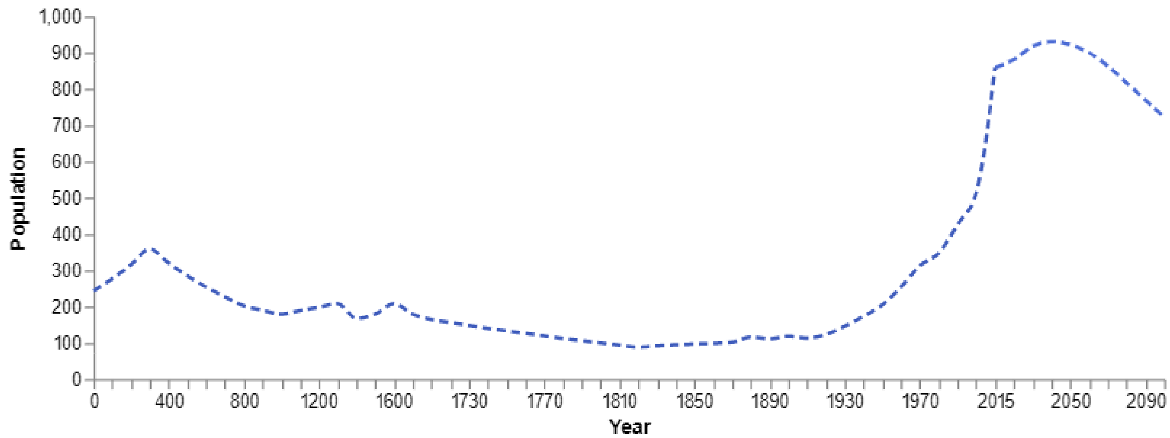

Figure 3.4 Population growth (City-Facts, JRC, CIESIN et al. 2017)

We obtain the following values for the estimated population after 25 years:

Table 3.5 Geometric estimation of the population after 25 years

Year	2020	2030	2040	2047
Population	881	917	930	939

3.4. Existing situation of the water system in Bazoun:

CHAPTER 4. WATER DISTRIBUTION DESIGN ANALYSIS

4.1. Data Collection

At this stage a collection of quantitative and qualitative data is required. We obtained a map from the Ministry of Energy and Water showing the topographical studies of the region, elevations at each point, the distribution of all residents within the area and with the details about all residents (type, number of apartments etc.). Those details are important as they will be used in the calculation of the water demand. We also got details about the water source of the region, from where the region is getting potable water.

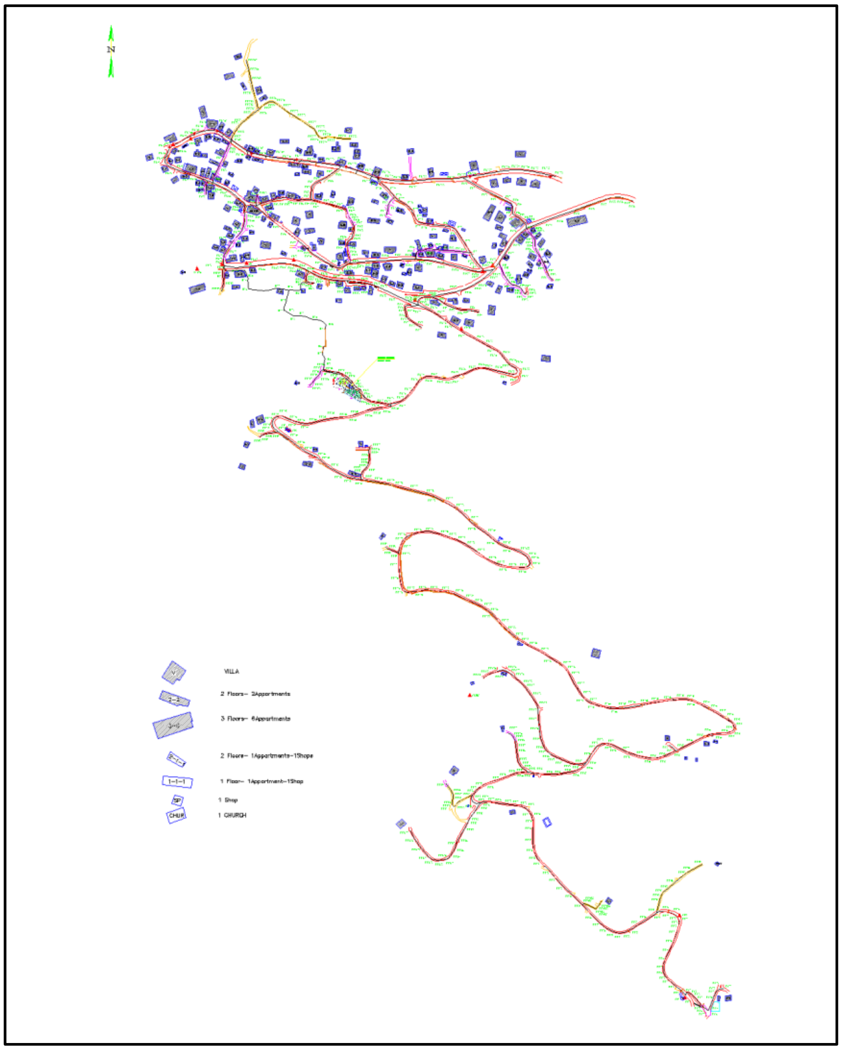

Figure 4.1 Data Collection

4.2. Preliminary Layout of the WDS

4.2.1. Layout of the Junctions

The junctions are added first. Junctions are located usually where one or multiple pipes intersect, or where the pipes end. At the junctions, we assign the water demand. We added them mainly at intersection or end of roads. We also assign the elevations at each junction based on the Topography of the region. The following figure shows the tentative layout of the junctions. We note that some junctions will not have any demand as the region has barely houses in the present or that some of the junctions are construction junctions, used for joining pipes together.

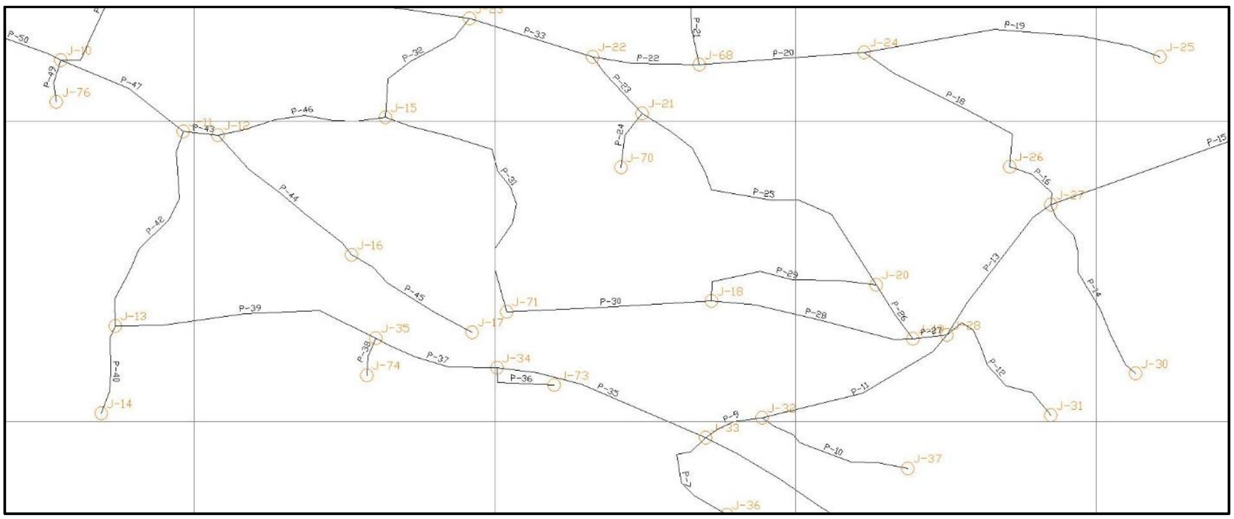

Figure 4.2 Junction Layout

4.2.2. Choice and Layout of the Pipes

The pipes are then drawn on the software by drawing from junction to junction. All the pipes during the layout are all assumed 6in. The length of pipelines is kept as short as possible and we make sure that the pipelines should be located underground of the public roads. The following figure shows the layout of the pipes. The system designed is considered to be a new water distribution network for the region of Bazoun, as data are very limited and information about the existing system is not provided.

As for the type of the pipes, considering multiple factors such as high pressure in the network, design periods etc., we first chose the **Ductile Iron Pipe (DIP)** as the pipe material in the system but due to costs, **PVC** will be used in the system as it presents many advantages:

- PVC pipes are light in weight, tough, resistant to chemical attacks and it is available in large lengths.
- It presents less friction thus less losses as its internal surface is considered smooth.
- The cost of transportation and installation is less expensive etc..

We note that the layout of the pipes is assumed to not have any conflict with the sewer systems. The existing sewer system of the region is not provided. However, the pipes are assumed to be located at a minimum distance of 1.5 m from the sewer pipes, and in case of crossing, the pipes of the water distribution system should be above the sewer ones, avoiding any contamination in case of leaking.

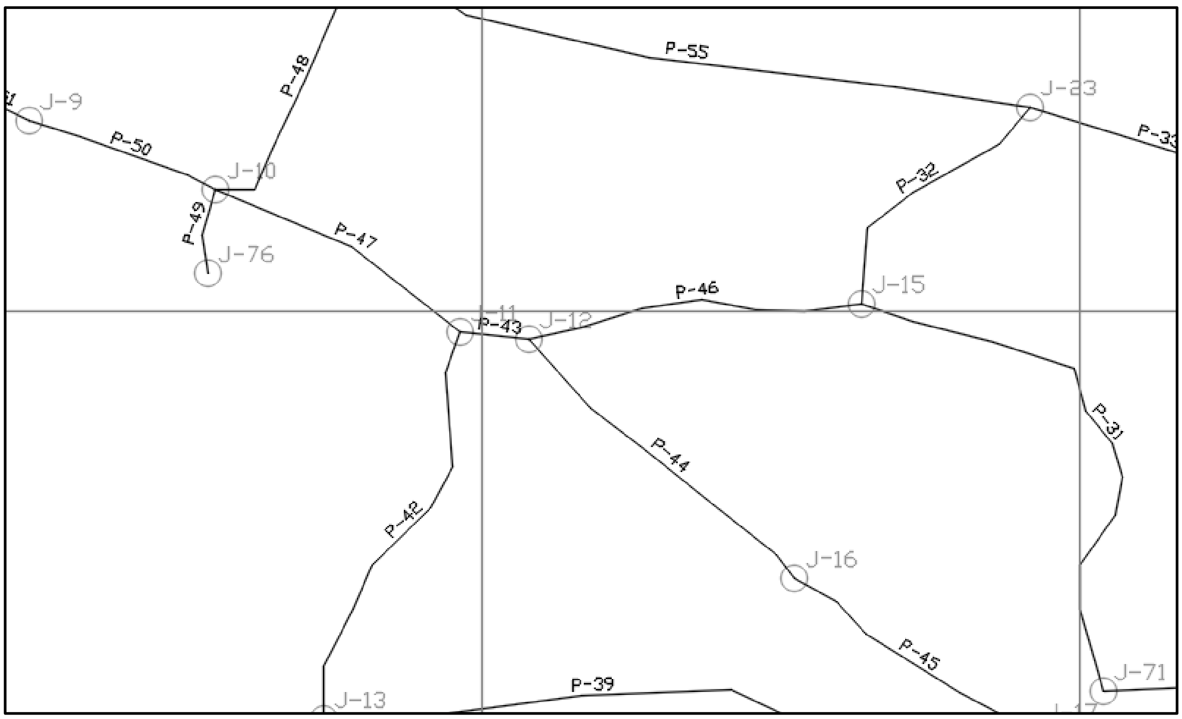

Figure 4.3 Pipe Layout

4.2.3. Classification of the Junction into zones

We divided the junctions into zones 1 and 2 according to their elevations; zone 1 for elevations less than 1500 m and zone 2 for elevations greater than 1500 m. Dividing the junctions into zones.

Table 4.1 Junctions distribution into zones

Junction	Elevations (m)	Zone
J-1	1,365.73	Zone 1
J-3	1,370.20	Zone 1
J-4	1,373.02	Zone 1
J-5	1,383.91	Zone 1
J-6	1,384.56	Zone 1
J-7	1,386.41	Zone 1
J-8	1,390.22	Zone 1
J-9	1,393.71	Zone 1
J-10	1,399.28	Zone 1
J-11	1,406.54	Zone 1
J-12	1,406.50	Zone 1
J-13	1,432.69	Zone 1
J-14	1,440.68	Zone 1
J-15	1,400.68	Zone 1
J-16	1,415.30	Zone 1
J-17	1,421.10	Zone 1
J-18	1,415.05	Zone 1
J-19	1,415.12	Zone 1
J-20	1,409.55	Zone 1
J-21	1,392.42	Zone 1
J-22	1,388.12	Zone 1
J-23	1,387.15	Zone 1
J-24	1,390.60	Zone 1
J-25	1,391.45	Zone 1

4.2.4. Thiessen Polygons

After layout of the pipes and junctions in the area, Thiessen polygons are generated on WaterCAD. Thiessen Polygons divide the areas into small, enclosed polygon, each assigned to one junction. The polygon represents the area of influence on the junctions. The total demand of the residents and buildings inside this polygon is assigned to said junction.

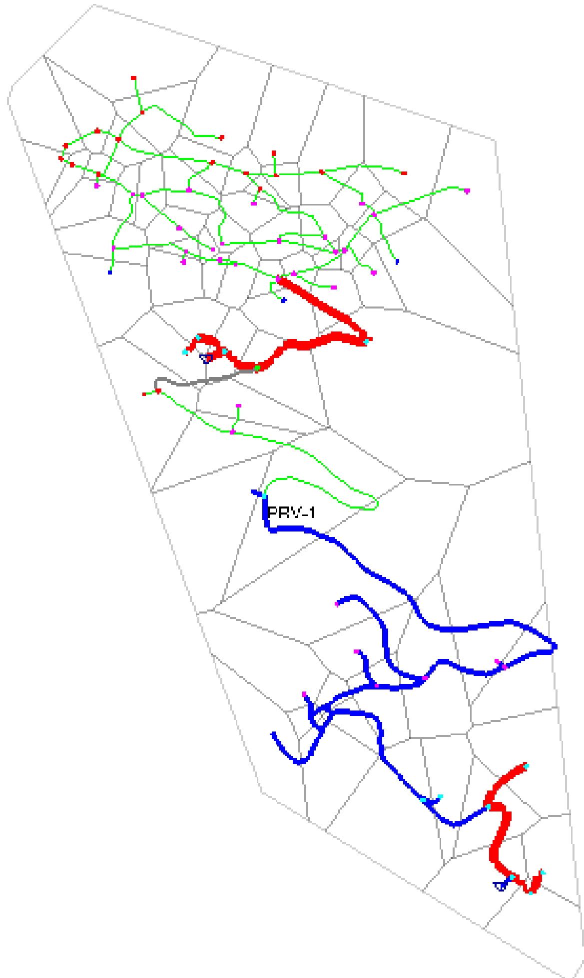

Figure 4.4 Thiessen Polygon

4.3. Determination of the Peak Factor:

The peak factor is determined from the Population. After estimating the population over the design period of 25 years. We obtained a population of around 9 hundred. Then the peak factor from the table is **2.75**.

Population	Peak factors		
	Maximum daily of the year	Maximum hourly of the year	Minimum hourly of the year
under 500	3,00	4,50	0,40
500 – 1 000	2,75	4,13	0,40
1 001 – 2 000	2,50	3,75	0,45
2 001 – 3 000	2,25	3,38	0,45
3 001 – 10 000	2,00	3,00	0,50
10 001 – 25 000	1,90	2,85	0,60
25 001 – 50 000	1,80	2,70	0,65
50 001 – 75 000	1,75	2,62	0,65
75 001 – 150 000	1,65	2,48	0,70
over 150 000	1,50	2,25	0,80

Figure 4.5 Determination of the peak factor

4.4. Calculation of the Water Demand

The Water Demand is calculated at each junction of the system. We will take for example junction J-74 for the demonstration.

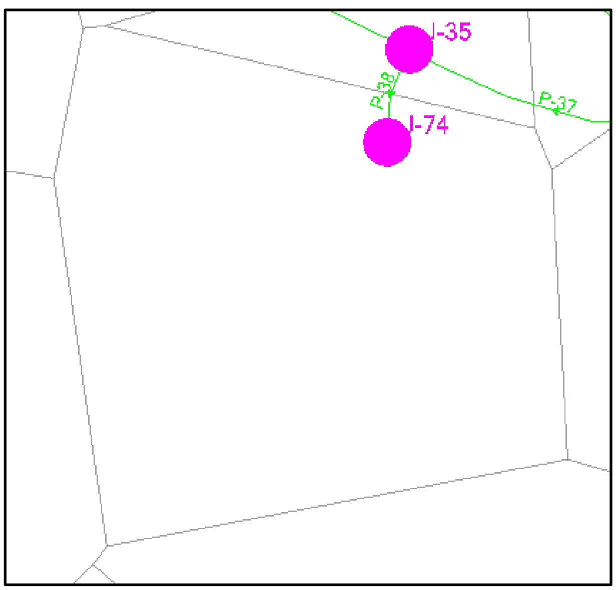

Figure 4.6 Junction J-74 Thiessen polygon

Inside the Thiessen polygon for junction J-74, the following residents are located:

Table 4.2 Residents' detail in Thiessen polygon J-74

Type	Number
Residential Unit	2
Villa	1

We calculate the Residential Demand, the Commercial Demand and the Total Demand, which is the sum of the residential and commercial demand. The Residential Demand includes the demand of the apartments, hotels. And the Commercial Demand includes the demand of the shop and stores, gas stations, restaurants, shopping center, offices etc.

We take the unit demand from the table in Section 2.9.3.3 (Table 2-1) and proceed with the calculation:

- **Residential Demand**

$$Q_{\text{residential}} = 2 \text{ apart.} \times 1000 + 1 \text{ villa } \times 1000 = 3{,}000 \text{ L/day}$$

- **Commercial Demand**

$$Q_{\text{Commercial}} = 0 \text{ L/day}$$

- **Total Demand**

$$Q_{\text{Total}} = 3{,}000 \text{ L/day}.$$

Finally, we add 20% for emergency leakage.

Then,

- **Total Demand**

$$Q_{\text{Total}} = 3{,}000 \frac{\text{L}}{\text{day}} \times 1.2 = 3600\ L/day.$$

This method is done on all Junctions to obtain the following table showing all demands:

Table 4.3 Water Demand at each Junction

Junction	Demand (L/day)
J-1	2460
J-3	6000

J-4	9600
J-5	23760
J-6	12000
J-7	3600
J-8	6000
J-9	9600
J-10	25200
J-11	12000

4.5. Calculation of the Pipe Diameter

After computing the Water Demand at each junction, we calculated the Diameter for each pipe. The size of the pipes is determined from the rate of flow of the system. We note that in order to calculate the diameter of the pipe, the demand is multiplied by the peak factor. AWWA (1989) states that for the design of the pipes in the WDS, the calculations should be based on the peak flow rate which is the highest flow rate during the day.

We multiplied the total demand at each junction with the PF.

Table 4.4 Peak Demand at each Junction

Junction	Demand (L/day)
J-1	6765
J-3	16500
J-4	26400
J-5	65340
J-6	33000
J-7	9900
J-8	16500
J-9	26400
J-10	69300
J-11	33000

From the WaterCAD Results, when the velocity obtained is greater than the required velocity (between 0.6 and 3m/s). Most pipes in the network have the same problem, either the velocity of the flow is less or greater than the range required. Then we need to find the required diameter. We set a fixed theoretical velocity for all the pipes. This value is around the average of the acceptable range for the velocity in the system.

- Theoretical velocity V = 1.2 m/s.

By fixing the value of the velocity and the flow, we calculate the new diameter as follow:

$$Q = A \times V = \frac{\pi D^2}{4} \times V$$

Then,

$$D = \sqrt{\frac{4Q}{\pi V}}$$

4.5.1. Unification of the pipe diameter

We obtained pipes of various diameters. However due to various causes, the best option is to adopt unified standard diameters for the pipes. Adopting a couple of fixed diameters presents many advantages: it helps during the manufacturing of the pipes; the fabrication becomes easier as it facilitates the interchangeability of the pipes with the various fittings available; finally, after changing the pipe diameter, the velocity and pressure will change, thus we will be adopting diameters where we obtain results that are within the required range.

For the pipes we went with the following:

- Pipes: Diameter = 3 in

The following figure represents all the pipelines, where most of the pipes are taken 3 in. it is due to the fac that the velocity resulted in the pipes is too low, thus it was decreased so that the velocity would increase on the pipes.

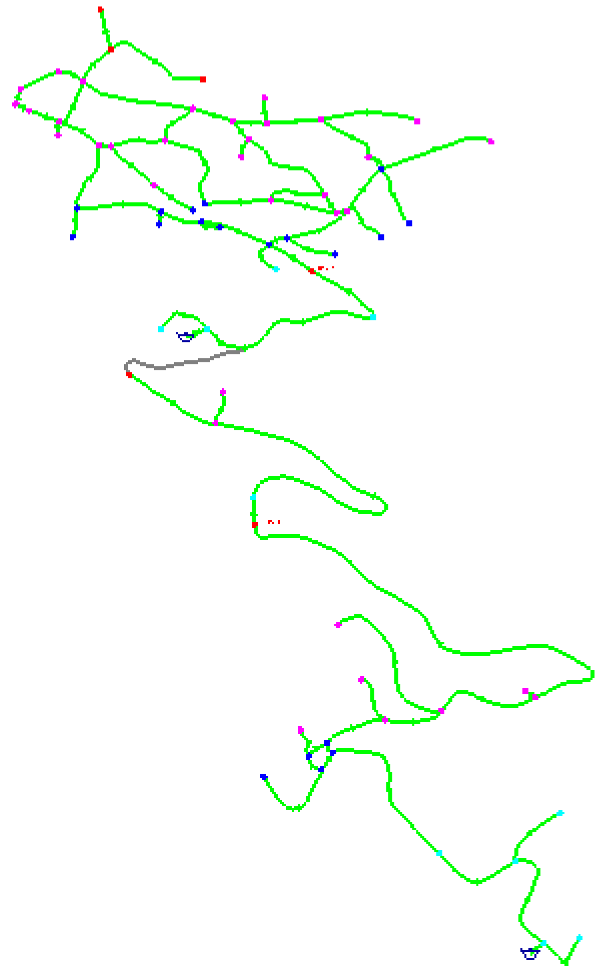

Figure 4.7 Pipe layout with chosen diameter

4.5.2. Pipes Cover

The underground pipes should be buried under a certain cover. This cover should protect the pipes from the environment and the surrounding that may damage the pipelines. The more the depth of the pipes, the better, however this will increase the cost of installation. In this project, the pipes are buried **1m underground** which should be enough.

4.6. Design of the Water Tank

The water tank Capacity is to be designed. Storage tanks are designed such as at peak day flow rates, they are filled when the water demand during the day is less than the average day demand, and emptied when the water demand is greater than the average water demand. Tanks are sized by taking into account the average, peak and fire flow rates, as well as considering the emergency storage in case needed (source failure for example) (AWWA, 1999).

The water tank should include the following:

- Consumption Storage
- Fire Storage
- Emergency Storage

In our case we installed 2 tanks in the region, each feeding different regions separated by pipe P-60. The pipe is considered permanently inactive (closed by gate valves) and used only in case of damage in one of the tanks, that way the other tank will be used to feed the whole region during repair works. Junctions are distributed on both tank in order to calculate the required demand.

4.6.1. Water Tank 1

Consumption Storage

This part of the water tank storage is filled when the demand is low and emptied when the demand is high. For 24h, the average storage for the tank is estimated around 20% of the peak total consumption of the day.

In our project, we calculated the total average and peak daily water demand in water tank 1:

$$\text{Total Average Water Demand} = 470{,}400 + 5{,}310 \text{ L/day} = 475{,}710 \text{ L/day} = 19.82 \text{ m}^3\text{/h}$$

$$\text{Total Peak Water Demand} = 1{,}308{,}202.5 \text{ L/day} = 54.50 \text{ m}^3\text{/h}$$

Then the required storage Q_1 is:

$$Q_1 = 475{,}710 \text{ L/day x } 20\% = 95.142 \text{ m}^3\text{/day}$$

Fire Storage

For the fire demand, we assume to control any fire at any location in Bazoun, that we require a fire flow rate of 60 m^3/h. During 24h, we assumed that the daily fire demand in the region is for 3 hours. Then we calculation the daily required demand.

$$Q_2 = 60 \text{ m}^3/\text{day} \times 3 \text{ hours per day} = 180 \text{ m}^3/\text{day}$$

Emergency Storage

The emergency storage is necessary in case of problems in the water source and its incapability to deliver water for a certain reason. Emergency storage should be considered that corresponds to the required time of repair of the problem. This time is estimated at around 4 hours per day.

$$Q_3 = 19.82\ \frac{m^3}{h} \times 4\ \text{h per day} = 79.28\ m^3/\text{day}$$

Total Water Tank Capacity

We calculate the sum of the previous storage and obtain the total capacity of the water tank:

$$Q = Q_1 + Q_2 + Q_3 = 354.4\ m^3$$

Then, we take the capacity if the Water Tank to be 400 m^3

4.6.2. Water Tank 2

Consumption Storage

This part of the water tank storage is filled when the demand is low and emptied when the demand is high. For 24h, the average storage for the tank is estimated around 20% of the peak total consumption of the day.

In our project, we calculated the total average and peak daily water demand in water tank 1:

$$\text{Total Average Water Demand} = 69{,}000\ \text{L/day} = 2.9\ m^3/h$$

$$\text{Total Peak Water Demand} = 189{,}750\text{L/day} = 7.9\ m^3/h$$

Then the required storage Q_1 is:

$$Q_1 = 22.4\ m^3/\text{day}$$

Fire Storage

For the fire demand, we assume to control any fire at any location in Bazoun, that we require a fire flow rate of 60 m^3/h. During 24h, we assumed that the daily fire demand in the region is for 3 hours. Then we calculation the daily required demand.

$$Q_2 = 60\ m^3/\text{day} \times 3\ \text{hours per day} = 180\ m^3/\text{day}$$

Emergency Storage

The emergency storage is necessary in case of problems in the water source and its incapability to deliver water for a certain reason. Emergency storage should be considered that corresponds to the required time of repair of the problem. This time is estimated at around 4 hours per day.

$$Q_3 = 2.9\ \mathrm{m3/h}\ \frac{\mathrm{m^3}}{\mathrm{h}} \times 4\ \mathrm{h\ per\ day} = 11.6\ \mathrm{m^3/day}$$

Total Water Tank Capacity

We calculate the sum of the previous storage and obtain the total capacity of the water tank:

$$Q = Q_1 + Q_2 + Q_3 = 213.9\ \mathrm{m^3}$$

Then, we take the capacity if the Water Tank to be 300 m^3

4.6.3. Choice of Tank Dimensioning and Location

Tank 1 will be taken as follow:

- Tank Capacity = 400 m^3
- Tank height: 4 m
- Calculation of the dimensions of the tank:

$$\mathrm{Area} = \frac{400}{4} = 100\ \mathrm{m^2}$$

We take the length and width of the tank equal (square area).

$$d = \sqrt{100} = 10\ \mathrm{m}$$

We take d = 10 m

Then the dimensions of the tank are: 10 m × 10 m × 4 m

And the new Volume of the tank is: V = 400 m^3

The tank is located on ground and is located at a point of elevation 1,489.5 m.

Tank 2 will be taken as follow:

- Tank Capacity = 300 m^3
- Tank height: 3 m
- Calculation of the dimensions of the tank:

$$\mathrm{Area} = \frac{300}{3} = 100\ \mathrm{m^2}$$

We take the length and width of the tank equal (square area).

$$d = \sqrt{100} = 10\ \mathrm{m}$$

We take d = 10 m

Then the dimensions of the tank are: 10 m × 10 m × 3 m

And the new Volume of the tank is: V = 300 m^3

The tank is located on ground and is located at a point of elevation 1,738.75 m.

4.7. Extended Period Simulation

After running the system in steady state, finding the pipe diameter and tank capacity. The system is then tested in EPS state. Extended period simulation helps in properly checking the behavior of the flow in the system, it is also important to check the behavior of the tank in the system, helps locate the different type of valves depending on the obtained pressure etc.

4.7.1. Water Demand in EPS

To change the system to EPS, the water demand should be changed. The demand pattern is introduced to the residential and commercial demand at each junction. This demand pattern shows the behavior of the demand throughout the day. From the below graph, we can observe that in the residential pattern, demand is at its highest around evening, which is the time for showers after work, where it is at its lowest after midnight as most residents are asleep and consumption is very low. For the commercial pattern, it is highest during the day, at noon, as most companies and factories open during the day and close afternoon till next morning. That's why the demand decreases gradually after 5 pm.

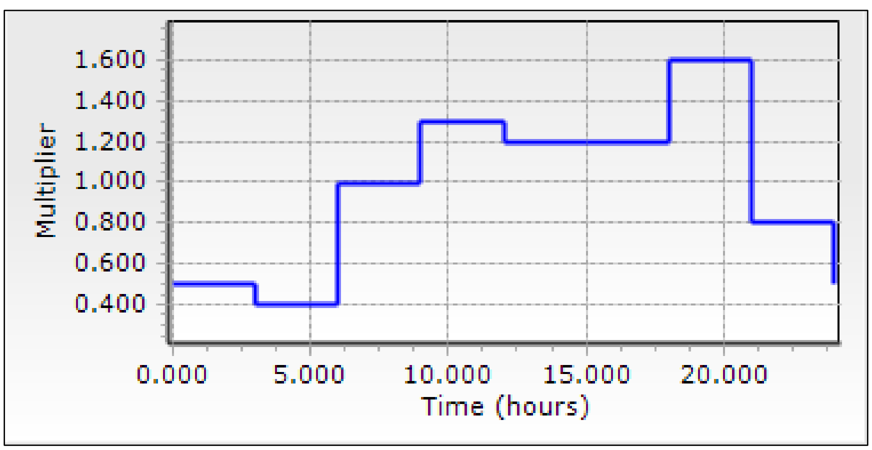

Figure 4.8 Hourly Hydraulic Patter for Residential Demand

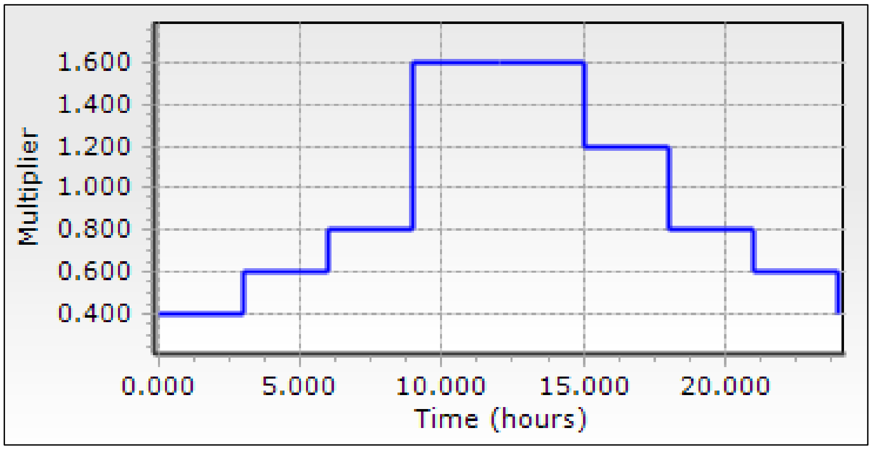

Figure 4.9 Hourly Hydraulic Pattern for Commercial Demand

Let's take for example Junction J-71. We will have:

Residential (L/day)	Commercial (L/day)
12000	**330**

Table 4.5 Demand Pattern for J-71

residential		commercial	
Time from Start	Demand	Time from Start	Demand
3	4800	3	198
6	12000	6	264
9	15600	9	528
12	14400	12	528
15	14400	15	396
18	19200	18	264
21	9600	21	198
24	6000	24	132

4.7.2. EPS Results and Solutions

After Running the system in EPS State, we obtained the results for the pressure and velocity in the system. First, the pressure obtained was very high at some locations, mainly in the junctions where the elevations is the lowest (mainly zone 2). This problem should be resolved as high-pressure results in many problems such as damage in pipes, leakage increase etc. We added to the system pressure reducing valves (PRV). 2 PRVs were installed in the system. It is added by analyzing the results obtained for the pressure: the zones where the pressure would start increasing, we would add a PRV.

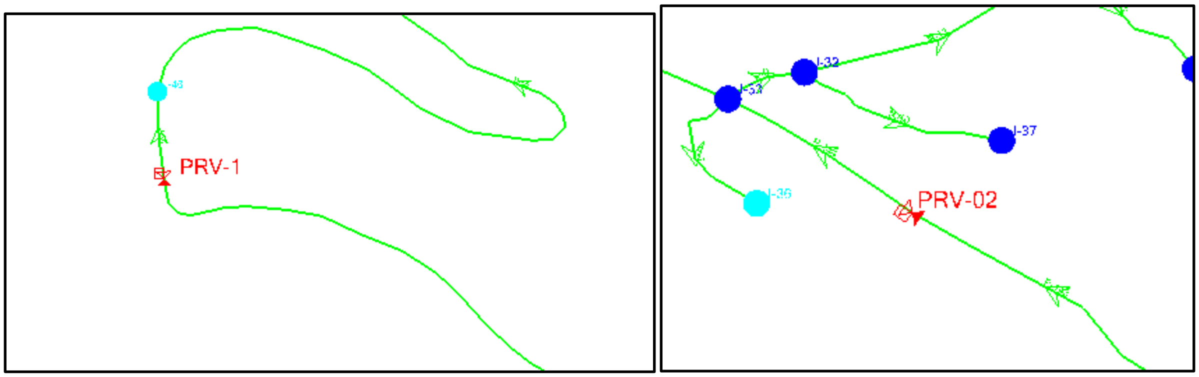

Figure 4.10 PRV Distribution in the System

We then run the system and obtained the pressure in the following figure that shows us that the pressure in the whole system range between 4 and 9 bars.

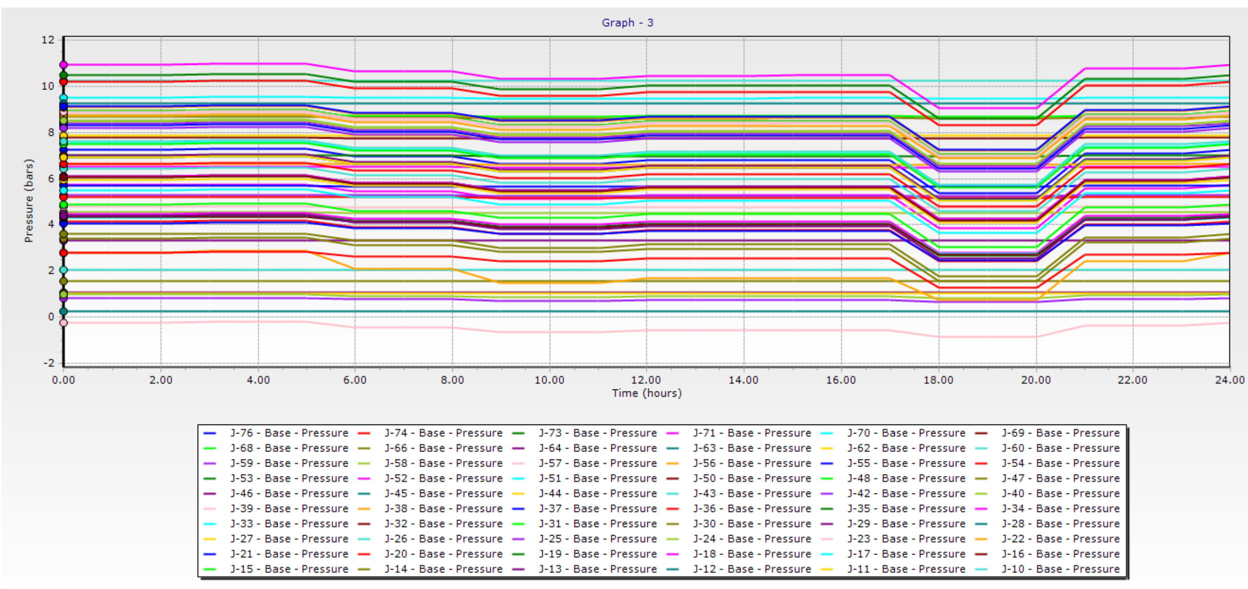

Figure 4.11 Pressure Results (Graph) on EPS

As for the velocity, some main pipelines had low velocity, especially during peak hours. The solution for this problem is to decrease the diameter of the pipes, which should increase the velocity. Then, we changed some pipes from 12 in to 3 in. obtaining allowable velocities in the pipes. We obtained the following graph that showed us that the velocity is still low at some point during the day, however, the value is still acceptable during consumption period.

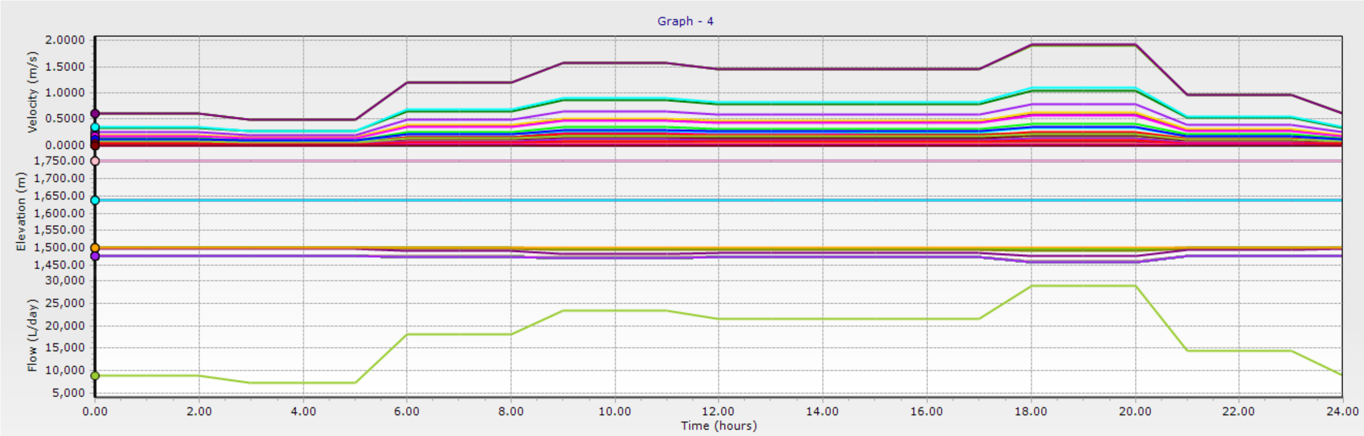

Figure 4.12 Velocity Results on EPS

The following graph illustrates the flow in the pipe exiting the tank WT-1, entering the system. We observe that the flow is at its greatest during the day as the demand is at its peak. And is at its lowest at night as low to no activities occur at night and thus the consumption is low.

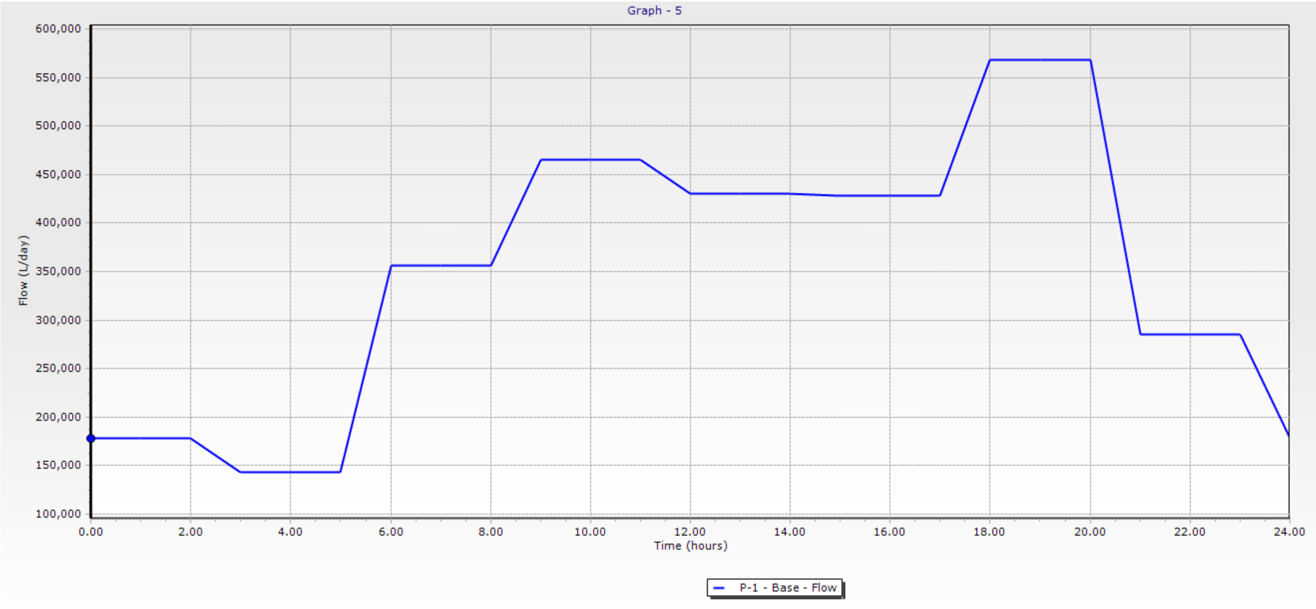

Figure 4.13 Results EPS of the flow Pipe 1

4.8. WaterCAD results – Flex tables

The following table shows the results obtained at the junctions where we observe an adequate value of the pressure at the junctions after adding the PRVs.

Table 4.6 - Flex tables - junctions

ID	Label	Elevation (m)	Zone	Demand Collection	Demand (L/day)	Hydraulic Grade (m)	Pressure (bars)
40	J-11	1,406.54	Zone - 1	<Collection: 2 items	6,000	1,477.35	7
41	J-12	1,406.50	Zone - 1	<Collection: 2 items	6,624	1,477.34	7
42	J-13	1,432.69	Zone - 1	<Collection: 2 items	16,800	1,477.40	4
43	J-14	1,440.68	Zone - 1	<Collection: 2 items	4,200	1,477.40	4
44	J-15	1,400.68	Zone - 1	<Collection: 2 items	10,800	1,477.34	8
45	J-16	1,415.30	Zone - 1	<Collection: 2 items	6,696	1,477.34	6
46	J-17	1,421.10	Zone - 1	<Collection: 2 items	1,200	1,477.34	6
47	J-18	1,415.05	Zone - 1	<Collection: 2 items	15,960	1,477.37	6
48	J-19	1,415.12	Zone - 1	<Collection: 2 items	1,200	1,477.38	6
49	J-20	1,409.55	Zone - 1	<Collection: 2 items	6,000	1,477.37	7
50	J-21	1,392.42	Zone - 1	<Collection: 2 items	3,000	1,477.35	8
51	J-22	1,388.12	Zone - 1	<Collection: 2 items	4,200	1,477.35	9
52	J-23	1,387.15	Zone - 1	<Collection: 2 items	4,800	1,477.34	9
53	J-24	1,390.60	Zone - 1	<Collection: 2 items	1,200	1,477.35	8
54	J-25	1,391.45	Zone - 1	<Collection: 2 items	1,800	1,477.35	8
55	J-26	1,411.59	Zone - 1	<Collection: 2 items	10,824	1,477.36	6
56	J-27	1,416.49	Zone - 1	<Collection: 2 items	7,200	1,477.37	6
57	J-28	1,415.41	Zone - 1	<Collection: 2 items	4,200	1,477.40	6
58	J-29	1,405.86	Zone - 1	<Collection: 2 items	3,600	1,477.37	7
59	J-30	1,442.53	Zone - 1	<Collection: 2 items	5,400	1,477.37	3
60	J-31	1,427.50	Zone - 1	<Collection: 2 items	12,000	1,477.39	5
61	J-32	1,433.46	Zone - 1	<Collection: 2 items	3,000	1,477.69	4
62	J-33	1,433.74	Zone - 1	<Collection: 2 items	1,800	1,477.78	4
63	J-34	1,431.75	Zone - 1	<Collection: 2 items	3,000	1,477.60	4

As for the velocities, the flex table for the pipes shows s the results obtained where the observe that the velocities are still very small at some pipes even after reducing the diameters to 3 in which the smallest pipes that can be used in the system. It is due to the low demand in the system.

Table 4.7 - Flex tables - Pipes

ID	Label	Length (Scaled) (m)	Start Node	Stop Node	Diameter (in)	Material	Flow (L/day)	Velocity (m/s)	Headloss Gradient (m/m)
97	P-1	47	R-1	J-40	3.0	PVC	237,324	0.6023	0.005
100	P-4	93	J-40	J-39	3.0	PVC	236,124	0.5993	0.006
101	P-5	292	J-39	J-38	3.0	PVC	236,124	0.5993	0.006
103	P-7	79	J-33	J-36	3.0	PVC	600	0.0015	0.000
106	P-9	41	J-33	J-32	3.0	PVC	135,334	0.3435	0.002
107	P-10	105	J-32	J-37	3.0	PVC	3,000	0.0076	0.000
108	P-11	138	J-32	J-28	3.0	PVC	129,334	0.3282	0.002

CHAPTER 5. GIS MODELLING USING ARCMAP

In this chapter we will be showing the GIS modeling done of Bazoun's Water Distribution System. We will be going through each component done on ArcMap. we used this Software as it enables us to have a Geodatabase of the region with all the information about each data entered in the Software. Water Utilities and Municipalities can benefit from storing the data in ArcMap as it shows clearly all the features in the WDS and the information entered are all geographically referenced.

5.1. Georeferencing of the WDS

From the official map that we obtained from the Ministry; the map includes the georeferencing of the region based on the official Lebanon Shapefiles. When we added the project to ArcMap, we used the Basemap in ArcMap. The BaseMap in ArcMAP is used for locational reference and is used to locate precisely where each data should be added. We compared the map obtained from Lebanon Shapefiles to the Basemap in GIS and found a certain offset distance. We decided to work on the official Lebanese Shapefiles.

5.2. Geodatabase

The geodatabase represents the data structure of ArcGIS. We created a geodatabase for our project where we added in it 3 main datasets: the first one "**Bazoun_Network**" contains all the WDS components; the second dataset is "**Bazoun_Region**" consists of a map of the region; and the third Dataset "**Smart_Network**" includes the components for the SMW. Each dataset includes relevant information that can be useful for the water utility companies when they need to check the system.

5.2.1. Bazoun Network

5.2.1.1. Pipes

For the pipes we mapped the pipes from the hydraulic model on GIS. The information assigned for the pipes include the following:

- **Diameter:** 3", 6", 8" or 12"
- **Type:** all pipes are Polyvinyl chloride (PVC)
- **Length:** the length of each type is automatically computed on ArcGIS

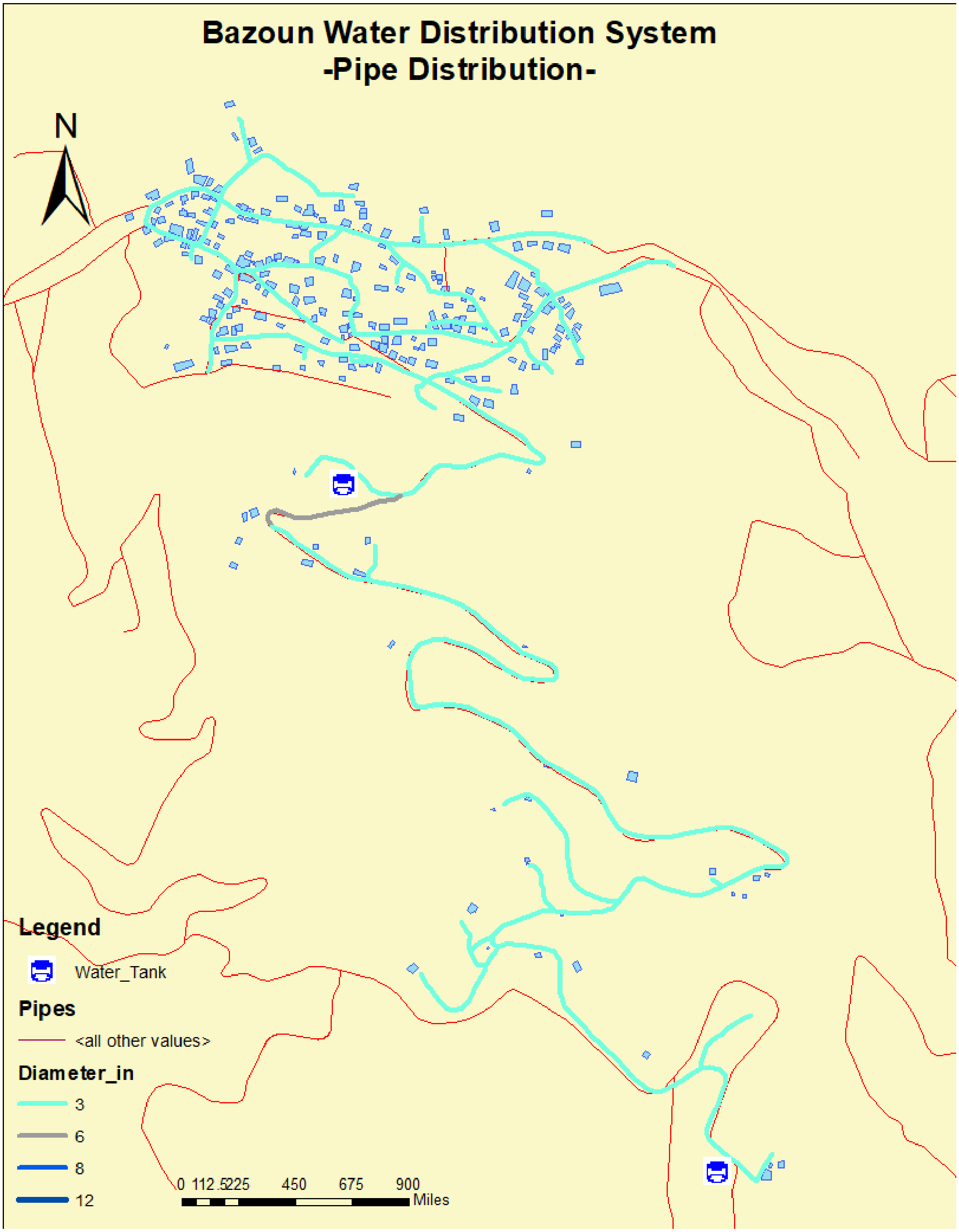

Figure 5.1 Pipe layout on GIS

5.2.1.2. Junctions

The junctions are added at each node, according to the model and assigned the following data:

- **Number:** to identify the junctions immediately and locate them on the map
- **Elevation:** the elevation at each pipe
- **Demand:** we added the residential and commercial demand at each junction. In case of any change (new construction for example).

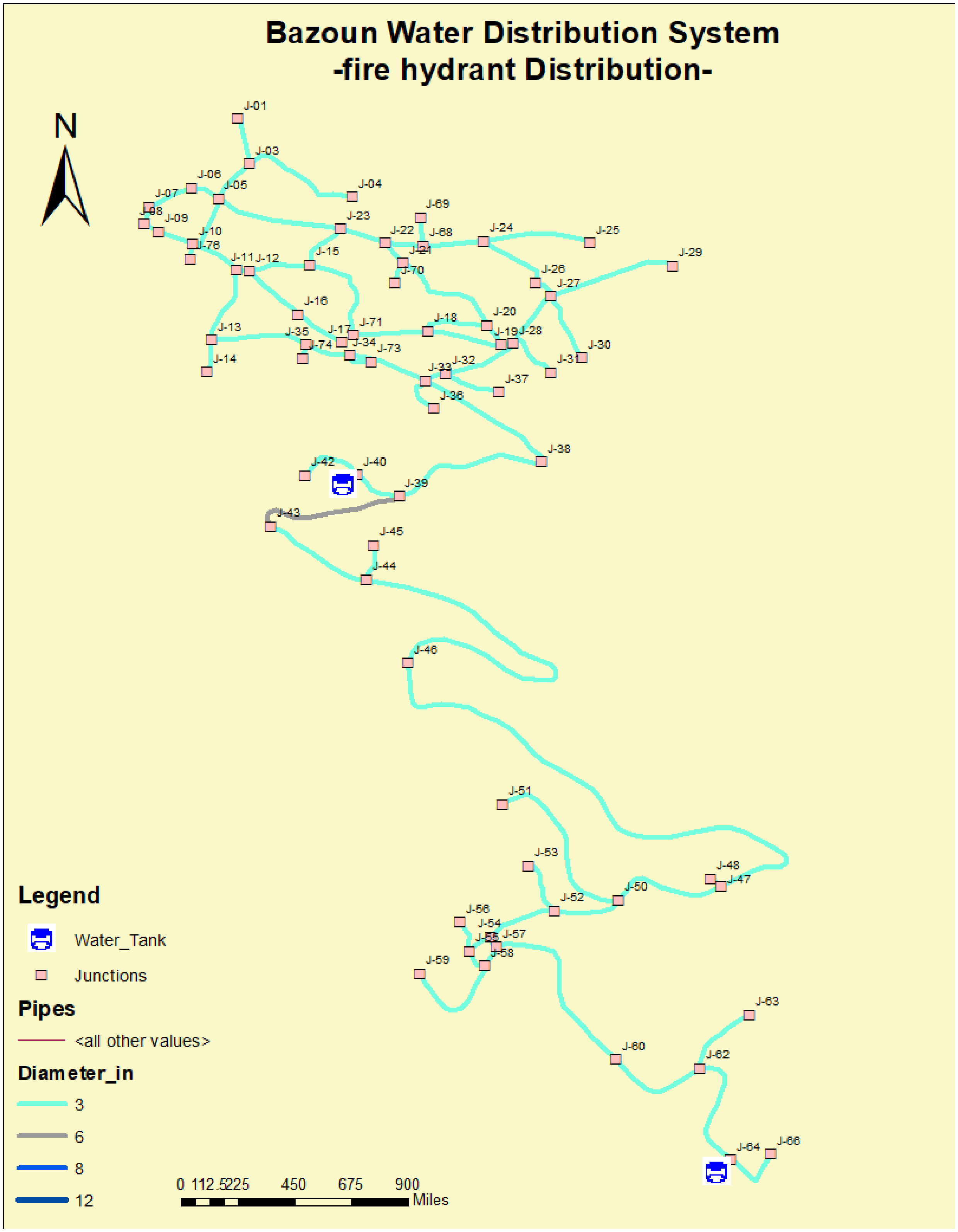

Figure 5.2 Junction Layout on GIS

5.2.1.3. Tank

The tank is added with its elevation and capacity.

5.2.1.4. Valves

All the valves were added on GIS and were classified by type:

- Gate Valves (GV) were added at each pipe, as they are isolation valves that can be used to isolate pipes during repair process or maintenance.
- Pressure-reducing Valves (PRV) are added based on the EPS results to reduce the high pressure in the system.
- Air-release Valves (ARV) should be added at the highest point in the system depending on the elevation at each point.
- Washout Valves (WO) should be added at the lowest points in the system.

The valves were also numbered so that the location of a specific valves can be easily done.

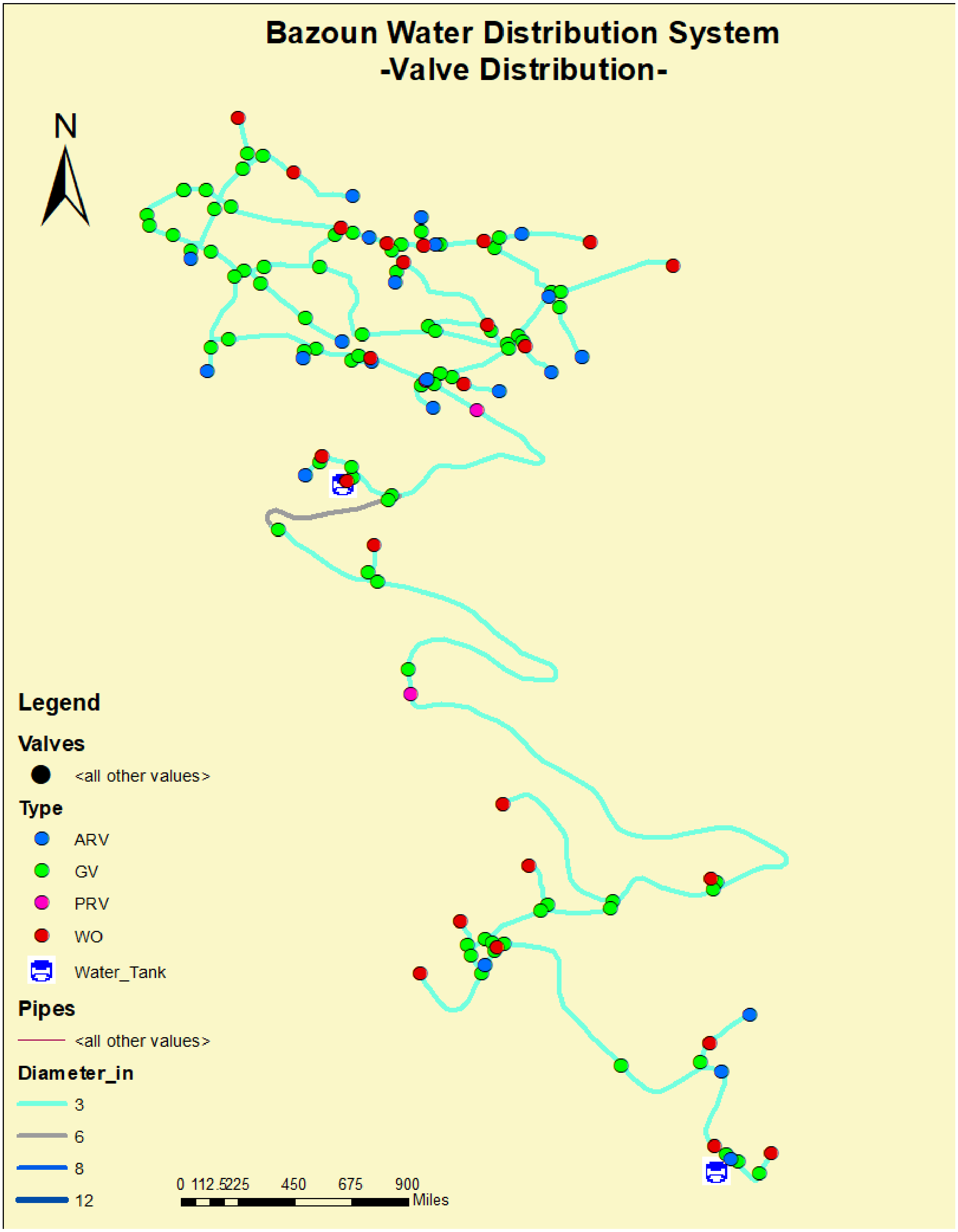

Figure 5.3 Valve Distribution on GIS

5.2.1.5. Fire Hydrants

For the Fire Hydrants, they are used to deliver water for firefighting. They are located mainly at the edge of road or at intersections, around 1 to 2 m from the edge of road.

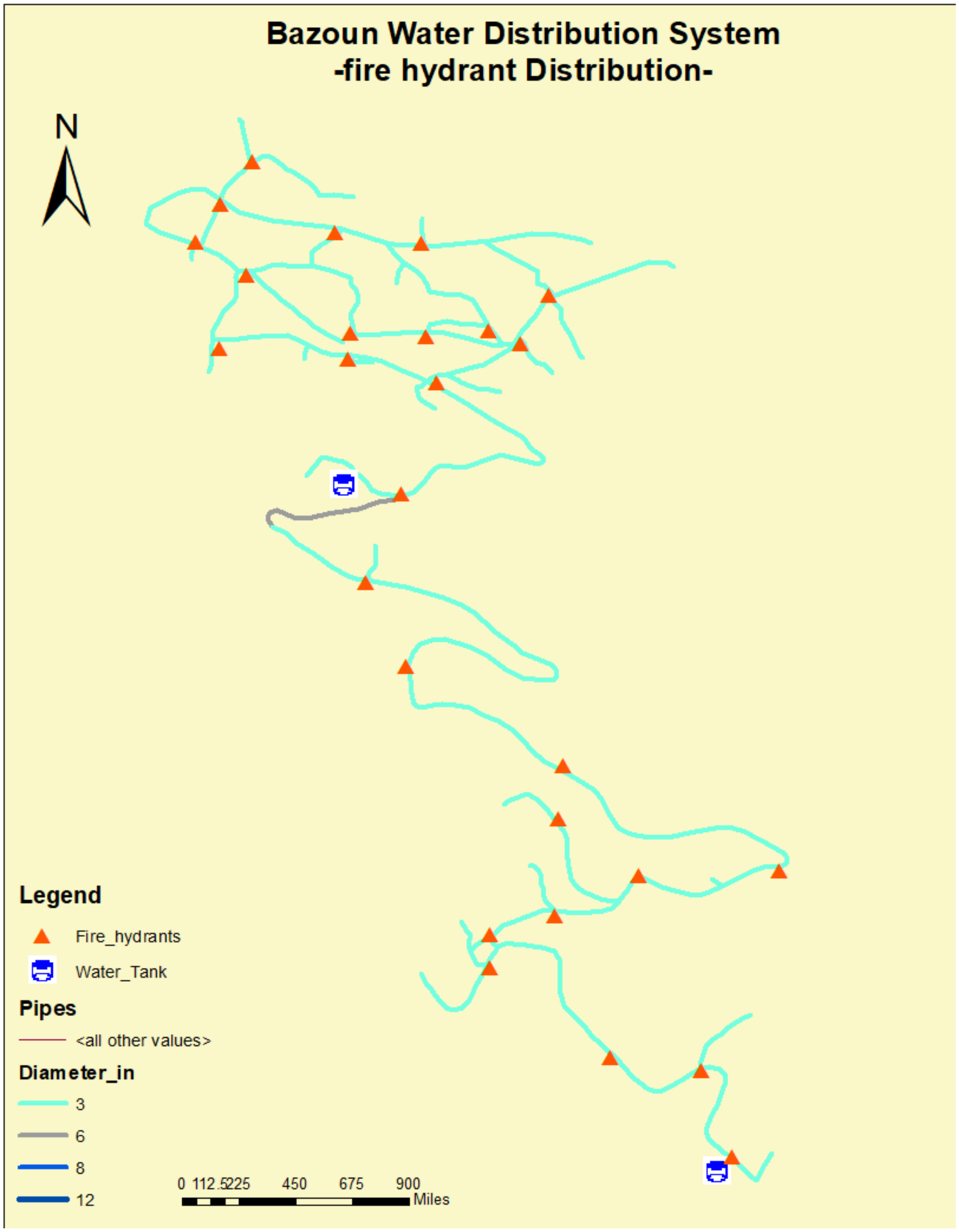

Figure 5.4 Fire Hydrants on GIS

5.2.2. Bazoun data

We added a dataset for the geographic data of Bazoun. Those data include a road map that was drawn from the Lebanese Shape Files and the distribution of the buildings in the region.

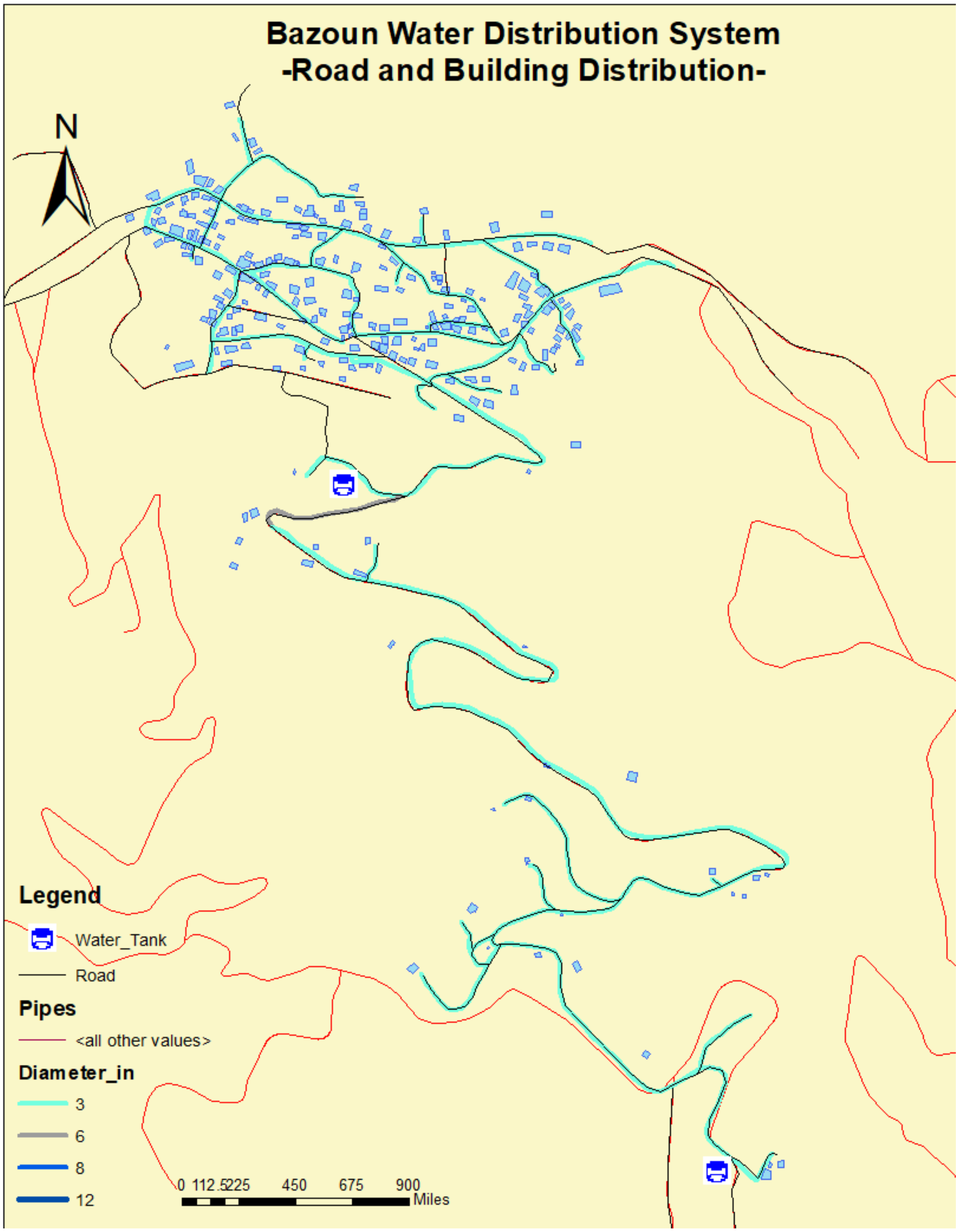

Figure 5.5 Bazoun Map on GIS

5.2.3. Smart Water Network

We added all the dataset related to the Smart Water Network that will be discussed later. The data include the following:

5.2.3.1. District Meter Areas

For the Smart Water Network, we used the District Meter Area Method (discussed in Chapter 6). Dividing the WDS into DMA was done on ArcGIS showing clearly the boundary of the DMA and what pipes it crosses.

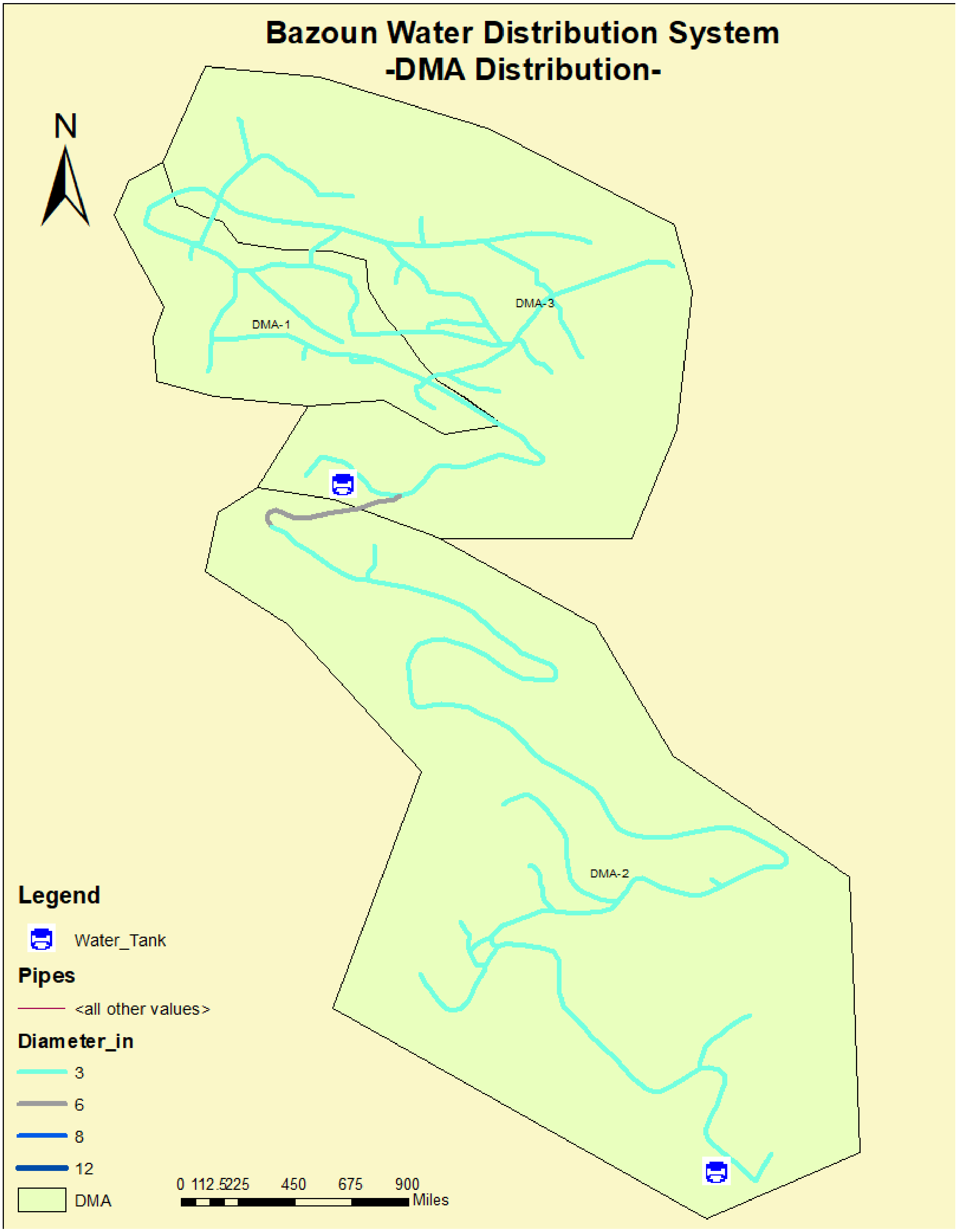

Figure 5.6 DMA distribution on GIS

5.2.3.2. Meters

We added in the system 2 types of meters:

- **Bulk Meters:** they’re the larger meters that are fitted to the pipes. they are located at the DMA’s boundary and measure the water flow entering the DMA.
- **Customer Meters**: those meters are located at each building and measures the water consumption of each consumer.

Each meter is classified by type and each customer meter is identified by a number.

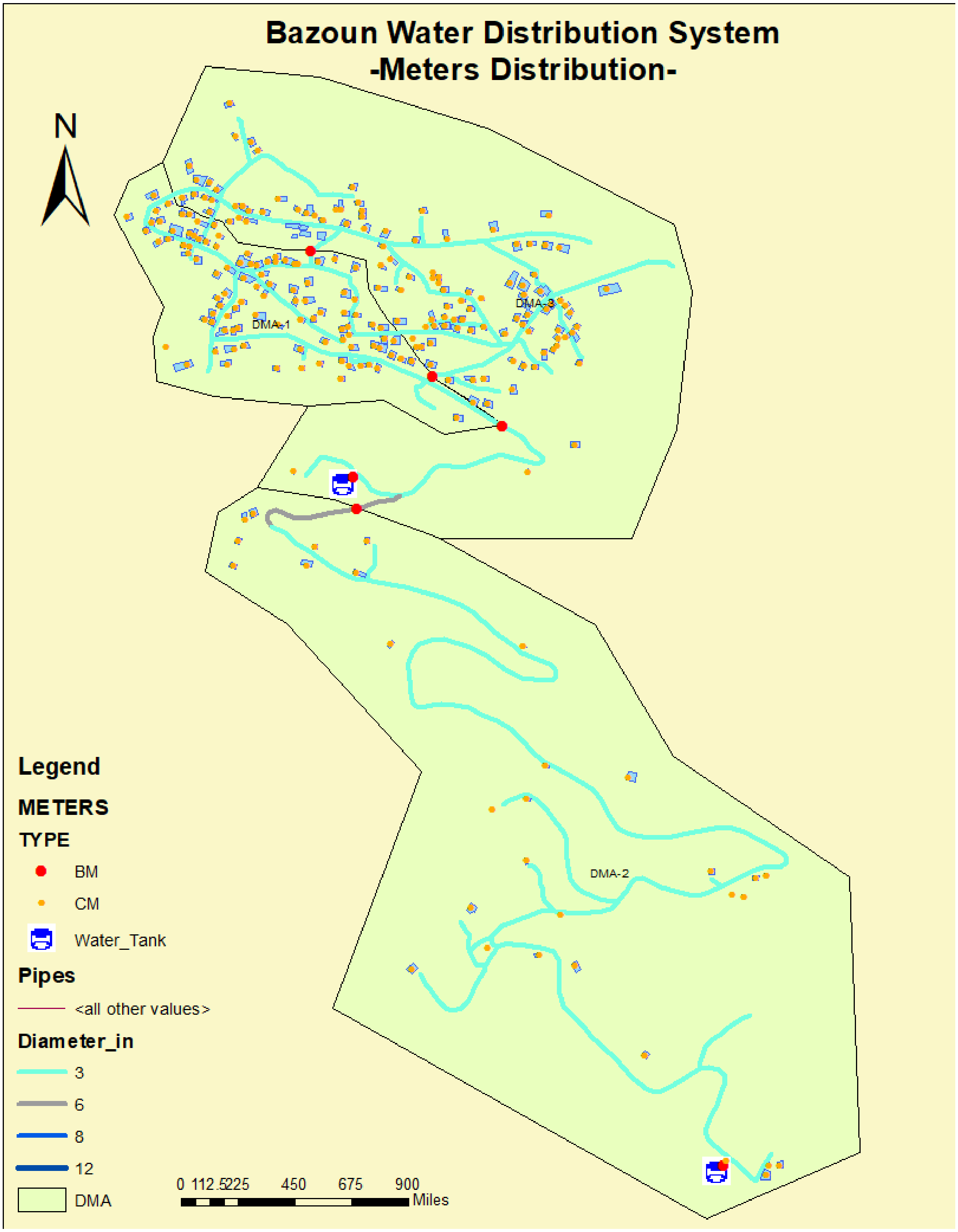

Figure 5.7 - Bulk and Customer Meters Layout on GIS

CHAPTER 6. SMART WATER NETWORK

In this chapter, we will be introducing the water network to the monitoring system that can be used to detect the losses and leakage in the system.

6.1. District Meter Area (DMA)

We added a feature class for the DMA where we divided the network into areas which will be isolated from each other. We divided the system into multiple DMAs. Each point where the DMA boundary crosses the Water pipelines, we install either a bulk meter or an isolation valve. That way, the water flow entering and exiting the DMA can be metered and quantified.

Multiple factors were taken into account while forming the DMAs:

- The size of the DMA shouldn't be too big, nor too small.
- The installed isolation valves should be located strategically.
- The DMA should include area of close elevation as much possible.

6.2. Monitoring System

The monitoring system will be composed of bulk meters and customer meters. We added Bulk Meters distributed in the DMAs. As for the customer meters, they are distributed at each building recording its water consumption during a period of time. These meters can record the water consumption and transmit the data through AMR technology. The meters are equipped with sensors and a radio transmitter. The water consumption data measured is transmitted via Radio Frequency (RF) to the collectors (water utility companies, municipalities, etc.) where the data are analyzed. The meters help monitoring any abnormal consumption in the system that might be the result of a leakage. The Minimum Nigh Flow method or the water balance method can be done in the system in order to detect leaks.

6.3. Scenario 1 – Leakage at DMA-1 using MNF

Let's take for example the DMA-1. DMA-1 intersects the WDS at multiple locations. We added bulk meters at 2 locations; one at a pipe where the flow is entering the DMA and the other where the flow is exiting DMA-1 (entering DMA-2) and for the rest we add isolation valves.

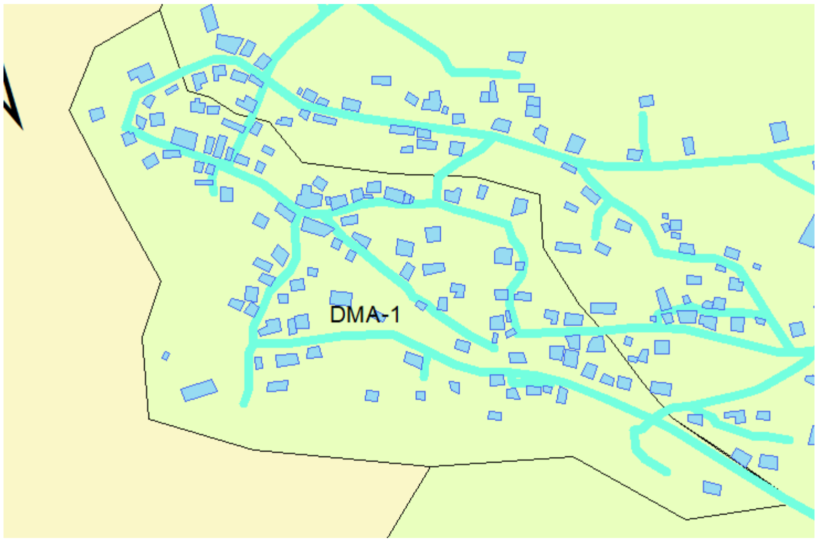

Figure 6.1 - DMA 1

The Bulk Meters measure the water entering and exiting the DMA. Then the water consumption inside this DMA is the difference between the water entering and the water exiting. In case of leakage inside the DMA, the water consumption will be much greater than the expected value (calculated).

We set in this scenario that we will be using the Minimum Night Flow (MNF) method to determine any leakage in DMA-1. In this scenario, we close the isolation valves. The bulk meters measure and send the data for the Consumption between 2 and 4 am (periodically). At night the demand is at its lowest, pressure is at its highest and leakage is dominant. If the MNF passes the threshold set, then the water utility companies are alerted of a leak in DMA-1.

We calculated the total consumption at night inside the DMA by calculating the consumption of each building located inside the DMA. We then find the consumption at night (between 2 and 4 am) from the multipliers.

Table 6.1 - Total Water Demand DMA-1

TOTAL RESIDENTIAL DEMAND (DMA-1)	220,800
TOTAL COMMERCIAL DEMAND (DMA-1)	1,830

Table 6.2 - Water demand in DMA-1

Residential			Commercial			total Demand (L/day)
Time from Start	Multiplier	Demand (L/day)	Time to start	Multiplier	Demand (L/day)	
2	0.5	110,400	2	0.4	732	111,132
3	0.4	88,320	3	0.6	1,098	89,418
4	0.4	88,320	4	0.6	1,098	89,418

The threshold is set by considering the night consumption (it includes toilet flushing, irrigation etc.). We can use Chebyshev's formula. To find the value of the threshold at each time, statistic research should be done over a certain period of time (1 week for example) where we measure the value of the consumption at the same time (2 am for example). Then we calculate the average value and standard variation of the consumption at each time. Then the measured consumption during this time frame is within the limit if its values doesn't exceed 3 standard deviations of the average value of the consumption: $X \leq \overline{X} + 3\sigma$. The following graph illustrates the consumption calculated for a certain day between 2 and 4 am.

6.4. Scenario 2 – Leakage at DMA-1 using Water Balance

Using the water balance method consists of measuring at each bulk meters the consumption in the system. This value should be close to the authorized consumption W_C which is the water consumed by the customers and the quantity used for firefighting, emergency purpose or for maintenance (unbilled authorized consumption). The increase in the difference between those values means that there is an increase in the quantity of the water losses W_L hence a probability of leakage.

6.5. Scenario 3 – Contamination in the System

Contamination of the WDS present a critical issue as it can results in many people getting contaminated in a short period of time. Once the Contamination is detected (can be detected through Water Quality Sensors), the water utility Companies can be alerted to act as quickly as possible. Closing the isolation valves around where the contaminated water is located prevents it from spreading to the rest of the Network.

CHAPTER 7. COST ESTIMATION - BOM

7.1. General Overview

A proper cost estimation of the Water Distribution System is critical to identify if the project is feasible or not, it gives a first idea of the cost of the project for the investors. Our cost estimation includes a **Bill of Material** only that is based on calculating the price of each component of the WDS.

7.2. Cost Estimation

7.2.1. WDS instruments

Table 7.1 WDS instruments Analysis

INSTRUMENTS COST					
Item	**Description**	**Qty.**	**Unit**	**Unit Rate**	**Amount US. $**
Pressure reducing valve	Standard: Cj/T219 Jb/T10674 En1074-5 GB 12221 Temperature: Ordinary Temperature Connection: Flange Valve Seat: Single-Seat Structure: Spring Diaphragm	2	count	100	200
Air Release Valve	Temperature: Low Temperature Connection: Flange Pressure: Auto Closed: Open	22	count	105	2310
Washout Valve	Media: Oil Temperature: Ordinary Temperature Type: OS&Y Wedge Type Material: Carbon Steel Connection Form: Double Flanged Pressure: Ordinary Temperature	26	count	80	2080
Gate Valve	Temperature: Ordinary Temperature Type: Straight-through Material: Stainless Steel Connection Form: Flange Pressure: Ordinary Pressure	76	count	350	26600
Customer Meter	Install: Horizontal Medium Temperature: Cold Water Level Measurement: B	244	count	160	39040

	Counter Instructions: Digital and Analogue				
Bulk meter	Install: Horizontal Medium Temperature: Cold Water Level Measurement: B Counter Instructions: Digital Nominal Diameter: DN15-300	6	count	180	1080
Fire Hydrants	Type: Outdoor Fire Hydrant Decompression: Normal Fire Hydrant Rotation: Ordinary Bolt Outdoor Fire Hydrant Type: Low Fire Hydrant Fire Hydrant Type: Ordinary Pressure: 250psi	27	count	500	13500
Receivers	Receiver System that includes a set of Antennas to collect the data send from the transmitters of the AMRs	1	count	10000	10000
			Total Price =	$	94,810.00

7.2.2. Tank

Our tanks are tanks made from reinforced concrete with an f'$_c$ of 35 MPa. Tank 1 has an area of 100 m^2 and height of 4 m, with a thickness of 30 cm. Tank 2 has an area of 100 m^2 and height of 3 m, with a thickness of 30 cm. The unit price for one cubic meter of the RC is 60$.

Table 7.2 Tank Cost Estimation

tank 1	**Description**	**unit**	**unit Price (US $)**	**Total Price (USD $**
Reinforced Concrete	f'c=30 Mpa	m3	60/m3	**$6,480**

Thickness to be used =	**30 cm**

Item	Length (m)	Width (m)	Qty.	Total area SQM
Tank Walls	4	10	4	160
Tank Slab/cover	10	10	2	200

Total area of tank =	360	m2
Total Volume of tank =	108	m3

tank 2	Description	unit	unit Price (US $)	Total Price (USD $
Reinforced Concrete	f'c=30 Mpa	m3	60/m3	**$5,760**

Thickness to be used =	**30 cm**

Item	Length (m)	Width (m)	Qty.	Total area SQM
Tank Walls	3	10	4	120
Tank Slab/cover	10	10	2	200

Total area of tank =	320	m2
Total Volume of tank =	96	m3

7.2.3. Pipes

Table 7.3 Pipes Cost Estimation

Item	**Description**	**Qty.**	**Unit**	**Unit Rate**	**Amount US. $**
Pipes 3"	PVC	10090.000	LM	$ 7.00	70630
Pipes 6"	PVC	278.000	LM	$ 8.00	2224
			Total Price ($) =		**72854**
			Price ($) =		**$72,854.00**
			Price ($) ROUNDED =		**$72,900.00**

7.2.4. Total Cost Estimation

Then we obtain a Total Cost of Bazoun's WDS:

Table 7.4 Total Cost Estimation

Bazoun Water Network Design - Cost Analysis -		
Summary Sheet		
Category	**Description**	**Price (USD)**
Instruments	Valves as Gate valves, water meters, Pressure reducing valves...	**$ 94,810.00**
Tank	Elevated Tank made of Reinforced Concrete with an f'c = 35 mPa	**$ 12,240.00**
Pipe	Ductile Iron Pipe	**$ 72,900.00**
	Total Price (USD) =	**$ 179,950.00**

CHAPTER 8. CONCLUSION

The Water Distribution System represents the source and infrastructure responsible of providing water to the households. it is critical to properly design a Water Network, able to provide an uninterrupted supply of potable water that is at required pressure. In Lebanon, the water infrastructure in on the verge of collapse, and thus future engineers are required to provide innovative new solutions to help this sector. In this project, we proposed the design of a Smart Water Distribution System, giving a first glance on what could the WDS be like in the country in the future.

We decided to work on Bazoun region. We collected the data of the region that showed us the demographic information, road map, buildings distribution, existing water source etc. All those information was taken from the ministry of energy and water in Lebanon. From those data collected, we did a preliminary layout of the WDS, adding the pipes and junctions. We divided the region into Thiessen polygons and calculated the demand at each junction. We then calculated the diameters of each pipe and the capacity of the tank. All of these calculations were done in Steady State on WaterCAD, considering the peak demand (maximum demand). We proceeded to run the system in Extended Period Simulation, considering that the demand varies throughout the day, hence, the pressure and velocities will vary. We obtained results showing pressures and velocities outside the required values, then we added valves and adjusted the pipe diameters until we obtained reasonable results.

The final Model was mapped on ArcGIS which is a software that enabled us to store all the data of the WDS components creating a geodatabase with all its datasets that can be easily accessed to and gives a clearly defined map that can be used by water utility companies, municipalities, NGOs or the ministry. The Map included the pipes' distribution, the junctions, the location of the valves, fire hydrants, etc. as well as the Smart Water Network equipment such as the bulk meters, customer meters etc.

We did a Conceptual design of the smart Water Network, showing the classification of the region into District Meter Area (DMA) and locating the bulk and customer meters. This results in a water network that is able to measure the water entering and exiting the DMA as well as the water consumed in the DMA.

Finally, we did a cost estimation of the whole project. We took the unit price of each WDS items, calculated the total quantity of each item and obtained the total price.

This project was a first step for us in the hydraulic field. We worked with motivation that one day we will be able to implement what we learned in real life and especially in Lebanon and shed the light on the rising problem of the Water Sector in the country.

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