DESERT ROSE H20

Final Design Report

Fredonia, AZ Water Safety Plan

CENE 486C

12/14/2017

This report shows the characterization of the Navajo Sandstone Aquifer, characterization of the water distribution and wastewater collection system, and outlines a scaled response in regards to a 20 year projection for the Town of Fredonia, AZ.

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List of Abbreviations:

Ac-ft	Acre-Feet
Gpm	Gallons Per Minute
Gpd	Gallons Per Day
Ppb	Parts Per Billion
Ppm	Parts Per Million
Psi	Pounds Per Square Inch
Pvc	Polyvinyl Chloride Pipes
ADEQ	Arizona Department of Environmental Quality
NTU	Nephelometric Turbidity Unit
FY16	Fiscal Year of 2016
AL	Action Level
ALG	Action Level Goal
TDH	Total Dynamic Head

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1.0 Introduction

The Desert Rose H_2O team has been tasked by the Town of Fredonia to develop a 20 year conservation plan from 2017 to 2037 by analyzing the current conditions and projecting future demands. The objectives were completed as follows: Characterizing the water source aquifer, distribution system, and wastewater collection system, as well as developing a scaled response to a predicted water crisis. The overall goal of the project was to maintain a sustainable water supply for the growing population.

1.1 Background

Fredonia, AZ is located in Northern Arizona immediately south of the Utah border. The town has a population of 1,323 residents. Fredonia is experiencing water scarcity issues as a result of their water source depleting. Their current source of drinking water are a series of groundwater wells in Water Canyon, just north of the Utah border. Figure 1 below shows an aerial map, showing the relative location of Fredonia in relation to the Arizona-Utah border.

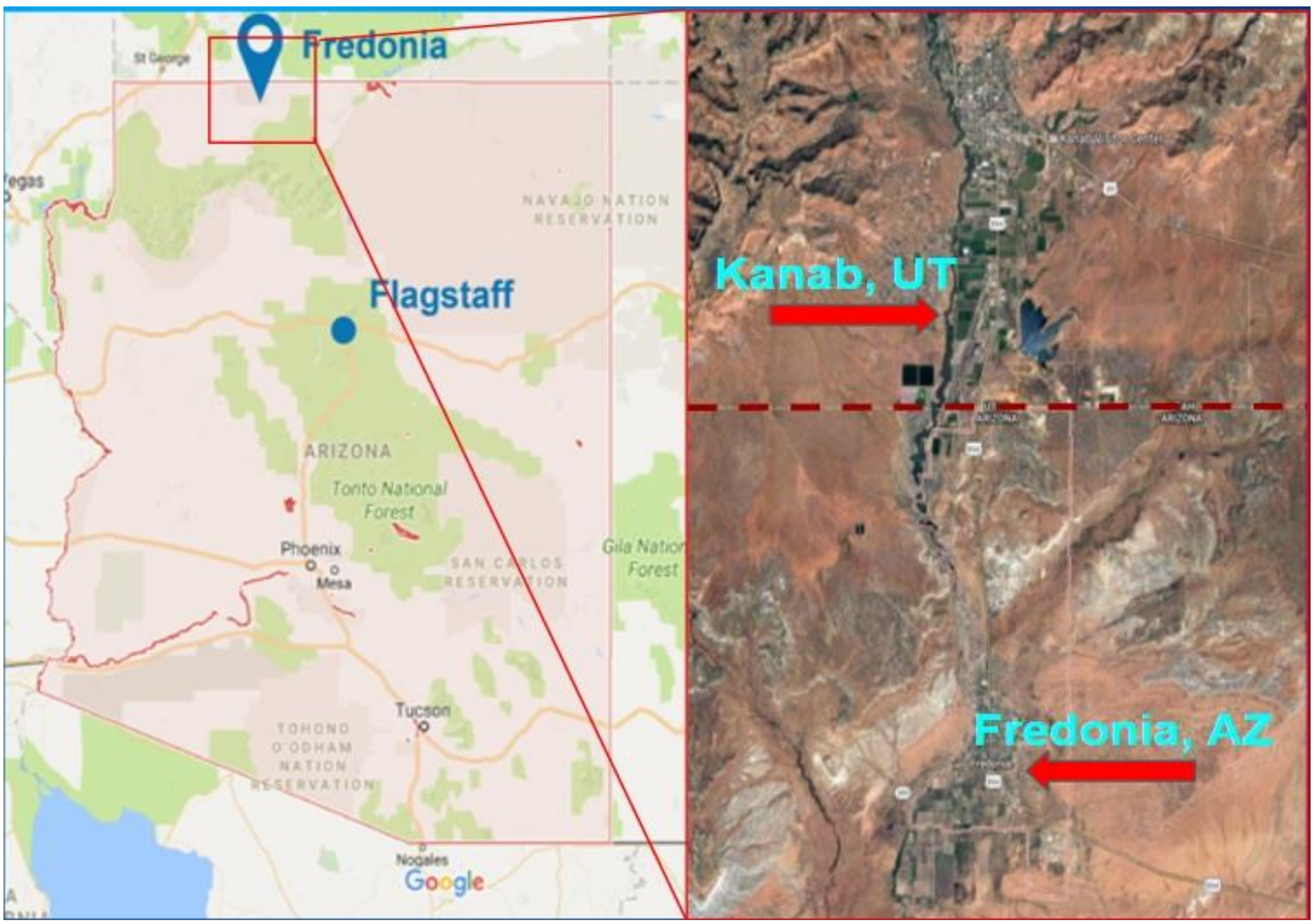

Figure 1: Aerial Map of Fredonia.

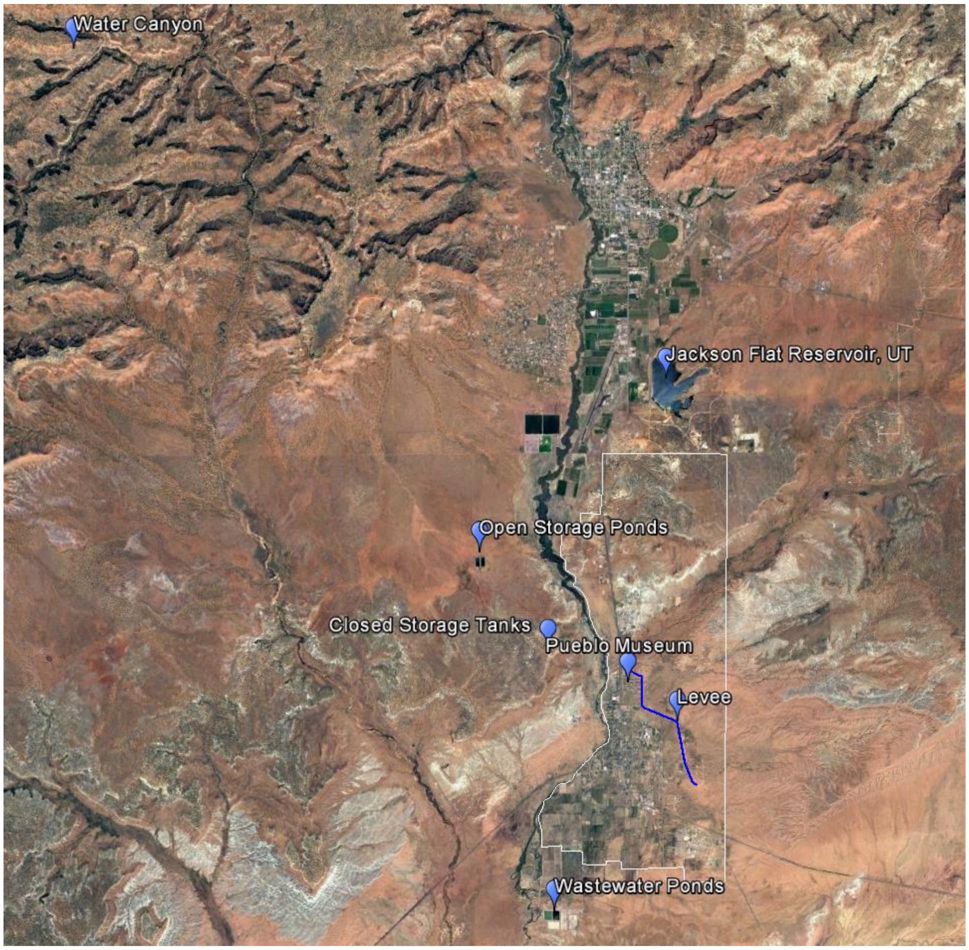

Figure 2: Locations of Water Infrastructure

Figure 2 shows the locations of the main water infrastructure components. The figure shows the locations of Water Canyon, the open storage ponds, closed storage tanks, Pueblo Museum, and wastewater evapotranspiration ponds. These locations are referenced in subsequent sections throughout the report.

2.0 Current Water Sources

The Town of Fredonia owns the water rights to 40 acres of land in Water Canyon in Utah, 16 miles northwest from Fredonia, as shown in Figure 2**.** The existing water right from Water Canyon is 600 gpm during the peak summer season (June to August). Water sources for Fredonia include 4 vertical groundwater wells and 8 horizontal wells located within these canyons. These wells are drilled into the Navajo Sandstone Aquifer [3]. The current pumping rates for these wells is 280 gpm. However, they experience the lowest demand during the winter season (September to May) with only 150 gpm, but the peak water demand during the summer season can reach 500 gpm.

2.1 Aquifer Characteristics

The four vertical groundwater wells are drilled into the lower layer of the Navajo Sandstone Aquifer on the Colorado Plateau. The aquifer layer extends from approximately 5,500 to 6,300 ft in elevation, giving it an approximate thickness of 800 ft. The layer has a partially saturated characteristic, with an approximate thickness of 450 ft of saturation [3]. The subsurface groundwater flows West to East, moving from the Upper Navajo Sandstone down into South Fork and Water Canyon. Figure 2 shows the different layers of the aquifer. The four groundwater wells are drilled into the lower Navajo Sandstone layer. These depths are specified in Table 3.

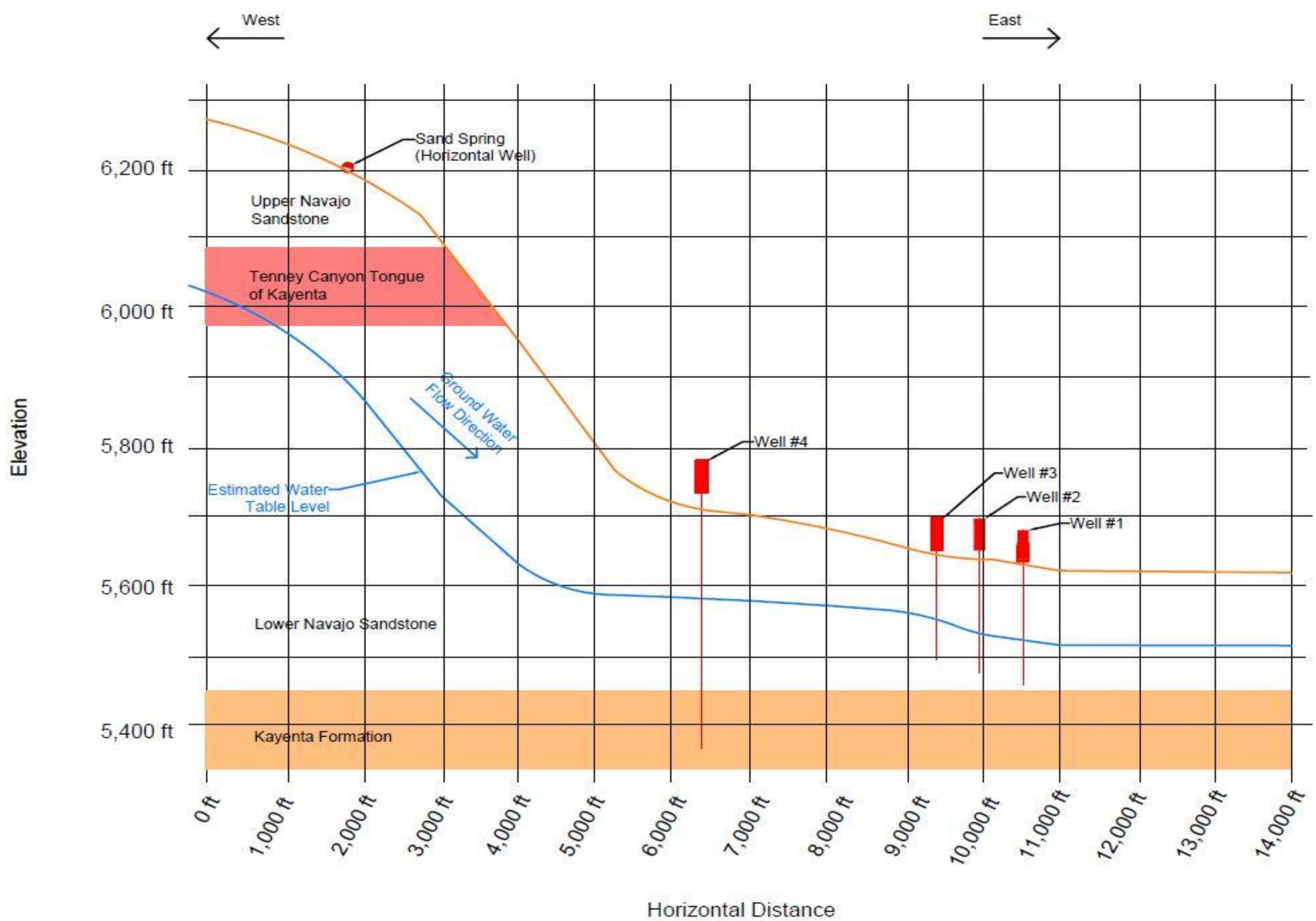

Figure 3: Navajo Sandstone Aquifer Layers with Groundwater Wells

The average elevation of Fredonia is 4,671 ft. Resulting from the elevation difference, wells are drilled into the lower layer. Figure 3 shows the profile view of the groundwater wells, layers of the Navajo Sandstone Aquifer, and estimated water table depths.

The aquifer is recharged through precipitation [4]. Infiltration from precipitation occurs through percolation through overlying deposits of fine-grained soils. Recharge in relation to precipitation infiltration estimates to be 5,500 to 110,000 ac-ft per year [4]. This rate is over the entire aquifer ground surface, not just over Fredonia.

The water table of the aquifer (in the vicinity of the groundwater wells) is approximately 95 ft below the surface. According to USGS data shown in Figure 3 below, the water table level in the aquifer has dropped approximately 8 ft since 1976 [5]. The data was acquired from a monitoring well close to the sight.

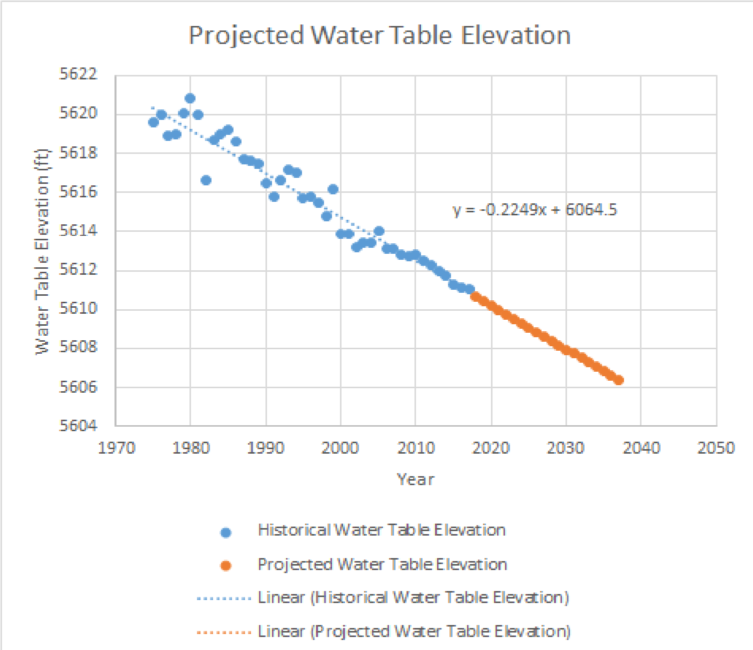

Figure 4: Navajo Sandstone Aquifer Water Table Depth

As shown in Figure 4, the historic water table elevation has dropped from 5,620 ft to 5,611 ft. When comparing the change in elevation to the number of years, it was determined that the level of the water table is dropping at a near-constant rate of .208 ft/yr. Using this rate, it was projected that the water table will drop an additional 5 ft over the 20 year projection.

2.2 Water Canyon Well Source

There are currently 11 groundwater wells installed in Water Canyon; only four of which are functional. A fifth well is operational, but periodically turns off, most likely due to electrical short circuits. Since it is not a consistent source, it was not considered in the analysis. The remaining 4 operational wells drill into the lower layer of the Navajo Sandstone Aquifer. Table 1 describes the depths of each well and the rate at which they pump. Additionally, eight horizontal wells have been drilled into the Navajo Sandstone Aquifer which produces a total of 80-100 gpm [4].

Table 1: Groundwater Well Depths and Capacities [3]

Well	**Capacity (gpm)**	**Depth (ft)**
#1	25	159
#2	30	155
#3	30	175
#4	40	330
Horizontal	80-100	NA

Although the maximum pumping capacity of the wells is 40 gpm each, the actual pumping rates are shown in the table above. For the horizontal wells, the total pumping rate between all of them ranges between 80 and 100 gpm. The individual values for each horizontal well is unknown.

With the current pumping rates, the drawdown of each well was determined. This was done using the Dupuit Equation, where:

$$Q = \frac{\pi * k * (H_o{}^2 - H_1{}^2)}{\ln(\frac{R_o}{R_1})}$$

Where: H_o = Water Table Elevation
H_1 = Height of Water Surface Above Aquifer Bottom
R_o = Radius of Influence of Pumping
R_1 = Radius of Pumping Well
k = Hydraulic Conductivity

It was assumed that the aquifer was unconfined since the lower layers of the Navajo Sandstone Aquifer are permeable materials. Since the H_1 value was not known, an iterative process was used, changing the H_1 and R_o values until the desired Q was obtained. Table 2 below shows the values that were used to calculate the drawdown in each well.

Table 2: Groundwater Well Drawdown

Component	Symbol	Well #1	Well #2	Well #3	Well #4
Flow	Q	0.056 cfs	0.067 cfs	0.067 cfs	0.09 cfs
Hydraulic Conductivity	k	4.92 X 10^{-6} ft/s	4.92 X 10^{-6} ft/s	4.92 X 10^{-6} ft/s	4.92 X 10^{-6} ft/s
Well Diameter	R_1	0.33 ft	0.33 ft	0.33 ft	0.33 ft
Radius of Influence	R_o	4.04 ft	5.47 ft	5.47 ft	8.44 ft
Water Levels	H_o	4088 ft	4070 ft	4070 ft	4090 ft
	H_1	4086.9 ft	4068.5 ft	4068.5 ft	4087.7 ft
Drawdown		1.1 ft	1.49 ft	1.49 ft	2.3 ft

The drawdown values are small, ranging from 1.1 to 2.3 ft. This is a result of the low pumping rates of the wells. If the pumping rates were to increase, the drawdowns would also increase.

As time progresses, the depth of the water table in the aquifer will continue to drop. As a result, the efficiency of each well will simultaneously decrease. The pump curve in Figure 5 shows this decrease in efficiency. The team was not able to identify the pump model numbers of the existing wells so the pump curve in Figure 5 was selected to show the effect of the decreasing water table. The curve represents a Gould 45 J Deep Water Pump; this was selected based on its pumping range of 20 to 70 gpm.

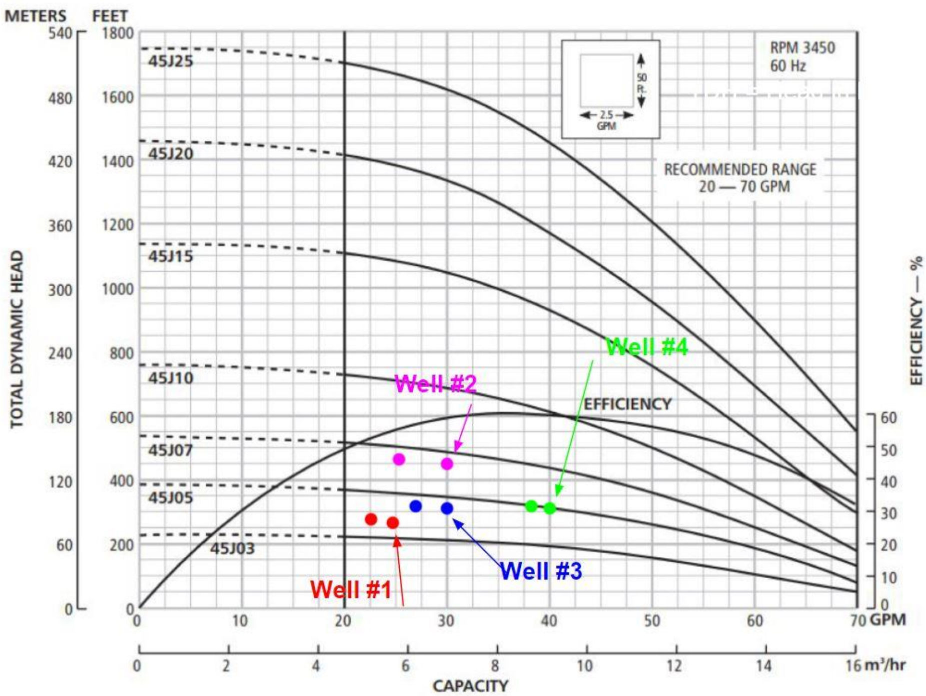

Figure 5: Gould 45 J Deep Well Pump Curve

The curve operates by comparing the total dynamic head to the total pumping rate. As the water table elevation decreases, the Total Dynamic Head increases. As shown on the left axis of the curve, this increase correlates with a decrease in pumping rate. Table 3 below shows the predicted differences in total dynamic head, pumping rates, and efficiency of each well.

Table 3: Pumping Efficiency Decrease

	Well #1	**Well #2**	**Well #3**	**Well #4**
Increase in TDH (ft)	4.7	4.16	4.7	4.7
Decrease in Q (gpm)	3	4	3.25	2
Efficiency Decrease (%)	12	13.3	13.3	5

By averaging the percent decrease in efficiency, it was determined that over the 20 year period, the overall source pumping rate will decrease by 11%, resulting in an 11% decrease in available source water.

3.0 Water Source Capacity

The following describes the groundwater source capacity and municipal water requirements.

3.1 Existing Water Source Capacity

Each groundwater well has a maximum pumping rate of 40 gpm, however, as shown in Table 3, each well is not pumping at full capacity. Combining the volumes from the groundwater wells and the horizontal wells, the current pumping rate is 280 gpm, total.

4.0 Water Storage Capacity

After treatment, the water is stored in three storage tanks, totaling 2 million gallons storage capacity [4]. These tanks are shown in Figure 6 below:

Figure 6: Fredonia Water Storage Tanks

Two additional storage ponds (totaling 30 million gallons) are also available. The three tanks include a 250,000 gallon tank, a 750,000 gallon, and a 1 million-gallon tank to equal 2 million gallons of closed storage. The tanks were constructed in 1953, 1976, and 2000 respectively. No continued treatment is required once in storage, but the quality is monitored quarterly. The stored water would have to be retreated if algae or any organics are present.

5.0 Water Quality Analysis

This section discusses Fredonia's drinking water quality and water treatment requirements.

5.1 Drinking Water Quality Reports

The Action Level (AL) of a contaminant is the concentration of contaminant that requires treatment if exceeded. The Action Level Goal (ALG) is the level of a contaminant in drinking water below which there is no expected health risks. The copper Al and ALG are 1.3 ppm and 1.3 ppm. The AL and the ALG for lead are 15 ppb and 0 ppb. Analyzing the Fredonia 2015 and 2016 water quality reports, the 2015 report indicated ranges of (0.01 – 0.03 ppm) and (0.0010 – 0.0011 ppb) for copper and lead, respectively [8]. Whereas the 2016 report indicted ranges of (0.017 - 0.244 ppm) for copper and (0.0050 - 0.0054 ppb) for lead [9]. Tables 4 and Table 5 below summarize this data.

Table 4: Action Level Goal Standards from 2015 Water Report [8].

Year	Contaminant.	Violation Y or N	Ranges of all samples (L-H)	Action Level	Action Level Goal
2015	Copper (ppm)	Y	L=0.01 H=0.03	1.3	1.3
	Lead (ppb)	Y	L=.0010 H=.0011	15	0

Table 5: Action Level Goal Standards from 2016 Water Report [9].

Year	Contaminant	Violation Y or N	Ranges of all samples (L-H)	Action Level	Action Level Goal
2016	Copper (ppm)	N	L=0.017 H=0.244	1.3	1.3
	Lead (ppb)	N	L=.0050 H=.0054	15	0

Considering the higher ranges of copper and lead in 2016, a violation was recorded on both contaminants in 2015 but not in 2016. This was a result of late sampling; the lead and copper samples were supposed to be collected at June 2014 but not were collected until August 2014 [10]. Failure to follow sample collection schedule is considered a violation of ADEQ standards, regardless of the values obtained that were in compliance with the standards. Despite the violation, Fredonia did not experience high levels of copper or lead.

5.2 General Requirements

Since Fredonia gets all its water from the pipeline that is mixed together with surface water in catchments, the water must be treated [11]. Further water quality requirements are discussed in sections below.

5.2.1 Surface Water Treatment

The Surface Water Treatment Rule states that 99% of cryptosporidium should be removed by filtration and not by disinfection. Cryptosporidium are micro parasites which cause stomach diseases. Turbidity is the cloudiness of the water. Turbidity limits should be less than or equal to 0.3 Nephelometric Turbidity Unit (NTU) in 95% of measurements, with zero incidents of more than or equal to 1 NTU. Turbidity should be monitored every 15 minutes [11]. The aforementioned water quality reports indicate that the regulations were all in compliance.

5.2.2 Existing Treatment Facility

Fredonia uses two water treatment facilities that are located northwest of the storage tanks. Both facilities utilize a non-conventional pressure filtration system to treat water. The filter uses Neptune Microfloc – Series E – Mixed Media Filter. The primary water treatment facility was constructed in 1992, and consist of two 8-foot diameter filters, with capacities of 251-502 gpm each. The second treatment facility was constructed in 1978, and consists of one 8-foot diameter filter with a capacity of 251-502 gpm. Both treatment facilities provide the town with 750-1500 gpm of culinary water treatment [11]. Table 6 show the capacities and construction dates of the two water treatment facilities.

Table 6: Capacities and Construction Dates of Fredonia Existing Water Treatment Facilities [1].

Treatment Facility	Year Constructed	Capacity (gpm)
First Treatment Facility	1992	251-502 (x2)
Second Treatment Facility	1978	251-502
		Total = 750-1,500

Based on a 20 year design life, both water treatment facilities have exceeded their proposed functional periods. This makes the systems more susceptible to failures. Groundwater from the source wells pass through a filter media consisting of gravel, sand and anthracite layers and is then chlorinated before being discharged into the storage tanks. Excess water is backwashed through the filter to remove any solids from the top layer. This backwashed water is then stored in one of two 15 million-gallon backwash reservoirs. There is a second chlorination building that is located at the reservoir site that treats water from the backwash reservoir during the summer months. This ensures that the water from the backwash reservoir is treated before it re-enters the distribution system. Figure 7 below shows the backwash reservoir.

Figure 7: Fredonia Backwash Reservoir

Water in the backwash reservoir is stored until needed during the summer months. There are two storage ponds, each containing 15 millions of stored water. It was assumed that 50% of this storage would be available for use.

6.0 Water Distribution System Analysis

The following describes the water distribution system utilized for Fredonia.

6.1 Existing Distribution System

Collected groundwater is transported from the sources to the treatment facility then one of two directions: Either into a backwash reservoir or into storage tanks. From the storage tanks, the treated water is gravity driven to the main part of Fredonia through varying diameters of PVC pipes. Figure 8 shows the distribution system, along with pipe diameters. This map only shows the location and diameters of each pipe. Individual elevations, pressures, etc. were not considered in the analysis.

6.2 Fire Flow

The State of Arizona requires a minimum fire flow of 1000 gpm for residential areas, and 1500 gpm for commercial, with a residual pressure of 20 psi to comply with International Fire Code 2003 [2]. Fredonia is not within compliance with this. Although the absolute minimum pressure is 20 psi, it is general practice to maintain residual pressure range of 40 to 100 psi [2].

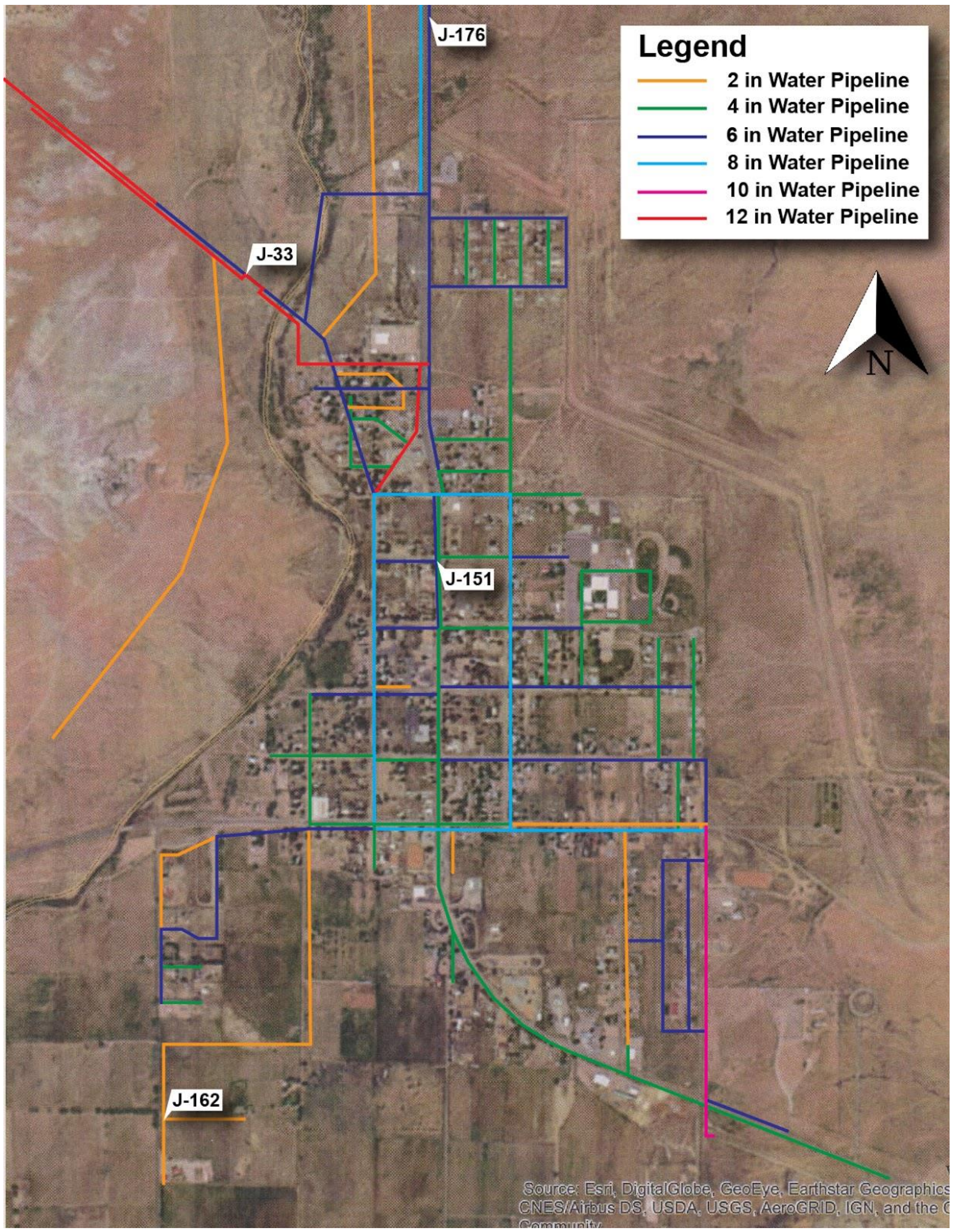

Figure 7: Fredonia Water Distribution Map

Throughout the distribution system, sections of the PVC infrastructure of the pipe network are compromised, requiring maintenance to prevent damage to the system. Some exposed pipes cut across the canyon, are suspended by wire, or precariously propped up by stones. Occasionally these pipes are destroyed by floods or landslides which requires the town to stop pumping until they repair the network.

7.0 Wastewater Collection System

The following describes the system in place that collects wastewater. Additionally, the treatment and storage processes are described.

7.1 Wastewater Collection System

All structures south of the Red Pueblo Museum (Figure 2) utilize a gravity fed sewer system. The system runs North to South, discharging into the evaporation ponds on the south side of town. Figure 9 shows the distribution of the sewer lines. All structures north of the Red Pueblo Museum utilize septic systems, not contributing to the wastewater collection and treatment process.

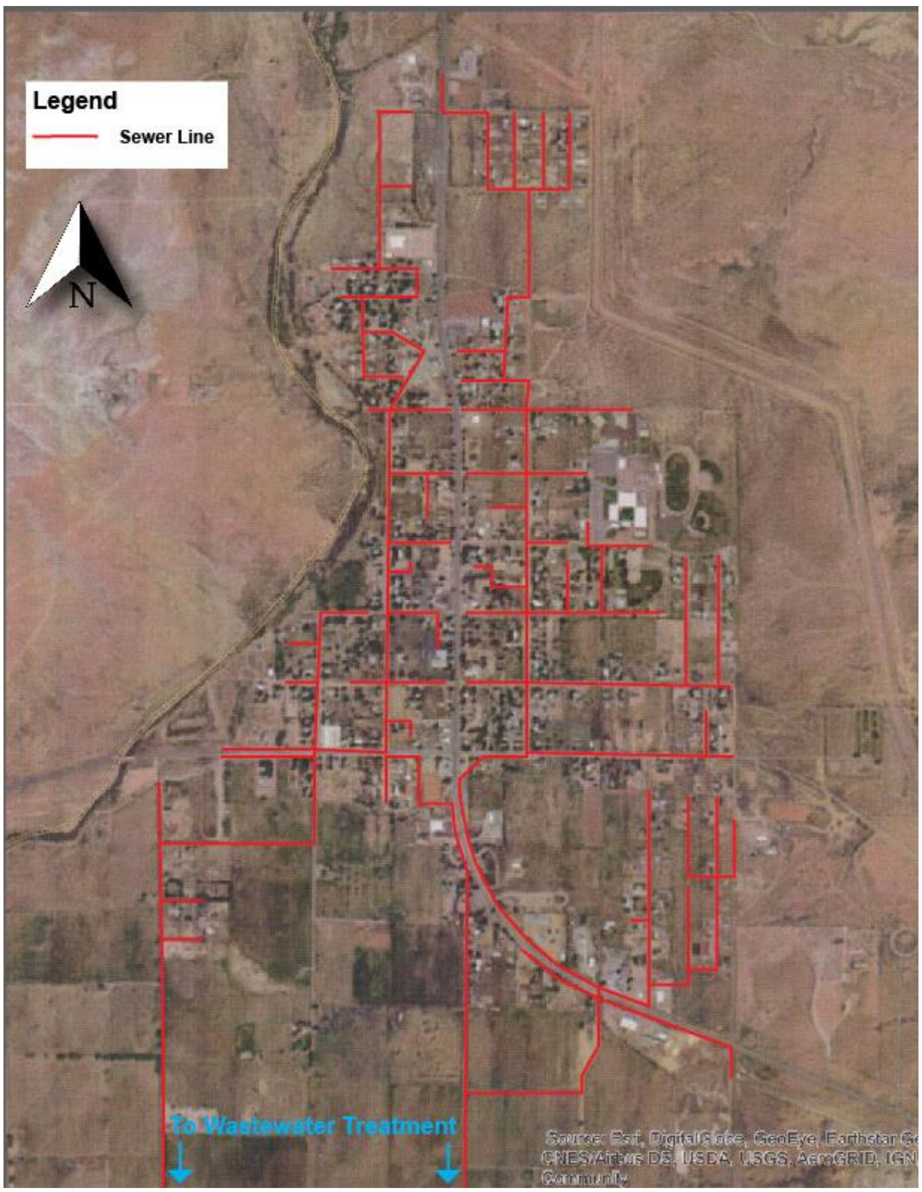

Figure 9: Distribution of Sewer Lines

7.2 Wastewater Treatment

Once fed into the treatment center, the effluent is grinded up to decrease particle size. From there, it is discharged into evaporation ponds where evapotranspiration occurs. Two (out of five) evaporation ponds are in use, averaging an inflow of approximately 50,000 gpd, total. No further treatment takes place. To maintain the quality of the surrounding soil, a monitoring well shows whether or not the wastewater is leaching into the surrounding soil [4]. Figure 10 shows one of the wastewater evaporation ponds.

Figure 10: Wastewater Evaporation Pond

8.0 System Users and Projected Demands

The following analyzes the current user breakdown, monthly usage volumes, historic population increase, projected population increase, and projected demand increase.

8.1 Current System Users and Usage

The 1,323 residents are the primary users. The town also provides drinking water to approximately 40 members of a Kaibab Paiute Tribe Community. Fredonia's Billing and Usage Summary breaks down monthly and annual utility averages between residential, commercial, industrial, agricultural, churches, and government owned properties.

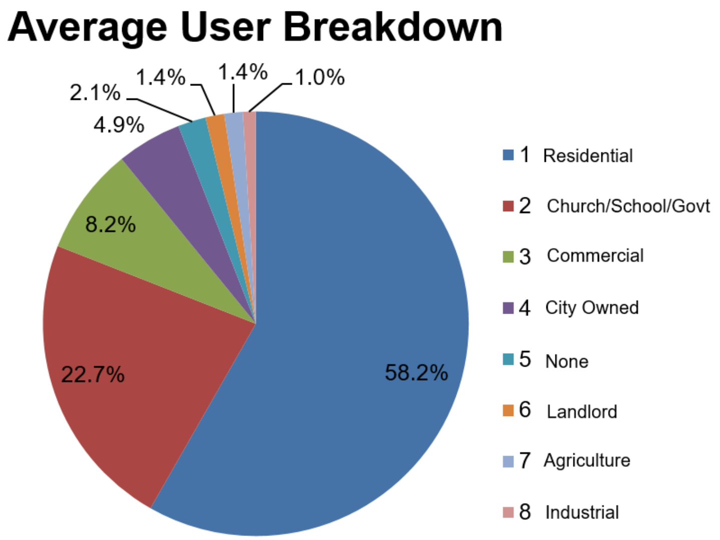

Figure 10: Average User Breakdown

The Figure above shows that the residents are the primary users of the water, resulting in demand projections following the same rate as population growth projections.

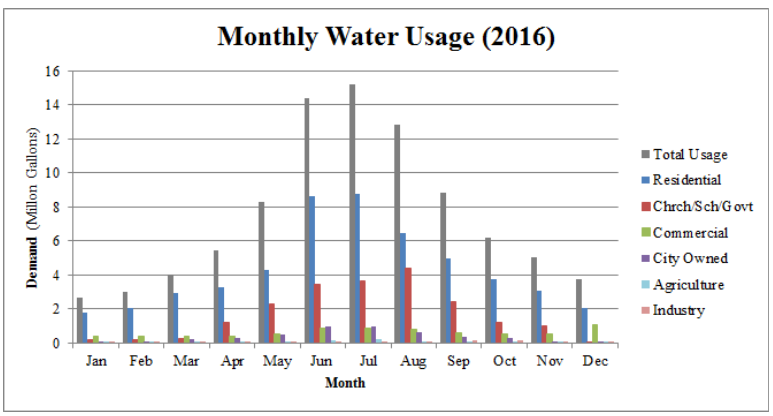

Figure 11: 2016 Monthly Water Usage

The Figure above shows the breakdown of monthly demands. The wells pumping at 280 gpm will yield 12 million gallons a month. During the summer months (June, July, August), the demand exceeds supply by approximately 6 million gallons, resulting in a water shortage.

8.2 Population Growth Rate

To estimate future demands, two population projections were used: One high estimate and one low estimate. The low estimate, based on the population growth from 2011 to 2016, is 0.22%. The high estimate is the historical population growth between 1970 and 2010 [1], which is 1.47% per decade. As a comparison, the current average growth for the entire United States population is 0.7%. Tables 1 and 2 break down the estimates.

Table 7: Current Population Growth

Year	Population	Growth (%)
2012	1,312	+0.46%
2013	1,318	+0.30%
2014	1,322	-0.2%
2015	1,319	+0.30%
2016	1,323	
Average Growth = +0.22% per year		

Table 8: Historic Population Growth

Year	Population	Growth (%)
1970	798	+3.03%
1980	1,040	+1.79%
1990	1,226	-1.39%
2000	1,055	+2.46%
2010	1,314	
Average Growth = +1.47% per decade		

The future population is calculated using the annual population growth rate formula:

$$F = P(1 + i)^n$$

Where: F = Future population
P = The current population
i = Growth rate (in decimal form)
n = Number of years in the study period.

The Objective of Table 7 is to determine the average growth rate of the current population growth, which is +0.22% per year.

The Objective of Table 8 is to determine the average growth rate of the historic population growth, which is +1.47% per decade.

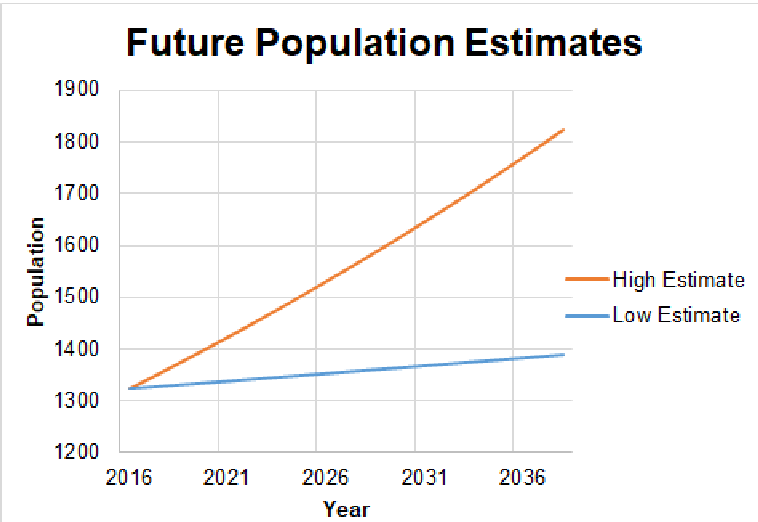

Figure 13: High and Low Population Estimates

The lowest population projection for the Town of Fredonia in 20 years is:

$F = 1323\ (1 + .022)^{20}$ = 1,383 users

The highest population projection for the Town of Fredonia in 20 years is:

$F = 1323\ (1 + .0014)^{20}$ = 1,771 users

Considering high and low estimates, Fredonia will have to accommodate between 1,383 and 1,771 users over the next 20 years.

8.3 Current Water Demand

According to the Fredonia's FY16 utility billing and usage summary, the average annual water consumption per capita is 176 gpm, or 254,000 gpd. This was calculated by converting the total annual water consumption, which is 92,688,000 gallons per year to gpm.

$$92{,}688{,}000\ \frac{gal}{year} * \frac{1\ year}{365\ days} * \frac{1\ day}{1440\ minutes} = 176\ gpm$$

Using the water use data for July, similarly, the summer average water use is 341 gpm or 491,000 gal/day. The winter months experience the lowest demand at 150 gpm. The maximum water demand in the summer currently reaches 500 gpm. These numbers will increase with time and population. The following section breaks down the range of possible future water demands.

The 176 gpm rate includes all users, including agricultural, industrial, commercial, and city owned users. The essential residents make up 58.2% of all users, resulting in 53.9 million out of the 92.7

million gallons used are used by the residents. The following calculation shows the average daily water use per capita.

$$53{,}500{,}000\ \frac{gal}{year} * \frac{1\ year}{365\ days} * \frac{1\ day}{1{,}323\ residents} = 111\ gpd\ per\ capita$$

This shows that each Fredonia resident uses an average of 111 gpd, which is well within the range for Arizona.

The Arizona Department of Environmental Quality (ADEQ) requires a minimum of 50 gallons per person per day be provided for 100 years [2]. Evidently, Fredonia residents receive more than 50 gallons a day, therefore the Town is not in violation of the provisionary requirement.

$$50\ \frac{gal}{day} * \frac{1\ day}{1440\ minutes} * 1{,}323\ residents = 45.9\ gpm$$

Since the current pumping capacity is 280 gpm, the Town of Fredonia is currently not violating the ADEQ standard.

8.4 Projected Water Source Demand

The future water demand is calculated using the population growth rate formula. It was assumed that the demand for water will increase at the same rate as the population. Currently the town uses 150 gpm during the winter, but the projected minimum water demand during winter months will be between 156.7 gpm and 200.8 gpm in 20 years (Figure 14). Currently the summer peak demand is 500 gpm, but the projected maximum water demand during summer months will increase to between 522.5 gpm and 669.5 gpm (Figure 14). This report displays a range of shortages and surpluses due to the range in percent growth.

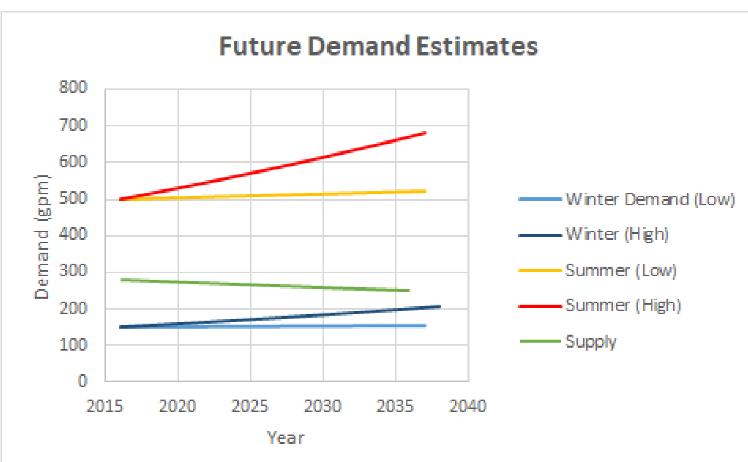

Figure 14: Future Demand Estimates

The following calculations show the peak values at the end of the study period:

Low Winter Projections

$$F = 150\ (1 + .022)^{20} = 156.7\ gpm$$
$$F = 150\ (1 + .0147)^{20} = 20.8\ gpm$$

Summer Peak Projections

$$F = 500\,(1 + .022)^{20} = 522.5\ gpm$$
$$F = 500\,(1 + .0147)^{20} = 669.5\ gpm$$

Average Projections

$$F = 176\,(1 + .022)^{20} = 180\ gpm$$
$$F = 176\,(1 + .0147)^{20} = 336\ gpm$$

The following figure compares the available supply to the predicted population estimates.

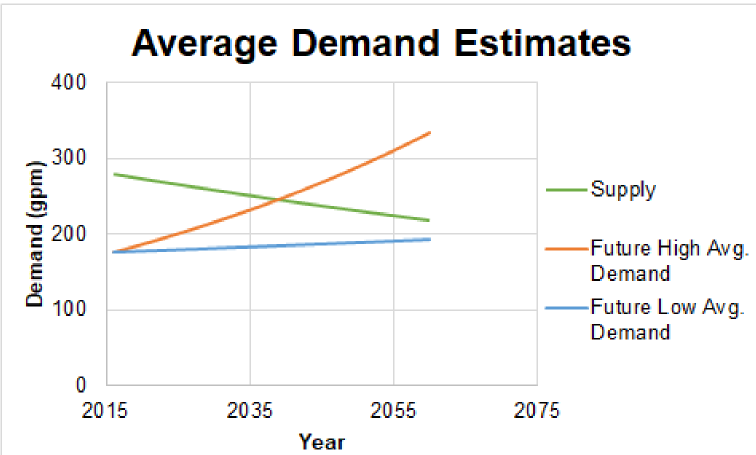

Figure 15: Average Demand Projections

Figure 15 shows that the average demand will surpass the pumping capacity as early as 2038. This means the storage tanks can no longer be replenished and the wells cannot provide enough water to the town, resulting in a shortage.

Per Capita values were not used because these projections are for the town's collective usage. Ideally, all sectors of the local economy (agriculture, industry, commercial, tourism) will grow as the population does, and Fredonia must prepare not only for residential water demand but also demand growths within the other areas of usage.

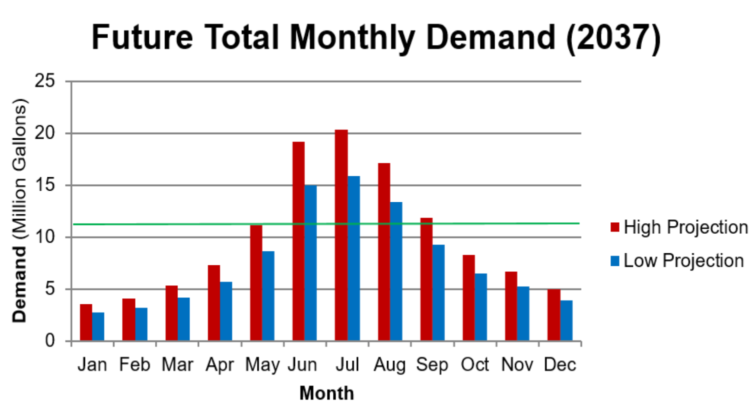

Figure 16: Total Monthly Demand 20 year Projection

For the summer months, the supply increased to 25 million gallons, resulting in a shortage of 11.3 - 24.8 million gallons between June and July. Since the depth of the water table in the aquifer drops, the maximum pumping capacity will decrease to 10.8 million gallons since the pumping capacity is expected to drop by 11% over the next 20 years.

8.5 Projected Storage Capacity Requirements

This section shows the time it will take to deplete and refill the 2 million gallon closed storage tanks during the future summer and winter months. Time until depletion is calculated by dividing the total storage capacity by the water shortages in the summer. Since the future demand (522.5 to 669.5 gpm) is much larger than the well capacity of 280 gpm, the water stored in tanks will be used to supplement the shortage of 242.5 to 389.5 gpm.

If the Town of Fredonia continues without changes to storage capacity, the 2 million gallon storage tanks would deplete in 3.6 to 5.7 days.

$$2{,}000{,}000\ \frac{gal}{389.5\ to\ 242.5\ gpm} * \frac{1440\ minutes}{day} = 3.6\ to\ 5.7\ days$$

The storage tanks can be replenished during the winter when the groundwater wells produce a surplus of 79.2 - 123.3 gpm. Using the same equation above with surplus values, the 2 million gallons tank can be completely filled in 11.3 to 17.5 days.

$$2{,}000{,}000\ \frac{gal}{123.3\ to\ 79.2\ gpm} * \frac{1440\ minutes}{day} = 11.3\ to\ 17.5\ days$$

These calculations only consider the 2 million gallon closed storage tanks because the water that is stored here requires no additional treatment as opposed to the exposed storage ponds. To deplete or replenish the 30 million gallon backwash ponds would take 15 times longer than the closed storage tanks.

$$30{,}000{,}000\ \frac{gal}{389.5\ to\ 242.5\ gpm} * \frac{1440\ minutes}{day} = 26.7\ to\ 85.5\ days\ to\ deplete$$

$$30{,}000{,}000\ \frac{gal}{123.3\ to\ 79.2\ gpm} * \frac{1440\ minutes}{day} = 169.5\ to\ 262.5\ days\ to\ refill$$

Combining all storage rates, including the storage ponds:

3.6 to 5.7 *days* + 26.7 to 85.5 *days* = 30.3 to 91.2 *days to deplete all storage*

11.3 to 17.5 *days* + 169.5 to 262.5 *days = 180.8* to *280 days to refill storage*

This shows it will only take 1 - 3 months to completely deplete the 32 million gallons during the summer and will take 6 - 9 months to refill. In the worst case scenario, Fredonia will experience 6 days without sufficient water supply. The current (2017) well and storage capacity is not sustainable if Fredonia grows at the historical rate of 1.47% or higher.

9.0 Recommended Scaled Response

To identify when Fredonia will experience a water crisis, the identified Crisis Points--points in which the water supply cannot satisfy the necessary demand. The response to each Crisis Point is discussed in Sections 9.1 through 9.4 below. Costs associated with each response are described in Section 9.5.

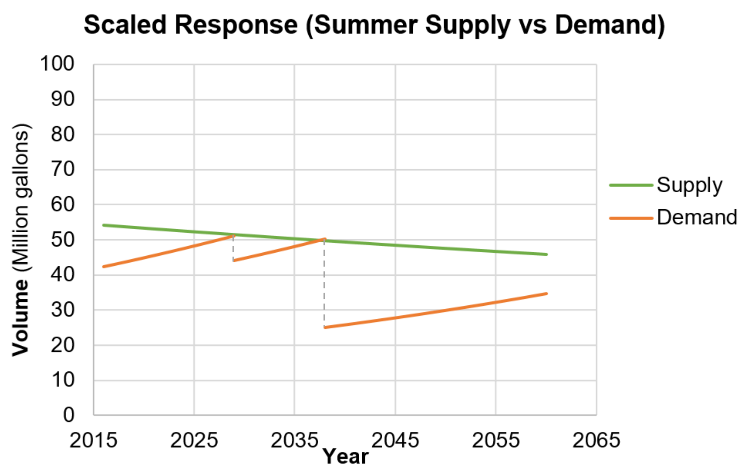

Figure 17: Scaled Response Crisis Points

Over the course of the 20 year projection, two Crisis Points were identified. The recommended solutions to these points focused on cost effect methods to decrease the demand. Since water shortages were predicted to only occur during the summer months, the calculated volume in Figure 17 only considered the summer season. Two additional Crisis Points were identified; however, they were not within the 20 year projection so they are not shown in the figure. However, they are discussed below.

9.1 Crisis #1 Response

The response to the first Crisis Point in 2029 is to incorporate voluntary conservation among the residents. This should be done by inducing rate hikes to discourage excess water usage. By comparing to similar water conservation case studies conducted in similar-sized towns [12], it is estimated that conservation efforts could decrease overall usage by 17%. This will reduce the summer demand volume to 43.4 million gallons. Appendix A includes a sample poster of what could be used to educate the citizens of water conservation efforts.

9.2 Crisis #2 Response

In 2037, the team recommends requiring conservation by implementing low-flow appliances into new construction projects and property resales. Additionally, a 150 gal/capita/day restriction will be enforced. This will conserve approximately 5.3 million gallons during the summer months and reduce demand to 24.8 million gallons.

9.3 Crisis #3 Response

In 2038, a new 8 million gallon storage reservoir shall be constructed. This will increase the supply in order to continue satisfying the demand. This will not reduce the demand, but will increase the available supply by 34.7 million gallons.

9.4 Crisis #4 Response

The team recommends building a wastewater treatment plant once the fourth Crisis Point occurs. Since this occurrence significantly exceeds the projected 20 year study, the actual year has not been determined. By constructing a wastewater treatment plant, all water supplied to Fredonia can be reused.

9.5 Costs of Implementation

Table 9 below shows the costs associated with each Crisis Response. For recommendations occuring in future years, the present worth cost was adjusted to account for a 3.22% inflation rate [13].

Table 9: Costs of Implementation

Response to	Response	Cost	Comments
Crisis #1 (2029)	Increase Rate Structure ($10 monthly fee)	$55,000/year	Use to subsidize conservation efforts
Crisis #2 (2037)	Enforce Restrictions	NA	Reduce to 150 gal/capita/day
Crisis #3 (2038)	8 Million Gallon Storage Reservoir	Present: $900,000 Future: $1.6 Million	To be functional by 2038
Crisis #4 (TBD)	Wastewater Treatment Plant	Present: $1.7 Million Future: $ 4.5 Million	TBD

The last two solutions express both the current price and the present day value of the cost of implementing them in the future.

10.0 Impacts

There will be three types of impacts towards the cost of implementation: Economic, social, and environmental. In the following section the positive and negative impacts of each criteria will be discussed.

10.1 Economic Impacts

Economically, the positive impact relates to the town's revenue. By implementing a rate hike, revenue will help boost the town's economy. The negative impact relates to the cost associated with the rate hike. The average income per household in Fredonia is about $45,000, so adding additional fees will negatively affect residents.

10.2 Social Impacts

By increasing education of conservation and water usage, residents will become more aware of their source and how to effectively utilize the water receive. However, resulting from restrictions, residents will need to change their daily habits to accommodate for the decrease in available water.

10.3 Environmental Impacts

By conserving water, not as much will need to be pumped from the aquifer. This will aid in the sustainability of the aquifer by reducing the volume of water that is taken from it. Long term, this will result in a longer lifespan of the aquifer and a slower decrease in the water table elevation. However, if pumping rates are increased, the aquifer will deplete faster and Fredonia could experience an additional water crisis not predicted in the scaled response.

11.0 References

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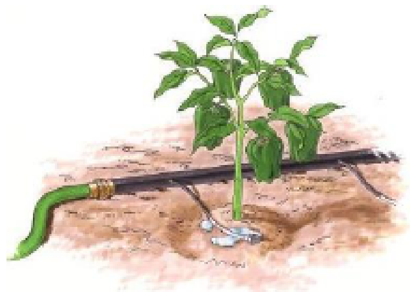
12.0 Appendix A: Water Conservation Poster

HOW TO CONSERVE WATER AT HOME

IN THE BATHROOM

Did you know that your toilet wastes the most amount of water in your home? It may use about 3-7 gallons per flush, and makes up about 30% of the average user's water consumption. Consider switching to a new, low flow toilet that uses 1.6 gallons per flush or less. Placing a brick or water bottle in your toilet tank will also help by displacing the water that would otherwise be used.



IN THE KITCHEN

When washing dishes by hand, don't let the water run while rinsing. Fill one sink with wash water and the other with rinse water.

IN THE GARDEN

Use drip irrigation systems for bedded plants, trees, or shrubs, or turn soaker hoses upside-down so the holes are on the bottom. Water slowly for better absorption, and never water on a windy day! These methods help avoid evaporation. Also try planting waterwise plant rather than lawns.

Prevent Leaking

Check all waterline connections and faucets for leaks. A slow drip can waste as much as 170 gallons of water EACH DAY, or 5,000 gallons per month. Winter is right around the corner. Make sure your pipes and outdoor faucets don't burst by properly insulating them.