PENN STATE UNIVERSITY
MASTER OF GEOGRAPHIC INFORMATION SYSTEM (MGIS)

HYDRAULIC ANALYSIS COMPARING EFFICIENCY OF ONE AND TWO-ZONE PRESSURE WATER SYSTEMS

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1. Executive Summary

Water Distribution System operations require enormous amount of energy and subsequently involve higher operational costs. With ever increasing costs of electricity in California and its high usage for well water pumping operations, the total costs for operating the City of Downey's 20 well pumps annually amounts to over $1.4 million dollars. Given this situation, it is paramount to evaluate other means of reducing electrical costs for system well pumping operations.

This study is focused on evaluating alternate methods for reducing water distribution system well pumping operational costs and provides a detailed overview of the comparative analysis of one and two zone pressure water distribution systems using an existing hydraulic model. This analysis consists of using hydraulic simulation methods to evaluate, extract, and compare zone pressure variability between one and two zone pressure systems and the well pumps' energy efficiency. As part of this study, specialized geographic information systems (GIS) workflow methods are used to assess and compare the annual power consumption rates. This study also includes an analysis for the payback period for proposed installation and field changes.

2. Project Objectives

This study quantifies the improvements in energy conservation and pressure variability by moving to a two zone system, and determines the payback period.

3. Introduction/Background/Discussions

The City of Downey is located in the Southwestern United States near Los Angeles, California. The City currently serves water to a population of about 113,000 residents through 21,500 meter connections. On an average day the system delivers about 10.2 million gallons of water. The City provides about 18,500 acre-feet of water annually. It relies solely on its groundwater wells to meet the potable water demands for its customers.

The City's water distribution system consists of 260 miles of water mains fed by 20 active deep groundwater wells which are located throughout the city. These wells vary in depth ranging from 1,000 to 2,000 feet below ground level. The water system consists of about 1,850 fire hydrants to help with fire hazard emergencies. The City utilizes the Central Basin and its aquifers as storage facilities for groundwater, which currently makes up all of the potable water used by the City customers. The system also has supplemented inter-connections, which provide water from the other water purveyors such as Metropolitan Water District and Central Basin Water Municipal District, in the event of emergencies or excess demand needs.

The 20 active wells currently produce a combined average of up to 21,000 gallons per minute (GPM). The estimated peak demand is 13,000 GPM, while the average demand is 10,200 GPM. The well operations are managed and controlled by City's Supervisory Control and Data Acquisition (SCADA) system located at the utilities yard and the pressures are maintained at 65 pounds per square inch (psi). Wells are brought online as the system pressure falls in order to maintain the average system pressure at 65 psi. There is an elevation change of 55 feet from the north end of the City to the south end of the

City resulting in a pressure variation of approximately 50 psi across the system. Due to elevation changes from the City utilities yard to the north and south ends of the city, the local pressure varies from a low of 48 psi to a high of 98 psi while the pressure measured at the utilities yard is 65 psi. Based on previous tests the lowest pressure noted at the northwest corner of the City was 44 psi and the pressure at the south end of the City was 98 psi. The City provides this potable water through a pipe network consisting of 4” diameter to 24” diameter mains.

The City’s groundwater wells are operated based upon one centralized pressure transducer located at the utilities yard. A predetermined pump/well sequence control strategy is used to stage pumps on/off based on a pressure-operating band. A system pressure of 60 to 70 psi is desired. When the pressure drops below the pre-determined set point of 60 psi, a well is turned off. If the pressure continues to drop, one or more wells, based on pre-programmed logic sequence, are turned on. Once pressure returns to 70 psi, wells are turned off in the reverse sequence of when they were turned on until pressure remains steady between 60 psi and 70 psi.

The City’s SCADA system supports the following operations in monitoring the Water Distribution System.

1. Flow rate and total volume
2. Flow check valve status
3. Differential pressure
4. Well water level
5. Well pump on/off control
6. kWh, power factor, voltage, AC power phase condition, AC power status
7. Well pump on/off and speed control
8. Well pump on/off status. Speed, motor vibration, motor temperature
9. Pump load
10. System pressure
11. Suction pressure
12. Discharge pressure
13. Valve position feedback

3.1. GIS and Hydraulic Mode Integration

A GIS decision support system provides critical information about the location and condition of water utility assets. The City of Downey currently maintains all its water distribution network elements and assets in the GIS. The City’s GIS database system is comprised of feature classes for water distribution mains and nodes such as pipes, valves, fire hydrants, junctions, and vaults etc. This system is very helpful and provides proactive support in addressing the issues of aging water infrastructures. The City’s current GIS consists of water infrastructure geometric network and attributes extracted and COGO’d from engineering record drawing and construction As-builts.

GIS features can easily be integrated with the hydraulic modeling software; however there are some distinct rules to be followed to bring GIS features in the Hydraulic Model Network. Orphan elements in any features class are not permitted in the modeling environment as it will cause the model to break down. A GIS features class can easily accommodate this situation and will not create any problems. A Hydraulic Model requires specific attributes such as: pipe material, pipe length, flow volume, pump energy equations, water levels (in Downey's case), node elevations, etc. compared with a GIS feature class where any number of attributes can be stored. A hydraulic model is usually skeletonized in order to keep only those pertinent parts of the hydraulic network that will have a significant impact on the behavior of the system.

3.2. Hydraulic Modeling Concepts and Existing Hydraulic Model of the City of Downey

A hydraulic model is a geometric network based on mathematical models which utilizes numerical equations to depict and simulate the behavior of the water distribution system. The system uses two basic types of equations which are solved for hydraulic calculations:

1) Mass continuity equations - The system satisfies the concept of volume of flow in the system is in equilibrium with the volume of flow out.
   $A_1V_1 = A_2V_2$
   Where A = Area of pipe
   V = Velocity water in the pipe
2) Energy conservation law - Water gains or loses energy as it moves through the system. Pumps add energy to the system and the friction and roughness reduces energy. Water loses energy when it passes through the junctions and valves.
   $P + (1/2)\rho V^2 + \rho gh = \text{constant}$
   Where P = pressure
   ρ = Fluid density
   g = Gravitational acceleration
   h = Elevation

Hydraulic model enables simulating the field condition and it allows for running "What-if" scenarios. Using results from a hydraulic model could help in making informed decision, such as size of water mains that would be required to support a new development area or when to remove aging water appurtenances.

A hydraulic model is comprised of links and nodes. The water pipes are defined as links and the valves, junctions, pumps, water reservoirs are described as nodes. The purpose each element serves in the system is defined as below:

1) A pipe conveys water from one node to another.
2) A reservoir node provides water to the system.
3) A junction removes or adds water to the system.
4) A pump node adds energy - in other words it raises the head of water elevation in the system.
5) A control valve controls the flow of water in the system.

3.3. Single Zone Water Distribution Hydraulic Model

The City's hydraulic model was built using water data from the City's GIS layers. The basic purpose of the model was to help in identifying aging infrastructure and to depict and simulates the field conditions. This model is a combination of GIS elements integrated with hydraulic logic and principles of the water flow system.

The various steps involved in creating City's hydraulic model are:

1) Extract and COGO water Infrastructure data from CAD based on construction As-builts and import into GIS feature classes.
2) Review GIS data per model requirements.
3) Import and develop network topology from GIS classes (skeletonization).
4) Collect water consumption meter data records.
5) Input/import water system infrastructure facilities such as well, pumps, valves, fire hydrants etc.
6) Using ortho imagery, extract elevation values for each node.
7) Based on pipe material types assign a roughness factor to the each pipe. In Downey's model the Hazen William roughness coefficient is used.
8) Allocate node demands based on type of land use.
9) Input and integrate pump curves for pump operations, and diurnal curve to define a pattern of 24 hour water usage. Sequencing logic for the pumps to turn on and off, and well draw down levels etc.
10) Import and assign fire flow demands to the fire hydrant nodes.
11) Test hydraulic model for any inconsistencies.
12) Run fire hydrant field flow tests.
13) Calibrate the model based on field flow tests.

Hydraulic modeling is carried out in Innovyze software which is an add-on to the ArcGIS Desktop software. This software provides supports functionalities from building to creating all possible what-if scenarios relevant to a water distribution system. Hydraulic system simulation can be observed in two main types define as "Steady State Simulation" and "Extended-period Simulation." In a steady state simulation the model provides a snapshot of unique computations about flows, pressures, pump operating parameters, and valve conditions based on fixed boundary conditions. This simulation refers to a state of system that is unchanging in time. These boundary conditions could be at the peak day time, peak hour time, average daily demand etc.

3.4. Extended Period Simulation (EPS)

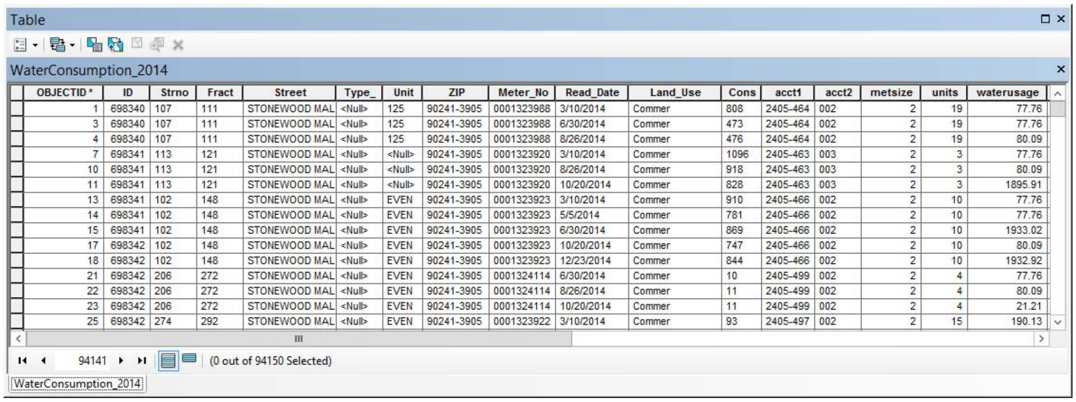
A steady state simulation provides extremely helpful analysis; however in computing the results in a series of hydraulic time steps such as pump run operations it is not helpful. A hydraulic time step can be defined as the time where the behavior of the system remains unchanged. An extended period simulation computes the results based on given time intervals for a cycle of duration. To analyze the Downey's water system a duration of 24 hours with an interval of one hour is utilized.

EPS system provide computed results for each interval to show how the system is behaving for the changing boundary conditions of consumption demands and wells being turned on and off.

4. Project Approach and Two Pressure Zone Methodology

To evaluate the goals of this project an extended period simulation (EPS) techniques for a time period of 24 hours are utilized. These simulations were conducted to compare pressures in one and two zone system and their energy efficiencies for the well pumps. The existing single zone hydraulic model was divided into two different boundary conditions to simulate a two zone pressure system.

As a first step, the latest household consumption data (Table1) from the Finance Department was acquired and converted to gallons per minute (GPM) units for utilization with the hydraulic model computations. This data was related to a parcel GIS layer and updated into the Water Distribution Hydraulic Model to depict current patterns of water consumption demands. Using InfoWater software tools the demands were allocated to the proper nodes in the model. Additionally, well pumps field test parameters (Table 2) were obtained from the City's Utilities Division staff and were updated into the model to reflect latest field conditions in the model.



OBJECTID *	ID	Strno	Fract	Street	Type_	Unit	ZIP	Meter_No	Read_Date	Land_Use	Cons	acct1	acct2	metsize	units	waterusage
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4	698340	107	111	STONEWOOD MAL	<Null>	125	90241-3905	0001323988	8/26/2014	Commer	476	2405-464	002	2	19	80.09
7	698341	113	121	STONEWOOD MAL	<Null>	<Null>	90241-3905	0001323920	3/10/2014	Commer	1096	2405-463	003	2	3	77.76
10	698341	113	121	STONEWOOD MAL	<Null>	<Null>	90241-3905	0001323920	8/26/2014	Commer	918	2405-463	003	2	3	80.09
11	698341	113	121	STONEWOOD MAL	<Null>	<Null>	90241-3905	0001323920	10/20/2014	Commer	828	2405-463	003	2	3	1895.91
13	698341	102	148	STONEWOOD MAL	<Null>	EVEN	90241-3905	0001323923	3/10/2014	Commer	910	2405-466	002	2	10	77.76
14	698341	102	148	STONEWOOD MAL	<Null>	EVEN	90241-3905	0001323923	5/5/2014	Commer	781	2405-466	002	2	10	77.76
15	698341	102	148	STONEWOOD MAL	<Null>	EVEN	90241-3905	0001323923	6/30/2014	Commer	869	2405-466	002	2	10	1933.02
17	698342	102	148	STONEWOOD MAL	<Null>	EVEN	90241-3905	0001323923	10/20/2014	Commer	747	2405-466	002	2	10	80.09
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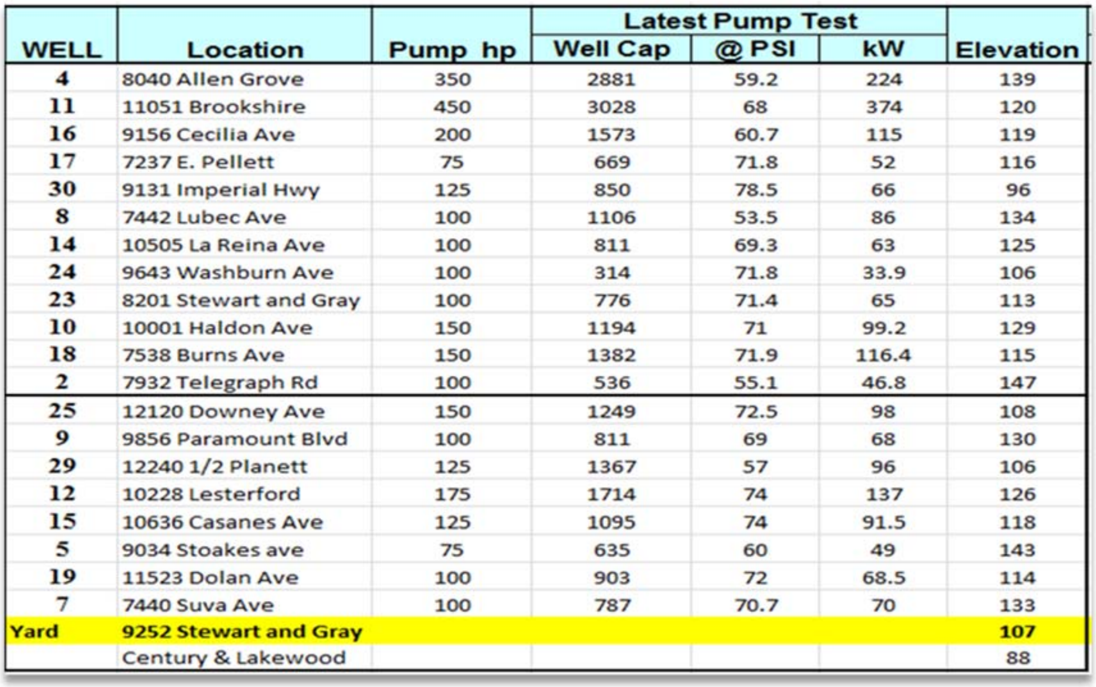
22	698342	206	272	STONEWOOD MAL	<Null>	EVEN	90241-3905	0001324114	8/26/2014	Commer	11	2405-499	002	2	4	80.09
23	698342	206	272	STONEWOOD MAL	<Null>	EVEN	90241-3905	0001324114	10/20/2014	Commer	11	2405-499	002	2	4	21.21
25	698342	274	292	STONEWOOD MAL	<Null>	EVEN	90241-3905	0001323922	3/10/2014	Commer	93	2405-497	002	2	15	190.13

Table 1. Water Meter Consumption Data Records



WELL	Location	Pump hp	Latest Pump Test			Elevation
			Well Cap	@ PSI	kW	
4	8040 Allen Grove	350	2881	59.2	224	139
11	11051 Brookshire	450	3028	68	374	120
16	9156 Cecilia Ave	200	1573	60.7	115	119
17	7237 E. Pellett	75	669	71.8	52	116
30	9131 Imperial Hwy	125	850	78.5	66	96
8	7442 Lubec Ave	100	1106	53.5	86	134
14	10505 La Reina Ave	100	811	69.3	63	125
24	9643 Washburn Ave	100	314	71.8	33.9	106
23	8201 Stewart and Gray	100	776	71.4	65	113
10	10001 Haldon Ave	150	1194	71	99.2	129
18	7538 Burns Ave	150	1382	71.9	116.4	115
2	7932 Telegraph Rd	100	536	55.1	46.8	147
25	12120 Downey Ave	150	1249	72.5	98	108
9	9856 Paramount Blvd	100	811	69	68	130
29	12240 1/2 Planett	125	1367	57	96	106
12	10228 Lesterford	175	1714	74	137	126
15	10636 Casanes Ave	125	1095	74	91.5	118
5	9034 Stoakes ave	75	635	60	49	143
19	11523 Dolan Ave	100	903	72	68.5	114
7	7440 Suva Ave	100	787	70.7	70	133
Yard	**9252 Stewart and Gray**					**107**
	Century & Lakewood					88

Table 2. Well Pumps Field Test Data

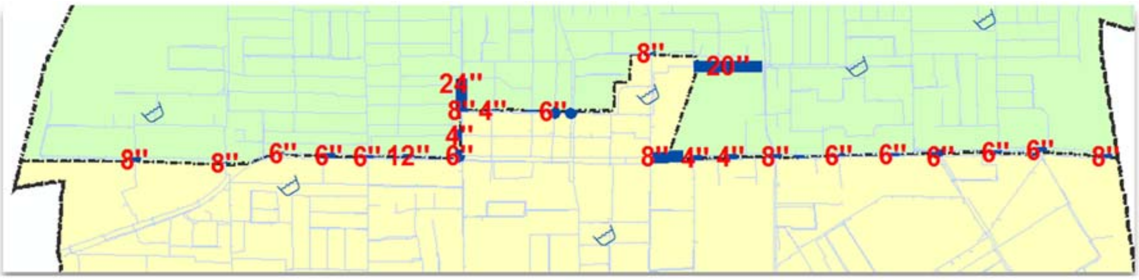
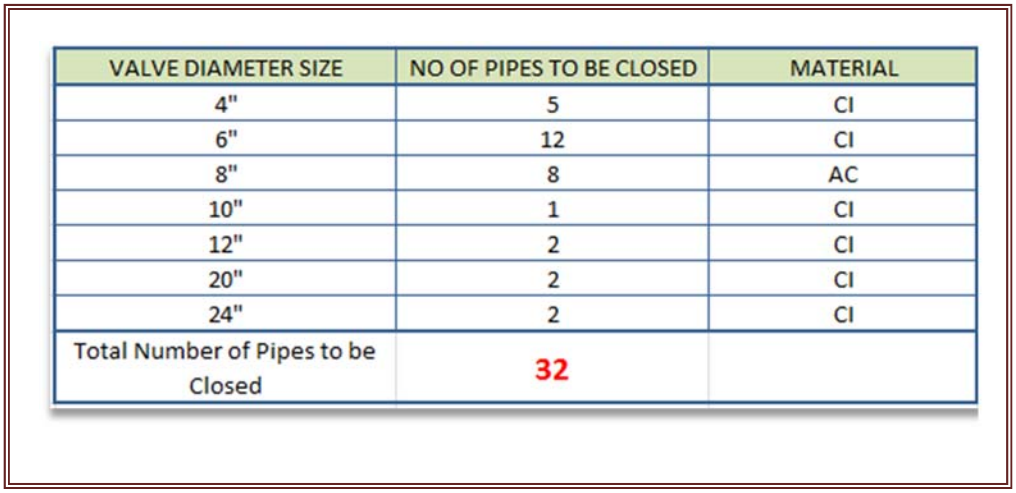


Figure 1. Two Zone Boundary Conditions



VALVE DIAMETER SIZE	NO OF PIPES TO BE CLOSED	MATERIAL
4"	5	CI
6"	12	CI
8"	8	AC
10"	1	CI
12"	2	CI
20"	2	CI
24"	2	CI
Total Number of Pipes to be Closed	32	

Table 3. Isolated pipes segments to be separated by pressure sustaining valves

The existing single zone pressure system was analyzed to locate optimal pipe segments for closure and to create a two zone boundary conditions (Figure 1). There were about 32 pipe segments (Table 3) needed to be closed to create such a system. The field implementation would require installation of pressure sustaining valves to accomplish these changes. The pressure controlling nodes (Figure 2) were moved to a geographically centralized locations for optimizing the effectiveness of well pumps controlling pressures. The model was updated with two zones well pump staging sequence for the pump start/stop operation logics. An extended period simulation for a period of 24 hours was ran to analyze the system.

The analyzed result illustrations include comparison graphs for control node pressures (Figure 3, 4, 5) and well flows (Figure 6, 7) for one and two zone simulations. The conclusion points were drawn comparing two large and two small well pump patterns in flow differences. The pressure comparisons were also depicted by pressure distribution maps between these two zones systems for two different time stamps, one in the morning hours at 6:00 a.m. (Figure 8, 9) and the second at evening hours 6:00 p.m.

The energy calculations were extracted using model in kWh units. A saving of 1,088,360 kWh (Table 4) was perceived through this comparative analysis (Figure 10). An annual average system demand and a lowest tier of rate charge of $0.11 per kWh from Southern California Edison Company (SCE) was used to draw these conclusions. According to these calculations a saving of $120,720 is perceived annually. The field modifications and the construction cost for the installation of 32 pressure sustaining valves were calculated to be $373,000 (Table 5). Using these extracted values a recovery period of 3.09 years was determined (Table 6).

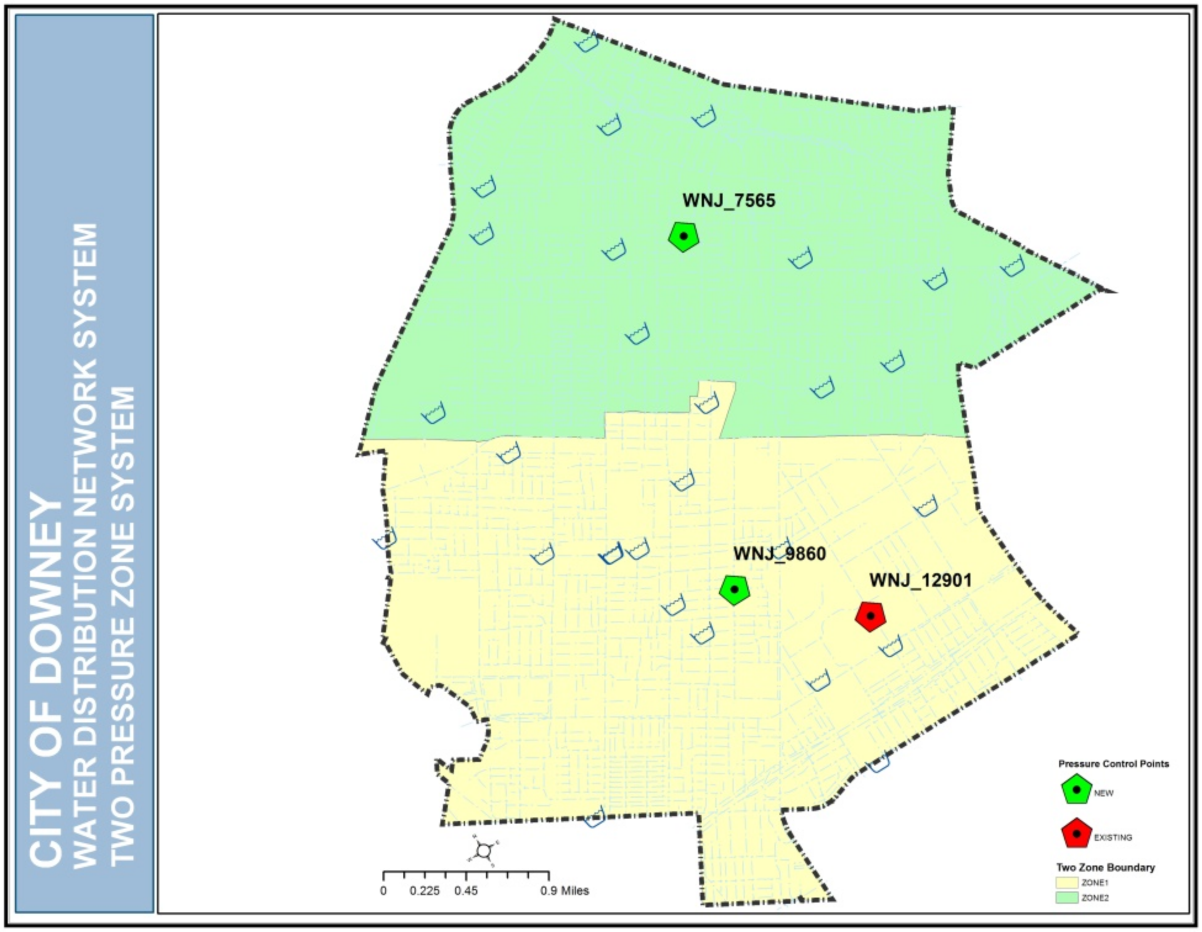


Figure 2. One and two boundary condition pressure control nodes

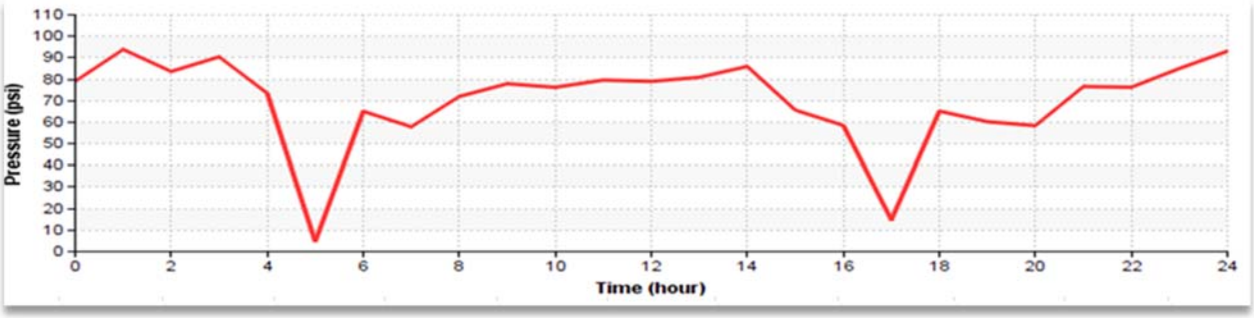


Figure 3. One zone pressure variation for 24 hours period

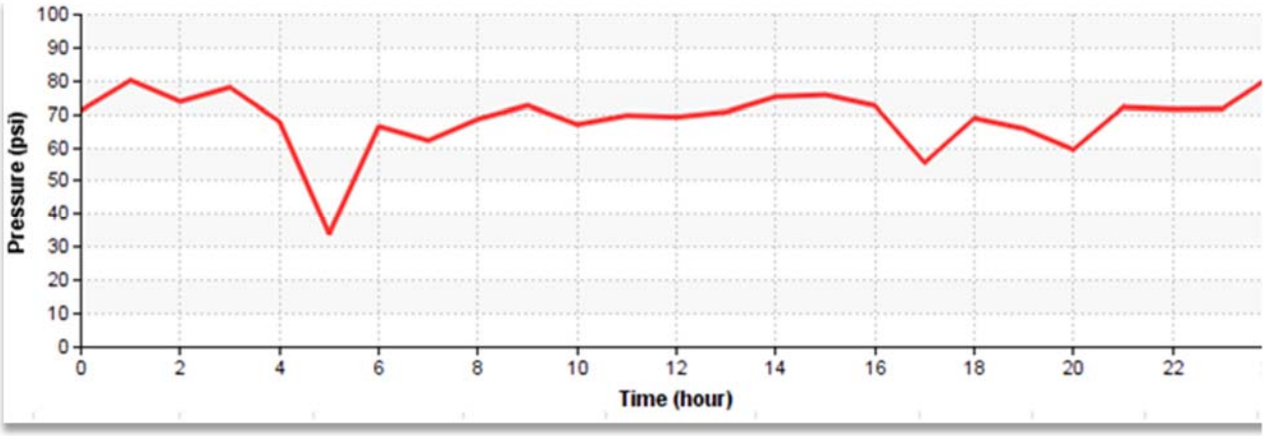


Figure 4. Two zone pressure variation for 24 hours period (North zone)

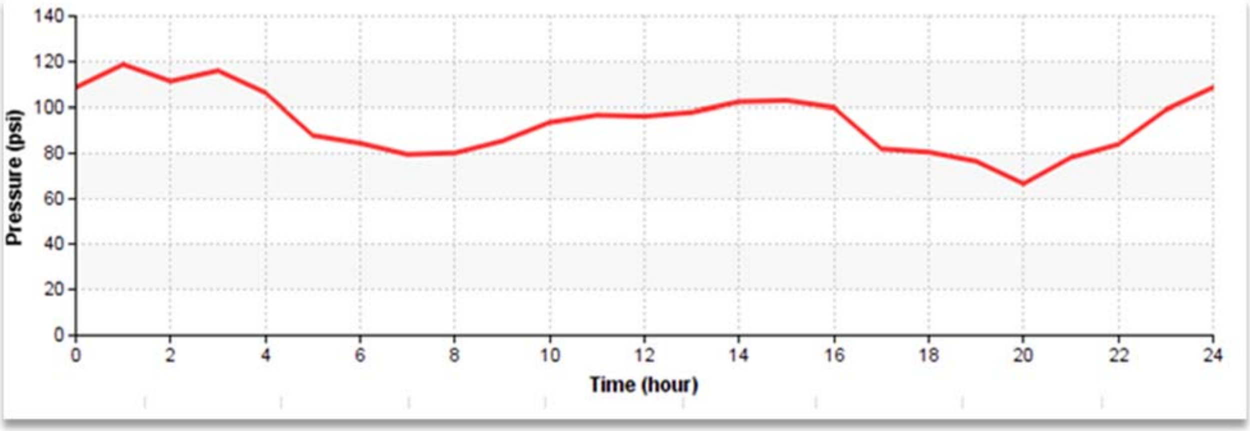


Figure 5. Two zones pressure variation for 24 hours period (South zone)

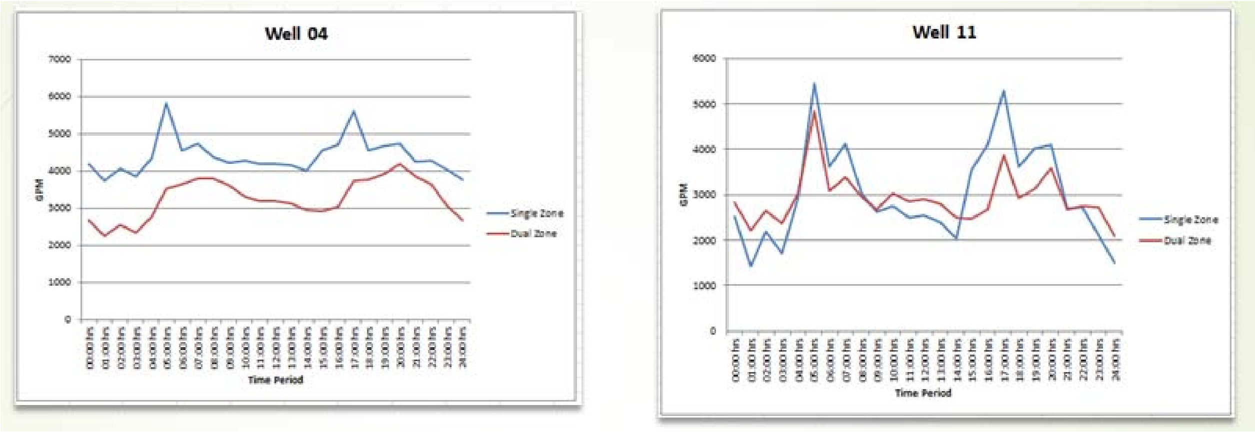


Figure 6. Pumps with 500 and 450 Horse Power (hp) discharge flow distribution patterns

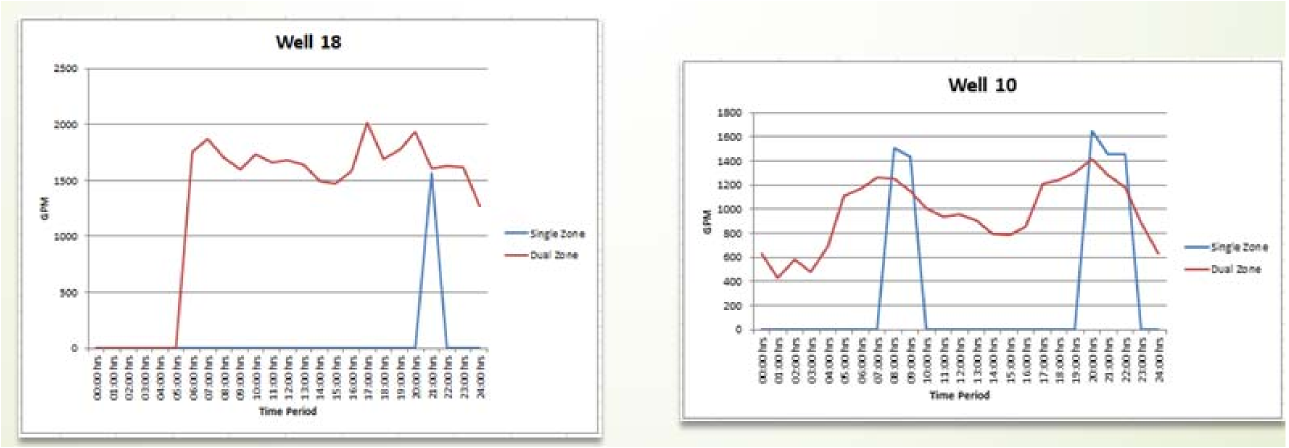


Figure 7. Pumps with 100 and 160 Horse Power (hp) discharge flow distribution patterns

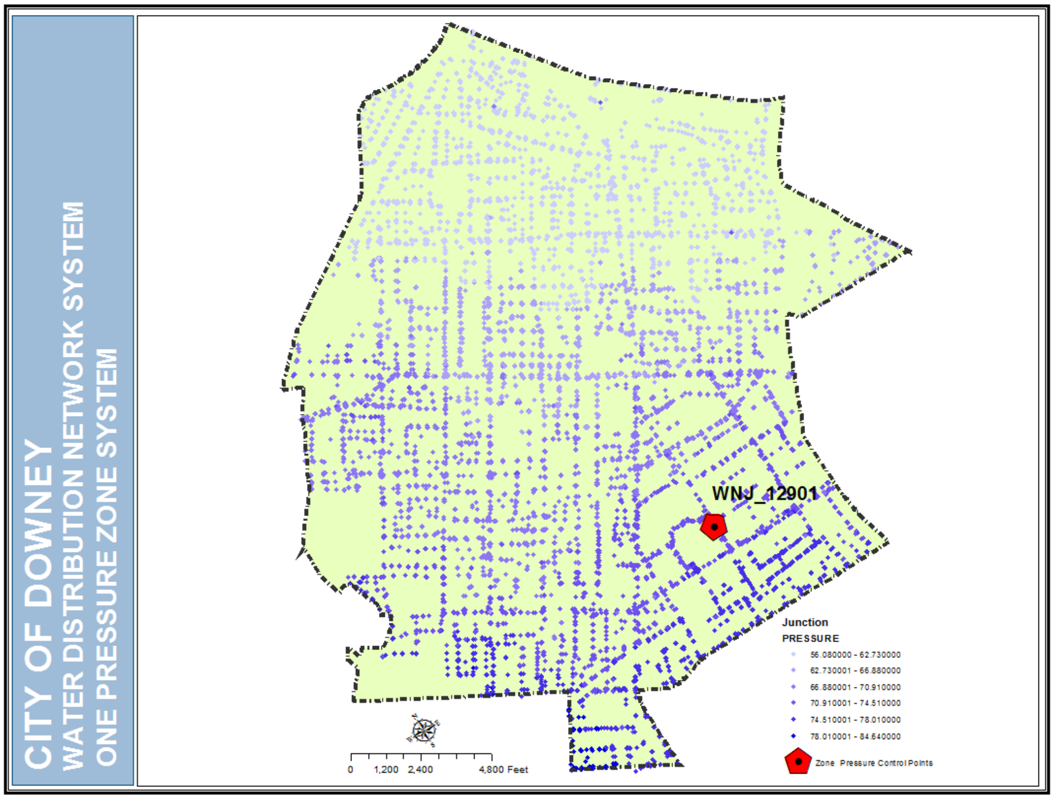


Figure 8. One zone pressure variation distribution pattern at 6:00 a.m.

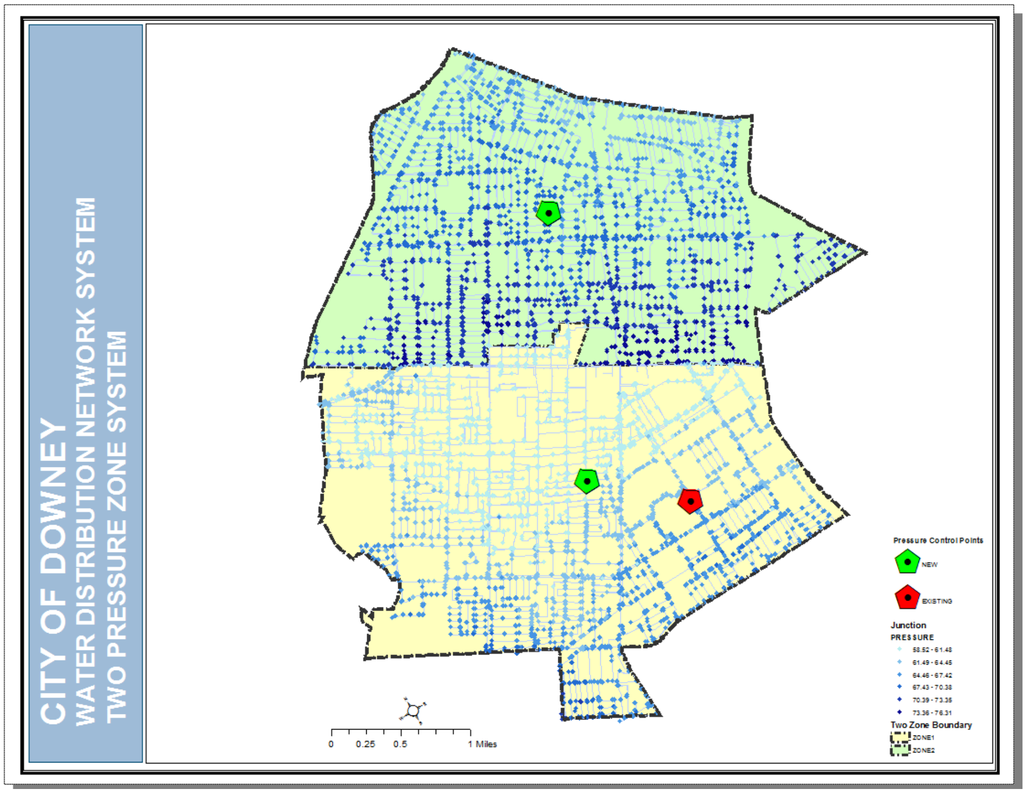
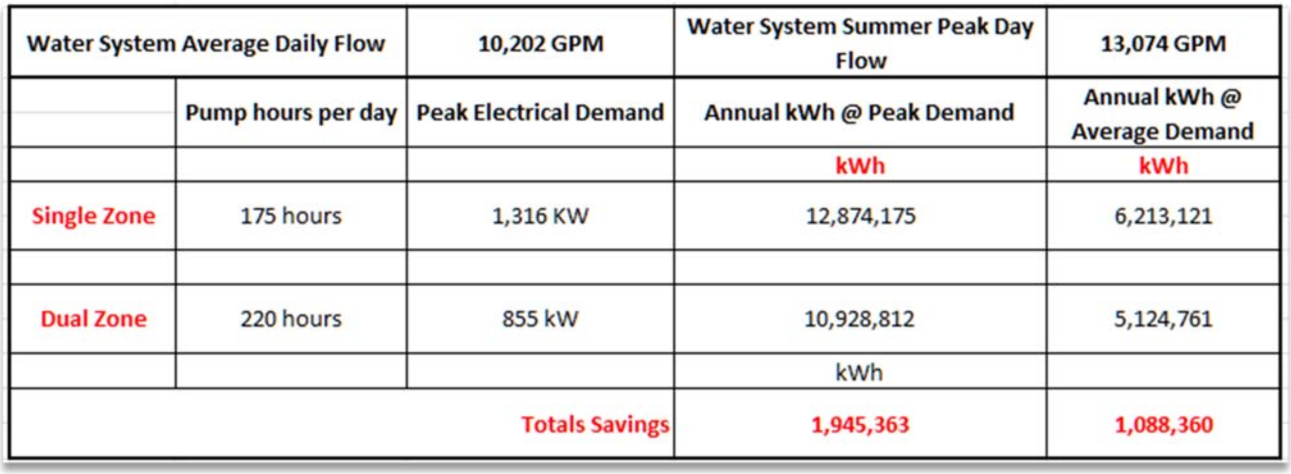


Figure 9. Two zones pressure variation distribution pattern at 6:00 a.m.



Water System Average Daily Flow		10,202 GPM	Water System Summer Peak Day Flow	13,074 GPM
	Pump hours per day	Peak Electrical Demand	Annual kWh @ Peak Demand	Annual kWh @ Average Demand
			kWh	kWh
Single Zone	175 hours	1,316 KW	12,874,175	6,213,121
Dual Zone	220 hours	855 kW	10,928,812	5,124,761
			kWh	
		Totals Savings	**1,945,363**	**1,088,360**

Table 4. Well pumps annual energy savings

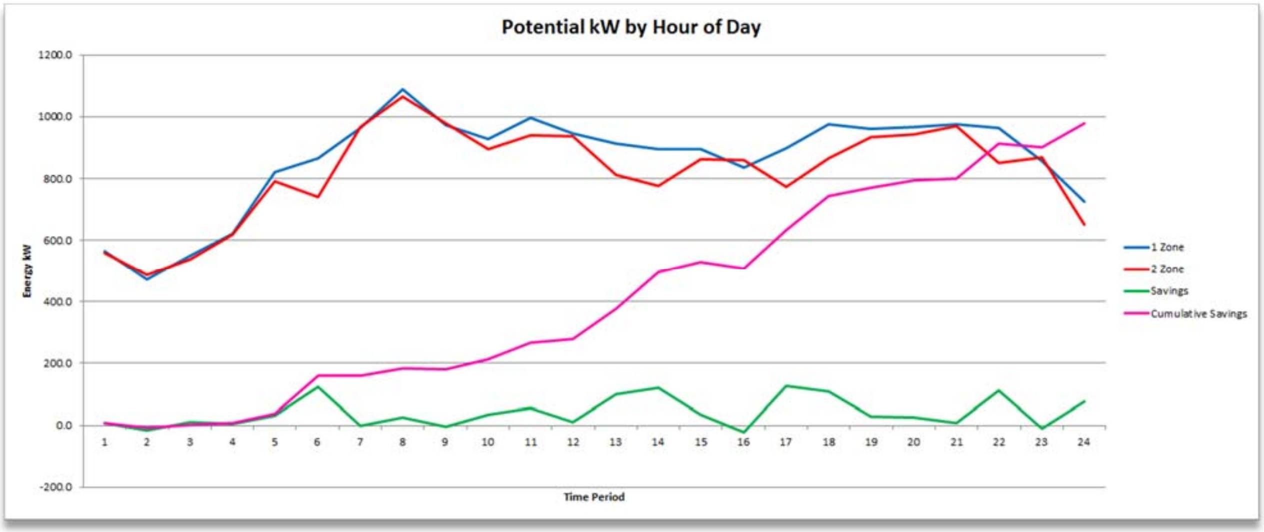
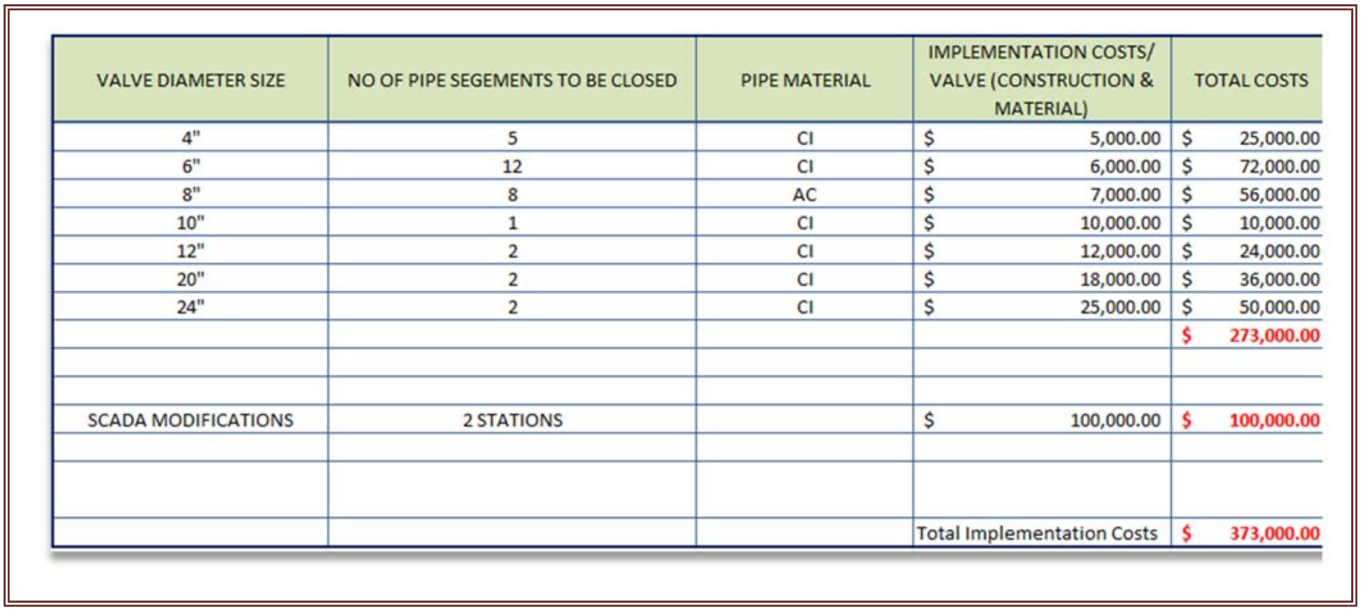
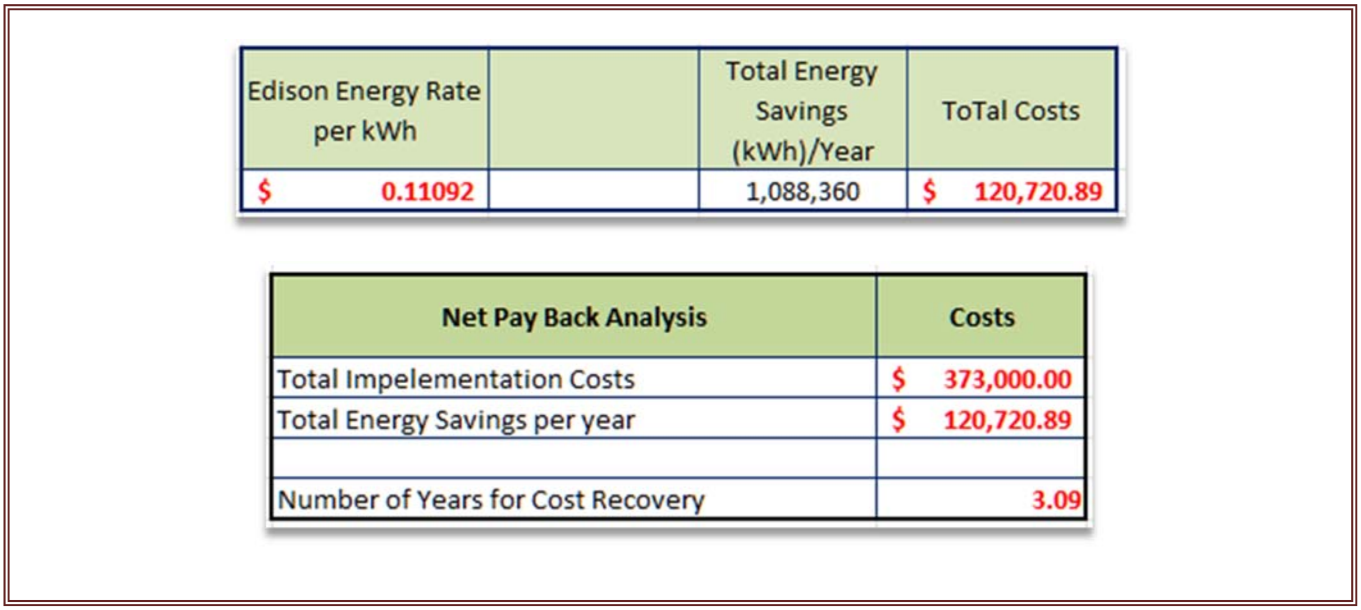


Figure 10. Energy consumption comparison graphs, energy saving between one and two zones and a cumulative energy saving



VALVE DIAMETER SIZE	NO OF PIPE SEGEMENTS TO BE CLOSED	PIPE MATERIAL	IMPLEMENTATION COSTS/ VALVE (CONSTRUCTION & MATERIAL)	TOTAL COSTS
4"	5	CI	$ 5,000.00	$ 25,000.00
6"	12	CI	$ 6,000.00	$ 72,000.00
8"	8	AC	$ 7,000.00	$ 56,000.00
10"	1	CI	$ 10,000.00	$ 10,000.00
12"	2	CI	$ 12,000.00	$ 24,000.00
20"	2	CI	$ 18,000.00	$ 36,000.00
24"	2	CI	$ 25,000.00	$ 50,000.00
				$ 273,000.00
SCADA MODIFICATIONS	2 STATIONS		$ 100,000.00	$ 100,000.00
			Total Implementation Costs	$ 373,000.00

Table 5. Implementation costs analysis



Edison Energy Rate per kWh		Total Energy Savings (kWh)/Year	ToTal Costs
$ 0.11092		1,088,360	$ 120,720.89

Net Pay Back Analysis	Costs
Total Impelementation Costs	$ 373,000.00
Total Energy Savings per year	$ 120,720.89
Number of Years for Cost Recovery	3.09

Table 6. Payback period analysis

5. Summary of Results

Results show improvement in:

1) A distribution of local pressure variations in the two zone system seems to have improved tremendously.
2) The two pressure zone system seems to have improved the distribution system well operations and in doing so there is a saving of pump energy costs.
3) Implementation costs are estimated to be recovered in 3.09 years of time period.

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