Perkins Water Tower and Water System Improvements Design

Oklahoma State University

CIVE 4043/4143

Ali Alfadhli, Josephine Lee, Lela Merkel, Christian Pikett, Philip Thompson

Table of Contents

1. Team Information

1.1 Team Members

Ali Alfadhli grew up in Kuwait. He finished his bachelor's degree in civil engineering at Oklahoma State University. After graduation, he planned to go back home and work for a transportation company to gain industry experience. After working for some time, he planned to pursue his master's degree. He had experience in stormwater, geosynthetics, and soil stabilization.

Josephine Lee grew up in Tulsa, Oklahoma. She received a bachelor's degree in civil engineering at Oklahoma State University and graduated in May 2023. She had experience in land development from an internship program with Quiddity Engineering, LLC. She worked on creating plats, preliminary designs, utility designs, Auto Turn exhibitions, watershed delineations, and dredging plans for single-family and multi-family home projects. The software she was proficient with included Civil3D and MATLAB.

Lela Merkel grew up in Stillwater, Oklahoma. She graduated from Oklahoma State University in May of 2023 with a bachelor's degree in civil engineering with an environmental focus. She had internship experience in water resources engineering and water utility design. In those internships, she worked on projects including waterline design, waterline rehabilitation, floodplain studies, and water distribution system modeling. Pertinent software she could use included AutoCAD Civil3D, ArcGIS, HEC-HMS, and HEC-RAS.

Christian Pikett, a native Texas resident, graduated with a Bachelor of Science in Civil Engineering in May of 2023 from Oklahoma State University. While engaged in his studies at Oklahoma State, he acquired experience through multiple internships and research opportunities. These included land development, software design, and geotechnical research. He had knowledge of computer software such as AutoCAD Civil3D and ArcGIS Pro.

Philip Thompson grew up in Lusaka, Zambia. He took a gap year after high school to get experience working in the Civil Engineering and Construction industry. He moved to the United States in 2019 for college and attended Oral Roberts University for one and a half years before transferring to Oklahoma State University. He completed a Bachelor of Science in Civil Engineering at Oklahoma State University and graduated in May of 2023. During the summer and winter breaks, he worked under a professional engineer to construct and design bridges, roads and house foundations. Those experiences helped him nurture his communication, teamwork, and engineering skills. After graduation, he planned to work in Tulsa to get the relevant experience to become a licensed professional engineer and wanted to open his own construction company.

1.2 Contact Information

Ali Alfadhli	ali.alfadhi@okstate.edu	(213) 322-5252
Josephine Lee	josephine.lee@okstate.edu	(918) 289-7874
Lela Merkel	lmerkel@okstate.edu	(405) 612-4140
Christian Pikett	ccpikett@gmail.com	(870) 703-9530
Philip Thompson	philip.thompson@okstate.edu	(539) 210-1082

2. Project Problem Statement and Proposal

2.1 Problem Description

The town of Perkins, Oklahoma held an approximate population of 3,300 residents as of the 2020 census[1]. The town was founded in 1889 by William A. Knipe and functioned off well-water infrastructure for the entirety of its existence[2]. The original water distribution system was developed in 1912[3]. The town's continued growth placed an increasing demand on its water infrastructure, and the need for this project arose.

This project was comprised of two interconnected projects.

In early 2023, the Iowa Tribe had plans to construct a medical center that would be located on the west side of town. At that time, the western side of Perkins was less developed than the eastern side; therefore, the medical center would have received insufficient water supply to provide adequate fire flow. With the medical center, Perkins expected new residential developments in surrounding areas that would further increase water demand. This necessitated the design and construction of a new water tower for the western side of the water system.

In addition, considering this development and the town's expected growth, the City of Perkins was concerned that the existing water infrastructure was aging and inadequate for sustaining prospective developments in terms of water pressure and flow. The City of Perkins wanted to know if their water pipes needed to be resized so that the water distribution system would remain resilient for the future.

Tower Inc., a team of undergraduate civil engineers, worked alongside the City of Perkins to find a long-lasting solution for their water problem by designing a new water tower and performing a water system analysis.

2.2 Team Project Proposal

The City of Perkins requested the help of Oklahoma State University to assist their water infrastructure concerns. First, an in-depth analysis of the current water distribution system was performed to assess its performance and provide recommendations for pipe improvements. It also provided the information necessary for the design of a new elevated water tower on the west side of town. The team's designs ensured that the water infrastructure was adequate for the new Iowa Tribe Medical Center and for the future of the City of Perkins.

2.3 Client Contact Information

Bob Ernst
City Manager, Chief of Police
citymanager@cityofperkins.net
(405) 612-0144

3. Applicable Codes and Standards

3.1 ASCE 7-22: Minimum Design Loads and Associated Criteria for Buildings and Other Structures[4]

The American Society of Civil Engineers (ASCE) is a professional body founded to promote the practice of Civil Engineering. ASCE 7-22 was created to provide structural load standards for general structural design. This standard was used for the structural loads of the water tower.

3.2 AC1 318-19: Building Code Requirements for Concrete Design[5]

The American Concrete Institute (ACI) is a national organization that creates standards for concrete design. ACI 318 was published to provide codes for concrete building design. This code was used in the design of the concrete column of the water tower.

3.3 AWWA D107-16: Composite Elevated Tanks for Water Storage[6]

The American Water Works Association (AWWA) provides design standards for water utility projects. AWWA D107-16 provides a set of standards for the design, construction, inspection, and testing for composite elevated tanks that consist of a steel tank and concrete support structure. This standard was used for structural standards of the composite elevated water tank.

3.4 ODEQ 252:626-5: General Design[9]

The Oklahoma Department of Environmental Quality (ODEQ) is dedicated to improving the quality of life and health of the citizens of Oklahoma. Title 252, Chapter 626, Subchapter 5 provides ODEQ's general design standards for public water utilities. This subchapter was used to ensure that the design of the water tower and waterline improvements met the minimum requirements for the state of Oklahoma with regards to flood protection.

3.5 ODEQ 252:626-17: Finished Water Storage[9]

Title 252, Chapter 626, Subchapter 17 of the ODEQ codes contains standards for finished water storage structures. This subchapter was used in the design of the water tower. It directed all entities to refer to the International Fire Code and American Water Works Association for further details. It also provided standards for maintaining storage for daily demands and high and low water level variations.

3.6 ODEQ 252:626-19 Distribution System[9]

Title 252, Chapter 626, Subchapter 19 of the ODEQ codes serves to provide permits and construction standards for all public water supply systems. This standard was used for pipe sizing, water pressure, and water flow standards.

3.7 IFC: International Fire Code[8]

The International Fire Code (IFC) is a global organization dedicated to the protection of the public through establishing standards for fire protection systems. The IFC provides minimum regulations of fire prevention systems and was used to ensure that the water tower provided enough flow and pressure for the health center's fire flow requirements. The 2003 Edition was used to comply with ODEQ 252:626.

3.8 EPA: Distribution System Water Quality[7]

The Environmental Protection Agency (EPA) is an organization focused on protecting the public health and safety by developing environmental regulations. Specifically, the information provided through this agency was used to ensure that the tank followed water discharge requirements from the Clean Water Act.

4. Project Constraints

4.1 Cost

The water tower was funded by the Iowa Tribe. They had a budget of $2.5 million for this project, so the water tower's construction cost had to fall within this budget. A life-cycle cost analysis was performed on the construction of the water tower to find the long-term cost of the project.

4.2 Community Approval

The Iowa Tribe and the City of Perkins desired that both of their logos be displayed on the outer surface of the water tank. The tower's purpose was to provide adequate pressure for fire flow to the health center, but the town showed interest in using the tower to provide storage for the town as well. As the town and Iowa Tribe were involved in the decision making, the water tower design had to satisfy both entities.

4.3 Location

The proposed location of the Iowa Tribe Health Center was located near a floodway. Construction in a flood way is prohibited according to ODEQ 252:626-5[9]. Therefore, the location of the water tower was carefully considered to avoid any adverse environmental impacts and any encroachment on cultural or sacred sites.

4.4 Demand and Size of Health Center

The water tower needed to provide enough pressure and storage for demands and fire flow to the health center. The water distribution system had to remain compliant with state regulations during fire flow conditions. The number of floors of the health center was not provided. For the fire flow calculations, it was assumed that there would be one story. It was also assumed that the health center would be protected by an automatic sprinkler system.

4.5 Tank Flushing

The quality of the water in the tank needed to meet EPA requirements. It was necessary to consider water usage to ensure that water storage intervals were not too long. The tank needed to be correctly sized to ensure that water circulated regularly to prevent the growth of harmful byproducts as well as prevent the deterioration of chlorination in the water.

4.6 Existing Infrastructure

For the water system improvements design, the existing infrastructure in Perkins constrained the solutions that could be created. The water system improvements could not impede upon other existing utilities and buildings. Any pipe resizing, additional pipes, or additional water infrastructure had to avoid causing new problems to any existing or planned infrastructure.

5. Summary of Data Gathered and Analyzed

5.1 Zoning

A present conditions zoning map of the City of Perkins was provided by Bob Ernst and is shown in Figure 1. Most of the city was zoned as residential developments. Agricultural and industrial developments were mainly located on the outskirts of town, and the commercial developments laid along the major streets in the city. In order to determine the extent of water tower storage and water system improvements, proposed zoning data was gathered to characterize the type of growth the city would experience in future years. It was determined that most of the expected growth in Perkins would be residential developments with some proposed commercial areas. The residential development would include single-family and multi-family developments. Figure 2 shows the proposed zoning of the areas surrounding the newest development in Perkins known as Kinder Wells.

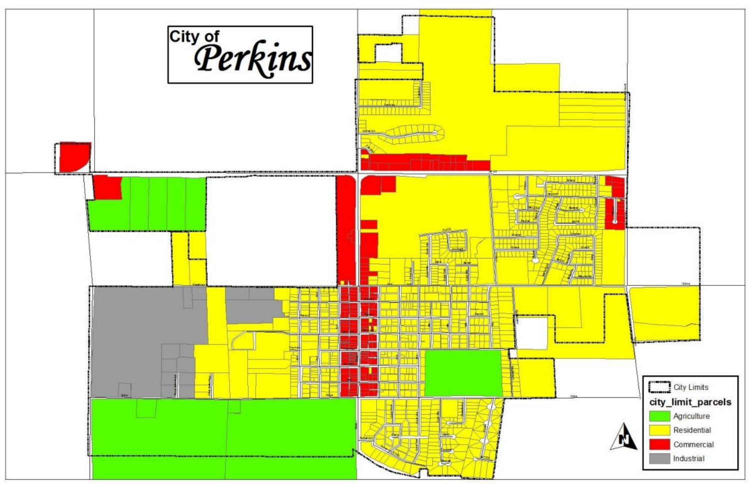

Figure 1. Zoning of the City of Perkins.

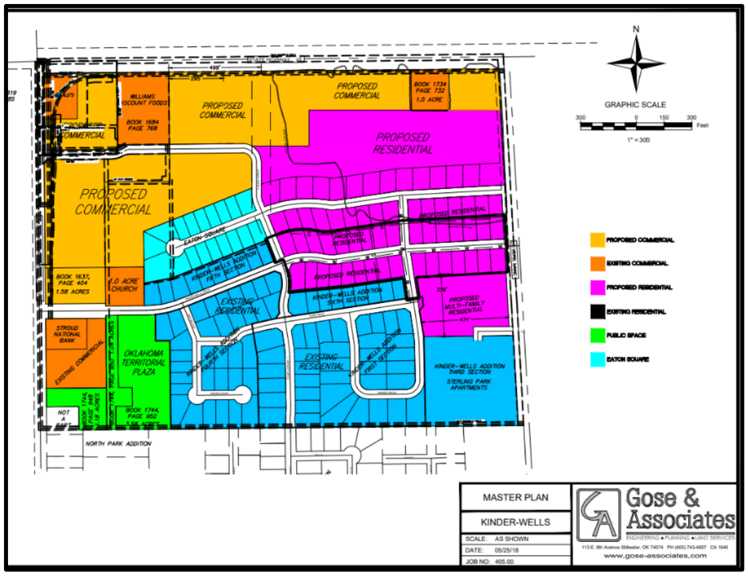

Figure 2. Proposed zoning of the Kinder Wells area of Perkins.

5.2 Soil Data

To determine the soil qualities of the prospective water tower site, the United States Department of Agriculture's Web Soil Survey (WSS) was used[10]. Figure 3 shows the soil map, and Table 1 provides the interpretation of the map. The majority of the area was categorized as hydrologic soil group B, and a small portion of the area was hydrologic soil group A. The soil in the area was found to be comprised primarily of loam and fine sandy loam.

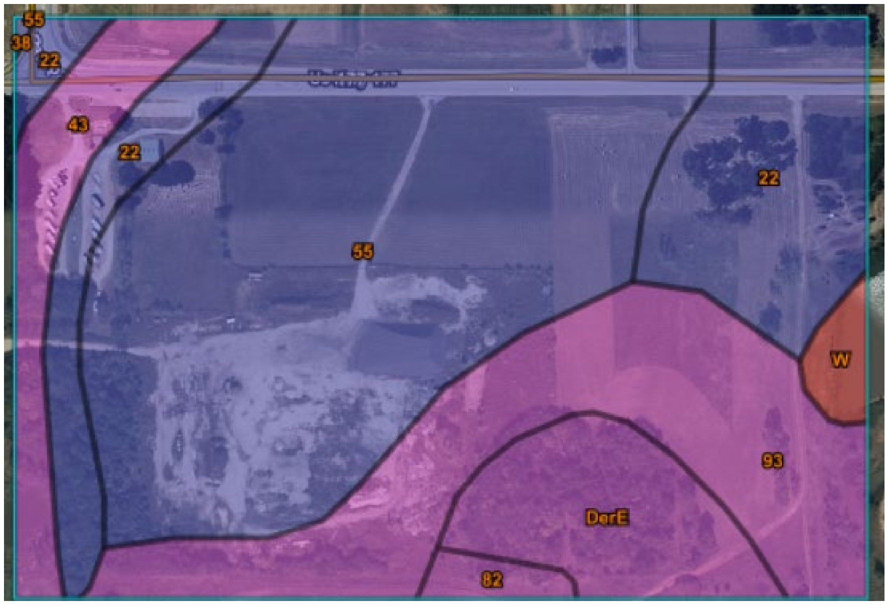

Figure 3. Soil map of proposed water tower and health center area.

Table 1. Soil data used to interpret Figure 3.

Tables — Hydrologic Soil Group — Summary By Map Unit

Summary by Map Unit — Payne County, Oklahoma (OK119)

Summary by Map Unit — Payne County, Oklahoma (OK119)

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
22	Konawa fine sandy loam, 3 to 5 percent slopes	B	15.9	18.9%
38	Navina loam, 0 to 1 percent slopes	B	0.1	0.1%
43	Pulaski fine sandy loam, 0 to 1 percent slopes, occasionally flooded	A	5.5	6.5%
55	Teller loam, 0 to 1 percent slopes	B	37.3	44.3%
82	Derby-Slaughterville complex, 1 to 5 percent slopes	A	1.0	1.2%
93	Slaughterville fine sandy loam, 1 to 3 percent slopes	A	16.4	19.5%
DerE	Derby loamy fine sand, 3 to 15 percent slopes	A	6.9	8.1%
W	Water	D	1.2	1.4%
Totals for Area of Interest			**84.2**	**100.0%**

5.3 Flood Map

A Federal Insurance Rate Map (FIRM) from the Federal Emergency Management Agency (FEMA) was obtained for the City of Perkins[11]. This map, map number 40119C0410F, panel 410 or 525, in Figure 4 shows the extent of the Special Flood Hazard Areas (SFHA) and the floodplains in the city. The proposed water tower site was located near a Zone AE floodplain. Zone AE is a SFHA, and building within the floodplain is prohibited by ODEQ 252:626 Subchapter 5[9]. The location of the water tower could not encroach upon the floodplain, and the water tower had to be designed to avoid this issue. Figure 5 shows an enlarged map of the water tower and health center area.

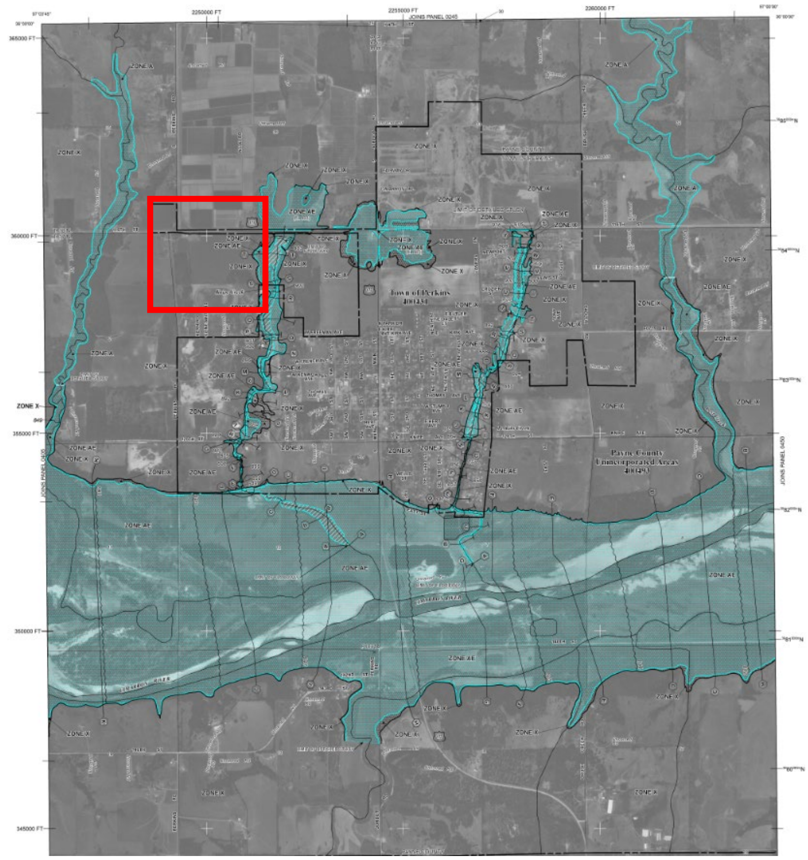

Figure 4. FEMA floodplain map of Perkins. The area shown in Figure 5 is boxed in red.

Figure 5. Enlarged floodplain map focused on water tower and health center area.

5.4 Water Distribution Map

Figure 6 shows the water distribution system on satellite imagery of Perkins[12]. The Perkins Water Distribution System file was provided by the City Manager, Bob Ernst. This pipe layout file contained roughness, length, and diameter characteristics of each pipe shown. The file also contained the location of water meters, wells, and water towers existing in the system. Michael Taylor, P.E., provided an additional file that contained the location and elevation data of the junctions in the system. Mr. Taylor also provided key information on the high, low, and typical water levels in the existing water towers. Table 2 shows a summary of the customer meters, water towers, and wells in the water system at the present time.

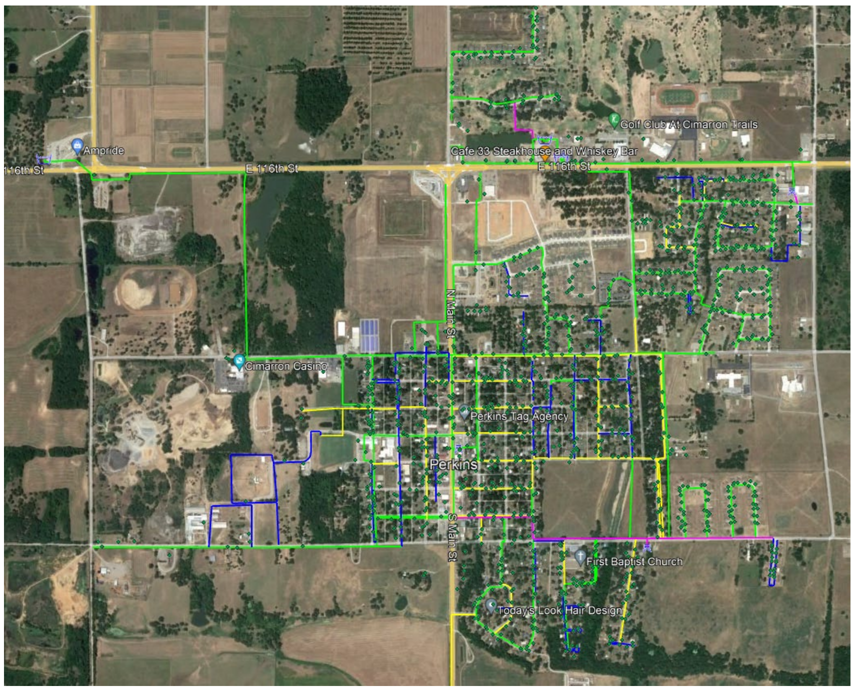

Figure 6. Perkins Water Distribution System.

Table 2. Summary of water distribution system at present conditions.

Feature	Number
Residential Meters	1,419
Commercial Meters	93
Water Towers	4
Water Wells	4

5.5 Water Tower Site Elevation Profile

To determine the approximate elevation profile of the water tower site, Google Earth Pro[12] was used. Figure 7 shows the elevation profile for the path highlighted in pink. This path was the preliminary estimate of where the water tower might be located. From the figure, it was determined that the profile was fairly flat, so steep grades were not an issue. Due to the uniform elevation, the water tower likely needed to be tall to add to the hydraulic head it could provide.

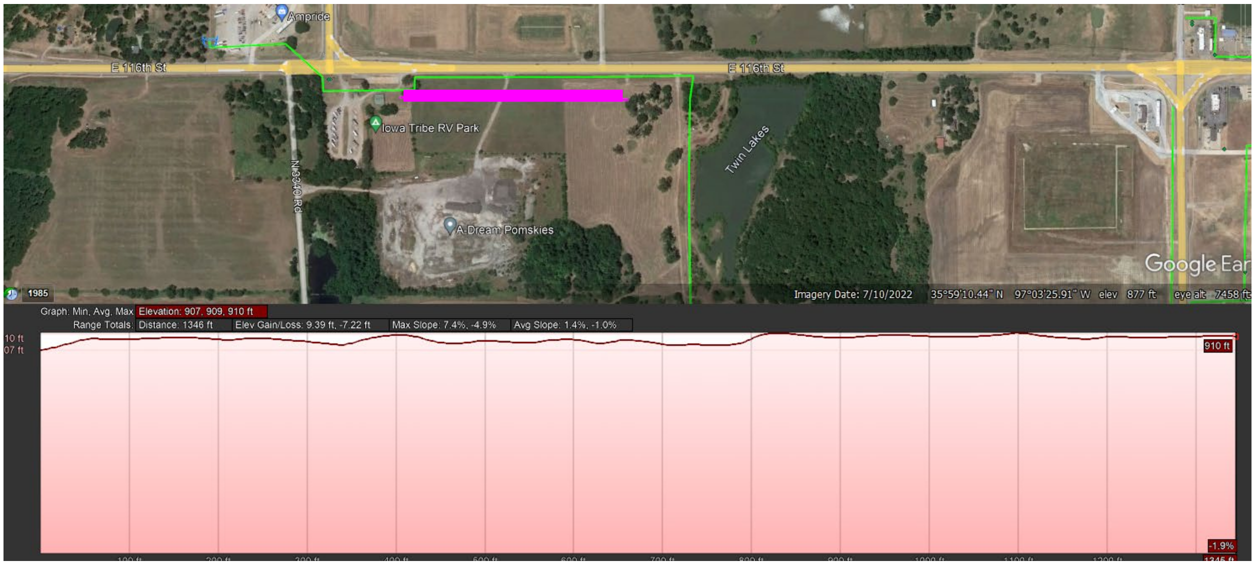

Figure 7. Approximate elevation profile of proposed water tower area. The elevation path is highlighted in pink.

5.6 Utility Demand Data

Water usage data was provided by the city. The city provided records of the daily amount of water taken from the wells in the city for the year 2022. A summary of the average daily water usage is presented in Table 3 below. For the water system analysis, the average demand of 232,000 gallons per day was rounded up to 250,000 gallons per day to account for any measurement errors and allow for conservative modeling.

Table 3. 2022 water usage data from water wells in Perkins.

Month	Average Daily Flow (thousands of gallons)	Total Flow (thousands of gallons)
January	250	7,737
February	226	6,561
March	216	6,704
April	227	6,808
May	223	6,922
June	208	6,244
July	229	7,113
August	316	9,810
September	267	7,998
October	133	4,117
November	226	6,793
December	265	8,216
Yearly Averages	232	85,023

6. Alternatives Analysis

6.1 Water System

6.1.1 Alternative Assessment

To alleviate Perkins' water system issues, four alternatives were assessed. Alternative 1 was an additional Main Street crossing. Alternative 2 involved connecting pipes from Casey's General Store to Ampride Travel Plaza. Alternative 3 connected a dead-end pipe south of Highway 33 to a junction near McDonald's. Alternative 4 was the combination of both Alternative 1 and Alternative 2. Figure 8 shows these alternatives. To assess these alternatives, a weighted decision matrix was used. Considerations included the efficacy of the alternative and the cost of improvement. The rank of the cost for each alternative was based on the length of pipe needed for the project. Main Street had the shortest pipe length, so it received the highest points. Alternative 4 would require the longest length of pipe, so it received the lowest points. Efficacy was based on how much each alternative improved the pipe pressures and flows in the present and future. Data from the water model for the highest-pressure node and lowest-pressure node were documented and compared to find which alternative had the greatest difference from present conditions. Alternative 4 had the best results when the future development was added. Alternative 1 and 2 performed the same for both present and future conditions, but the results showed that Alternative 4 performed slightly better than the two. Alternative 3 provided little change in the system for each simulation. For the fire flow performance, Alternatives 1, 2, and 3 were adequate for present conditions, but they struggled to provide fire flow in future conditions. From the future layout with fire flow conditions, Alternative 4 performed the best, so it was given the highest rank for fire flow. Overall, Alternative 4 had the highest potential, especially for fire protection, and was chosen as the project approach.

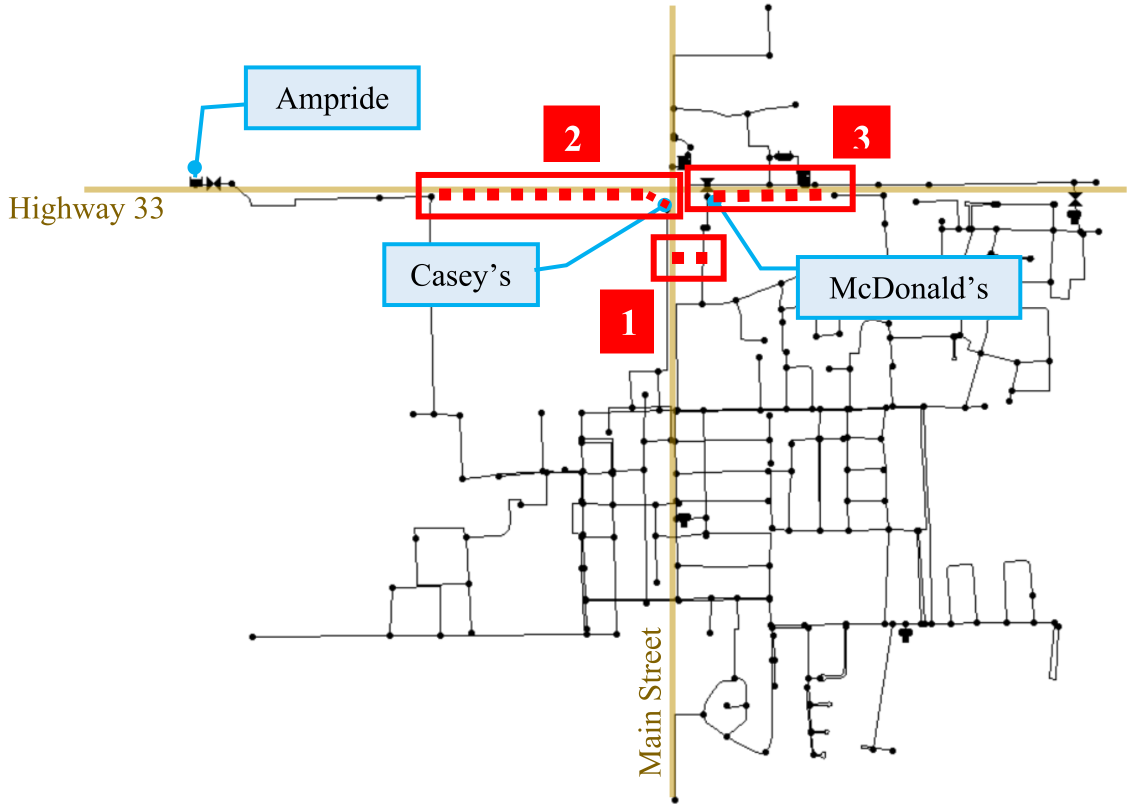

Figure 8. Image of Perkins water system with improvement alternatives.

6.1.2 Alternative 1: Main Street Crossing

The first alternative was to install a new water line crossing Main Street. The water infrastructure network in the City of Perkins was divided into two pressure planes: east and west. Since most of the development in the city was on the east side, several portions of that side of the city struggled with low pressure. Adding a new water crossing under Main Street increased flow between the two pressure planes and promoted greater circulation of water.

6.1.3 Alternative 2: Connecting Ampride and Casey's

The second alternative was to add new pipes to connect the pipes near Ampride to the pipe at Casey's. The goal of this alternative was to add more ways for water to flow from the well near Ampride; this would improve circulation on the west side of town. However, this alternative would require significantly longer pipes to connect a new junction at the intersection. Therefore, this alternative was an expensive option.

6.1.4 Alternative 3: Connecting Dead-end to McDonald's

The third alternative for improving overall water movement in the network was to connect a dead-end pipe located on the east side of town to an existing junction near McDonald's. This would create an additional connection within the water system network and facilitate better circulation of water.

6.1.5 Alternative 4: Combination of Alternative 1 & 2

The fourth alternative was added after performing future fire flow analyses. At maximum day flow with the addition of fire flow for the new health center, the water distribution system performed poorly with Alternatives 1, 2, and 3. It was clear that a combination of alternatives was needed for fire safety. This alternative combined the Main Street crossing and the connection of Ampride to Casey's. While this alternative was the most expensive, it was deemed the best alternative to provide fire flow for the city.

6.1.6 Decision Matrix

The decision matrix used to calculate the best alternative for the water system improvement design is shown in the figure below. An alternative given a rank of '1' for a criterion means that the alternative is the worst choice for that consideration. A rank of '4' means the alternative is the best choice for that criterion.

Weighted Decision Matrix		Water System Alternatives							
		Main St. Crossing		Connect Ampride to Casey's		Dead-end to McDonalds		Combination of Alt 1 and 2	
CRITERIA	WEIGHT	RATING	TOTAL	RATING	TOTAL	RATING	TOTAL	RATING	TOTAL
COST	20%	4	20%	2	10%	3	15%	1	5%
FUTURE EFFICACY	20%	2	10%	3	15%	1	5%	4	20%
PRESENT EFFICACY	20%	3	15%	2	10%	1	5%	4	20%
FIRE FLOW PERFORMANCE	40%	2	20%	3	30%	1	10%	4	40%
	Max	TOTAL Main St. Crossing		TOTAL Connect Ampride to Casey's		TOTAL Dead-end to McDonalds		TOTAL Combination of Alt 1 and 2	
	100%		65%	65%		35%		85%	

Figure 9. Water System Alternatives Decision Matrix.

6.2 Water Tower

6.2.1 Alternative Assessment

For the water tower design, three alternatives were identified as follows: single-pedestal spherical tank, composite elevated tank, and fluted column tank. These options were evaluated under three criteria in a weighted decision matrix. Construction cost was given a weight of 50% and was based on cost estimates of a 250,000-gallon tank and a shallow foundation from Gerard Tank & Steel, Inc. Maintenance costs received a weight of 20%, and life cycle maintenance estimates were provided by Landmark Structures. Community approval received a weight of 30%. The water tower project was in the City of Perkins and was funded by the Iowa tribe, so approval from both parties was necessary. After the analysis, the results indicated that the best option was to construct a composite elevated tank. The second-best alternative was the single-pedestal spherical tank, and the fluted column alternative was ranked last.

6.2.2 Alternative 1: Single-Pedestal Spherical Tank

A single-pedestal spherical water tank consists of a spherical shell supported by a single pedestal in the center of the tank bottom. The overall structure has an inverted tear drop shape. The entire structure is constructed out of steel and is ideal for small to medium sized elevated water tanks. The single-pedestal spherical tank was ranked the cheapest for total construction cost. This alternative had an average estimated construction cost of $1.65 million and an average estimated lifetime maintenance cost of $1 million. Although the construction cost was the lowest of the three alternatives, the maintenance cost was higher than that of the composite tank. The single-pedestal spherical tank was ranked the lowest for community approval because the City Manager expressed interest in a composite tower. The single-pedestal's final score was 73%.

6.2.3 Alternative 2: Composite Elevated Water Tank

A composite elevated water tank is a type of water storage tank that is made up of a steel bowl and a concrete support structure. The steel bowl is designed to hold the water, while the concrete support structure provides stability and support to the tank. The structure is ideal for larger water tanks due to lower costs. The composite tank outperformed both opposing alternatives regarding maintenance cost and community opinion. The average estimated construction cost was $1.8 million, and the average estimated lifetime maintenance cost was $0.7 million; while this tank had a more expensive construction cost than the single-pedestal spherical tank, it had cheaper maintenance costs. This alternative was ranked the highest in community approval because the client showed interest in this design. The composite elevated tank scored a total of 83%.

6.2.4 Alternative 3: Fluted Column Tank

A fluted column water tank is a type of elevated water storage tank that features a fluted column as its main support structure. The fluted column is typically made of steel and is designed to provide stability and support to the steel bowl tank. The tank is ideal for a larger storage capacity and is aesthetically pleasing. The fluted column tank ranked the most expensive in construction cost at a price of $1.9 million. It placed second in community opinion due to its similar appearance to the composite elevated water tank. This alternative had the highest maintenance cost due to the greater surface area of steel to be coated and maintained. This alternative received a total score of 43%, making it the least desirable option.

6.2.5 Decision Matrix

The decision matrix used to calculate the best alternative is shown in the figure below. Each alternative was ranked from 1-3 for each criterion. A rating of 3 is good, and a rating of 1 is bad.

Weighted Decision Matrix

Water Tower Alternatives

CRITERIA	WEIGHT	Composite Storage Tank RATING	Composite Storage Tank TOTAL	Pedestal Sphere RATING	Pedestal Sphere TOTAL	Fluted Column RATING	Fluted Column TOTAL
CONSTRUCTION COST	50%	2	33%	3	50%	1	17%
MAINTENANCE COST	20%	3	20%	2	13%	1	7%
COMMUNITY OPINION	30%	3	30%	1	10%	2	20%

Max	TOTAL Composite Storage Tank	TOTAL Pedestal Sphere	TOTAL Fluted Column
100%	83%	73%	43%

Figure 10. Elevated Water Tank Decision Matrix.

7. Description of Selected Approach

7.1 Water System Improvements Design

The selected approach for the water system improvements design was the combination of the Main Street Crossing and the Ampride to Casey's connection. This alternative was the best option from the weighted decision matrix largely due to its efficacy in present, future, and fire flow conditions. This solution was to connect existing 6-inch water lines on either side of Main Street and to install new 6-inch water lines from the dead-end at Casey's towards the western side of town. Required pipe lengths were estimated using Google Earth to measure the proposed layouts. The Main Street portion of this alternative consisted of approximately 440 feet of pipe to connect the east and west side of Main Street. The Ampride to Casey's part of this alternative consisted of approximately 2,900 feet of pipe. The pipe was chosen to be a 6-inch PVC pipe to match the existing infrastructure in the area. The location of the selected approach is shown in Figure 11.

Figure 11. Image of selected approach location boxed in red.

7.2 Water Tower Design

Based on the weighted decision matrix for the water tower alternatives in Figure 10, the Composite Elevated Water Tower was selected as the prime alternative. This alternative required designs for the welded steel water bowl and the concrete support structure for the support walls and the tank dome floor. Using reference drawings from similar projects, AWWA D107-16, and ACI 318-19 design standards, dimensions for a steel tank were designed for a capacity of 250,000 gallons of water as shown in Figure 12.

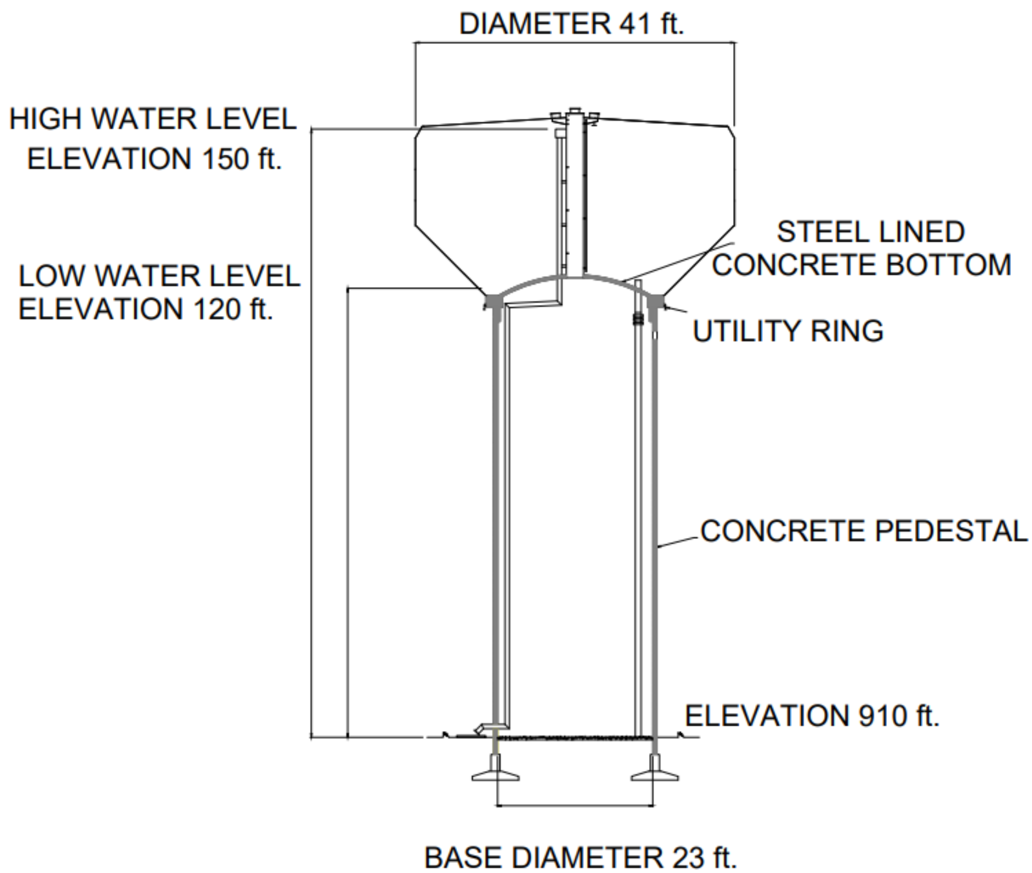

Figure 12. Section view of composite elevated water tower.

8. Summary of Engineering Design and Analysis

8.1 Hydraulics and Hydrology

8.1.1 Fire Flow

The most important factor for the water tower design was the ability to provide additional flow to meet fire flow requirements for a proposed 30,000 ft^2 Iowa Tribe of Oklahoma Health Center. Fire flow was calculated using tables and regulations in the International Fire Code (IFC). The building was assumed to be a Type IIIA building. Per the IFC, Type IIIA buildings have noncombustible exterior walls, and interior walls can be made of any material that can provide up to 1 hour of fire resistance. From IFC Table B105.1, a 30,000 ft^2 Type IIIA building requires 2,500 gpm of fire flow for 2 hours. The IFC fire flow tables are located in Appendix C. It was also assumed that the health center would have an automatic sprinkler system. According to IFC Section B105.2, the required fire flow for a building other than a one- or two-family dwelling may be reduced by 50% when an automatic sprinkler system is installed, but the reduced flow cannot be less than 1,500 gpm. Thus, the fire flow was calculated as shown in Equation 1. This calculated fire flow was lower than the minimum of 1,500 gpm, so 1,500 gpm was used as the design fire flow. Since the total volume of the tank needed to account for future development, a volume of 250,000 gallons was chosen as the water tower design volume.

$$\text{Required Flow} = 0.5 * 2{,}500 \text{ gpm} = 1{,}250 \text{ gpm} \qquad (Equation\ 1)$$

$$\text{Required Volume} = 1{,}500 \text{ gpm} * 2 \text{ hr} * \frac{60 \text{ min}}{\text{hr}} = 180{,}000 \text{ gal} \qquad (Equation\ 2)$$

8.1.2 Demands

The water usage demands of the City of Perkins were calculated for an accurate analysis of the water system. Based on the well data discussed in Section 5.6 of this report, the water demand was determined to be 250,000 gallons per day in 2022 when there were 1,512 meters in the water system. The average daily demand per meter was found by dividing the average water demand by the total number of meters in the network as shown in the equations below.

$$\text{Customer demand} = 250{,}000 \frac{\text{gal}}{\text{day}} * \frac{\text{day}}{1440 \text{ min}} * \frac{1}{1512 \text{ meters}} = 0.115 \frac{\text{gpm}}{\text{meter}} \quad (Equation\ 3)$$

To best characterize the water usage in the system, diurnal curves were used to model the temporal differences in water usage throughout the day for residential and commercial meters. The average daily flow diurnal curves from AWWA M32 were provided by Michael Taylor of Cowan and are shown in Figure 13. To find maximum day flow, a factor of 2.2 was applied to the average day curves. The AWWA maximum day flow diurnal curves, also provided by Michael Taylor, are shown in Figure 14.

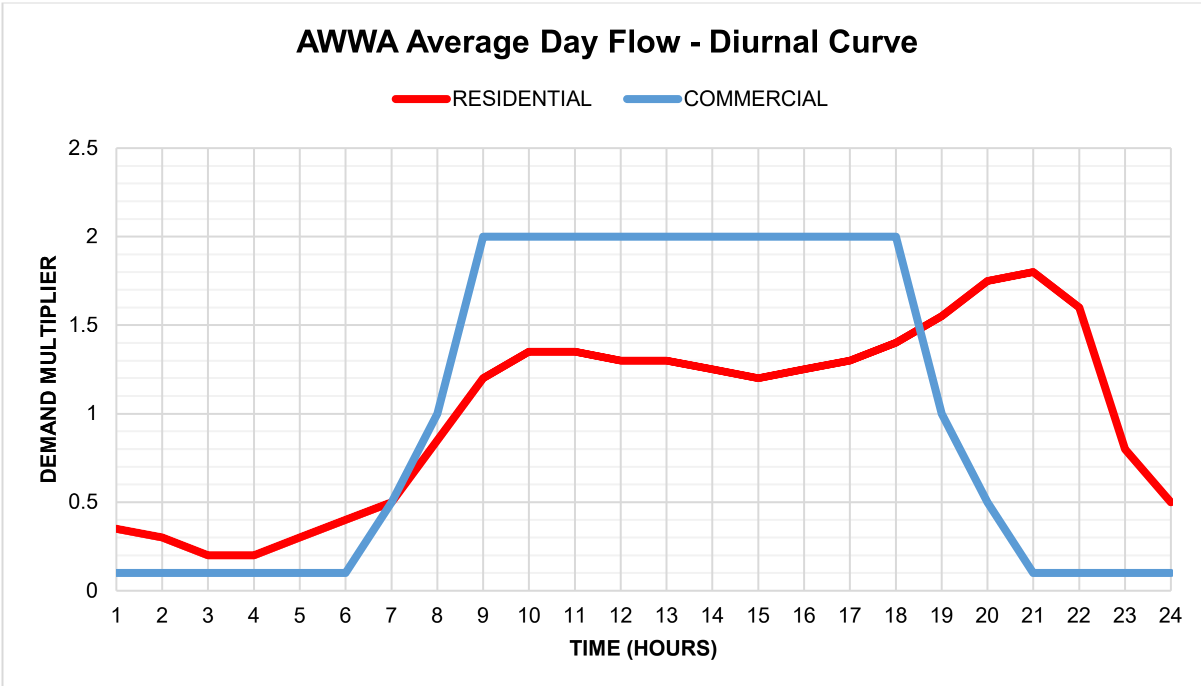

Figure 13. Average day flow diurnal curves for residential and commercial water use.

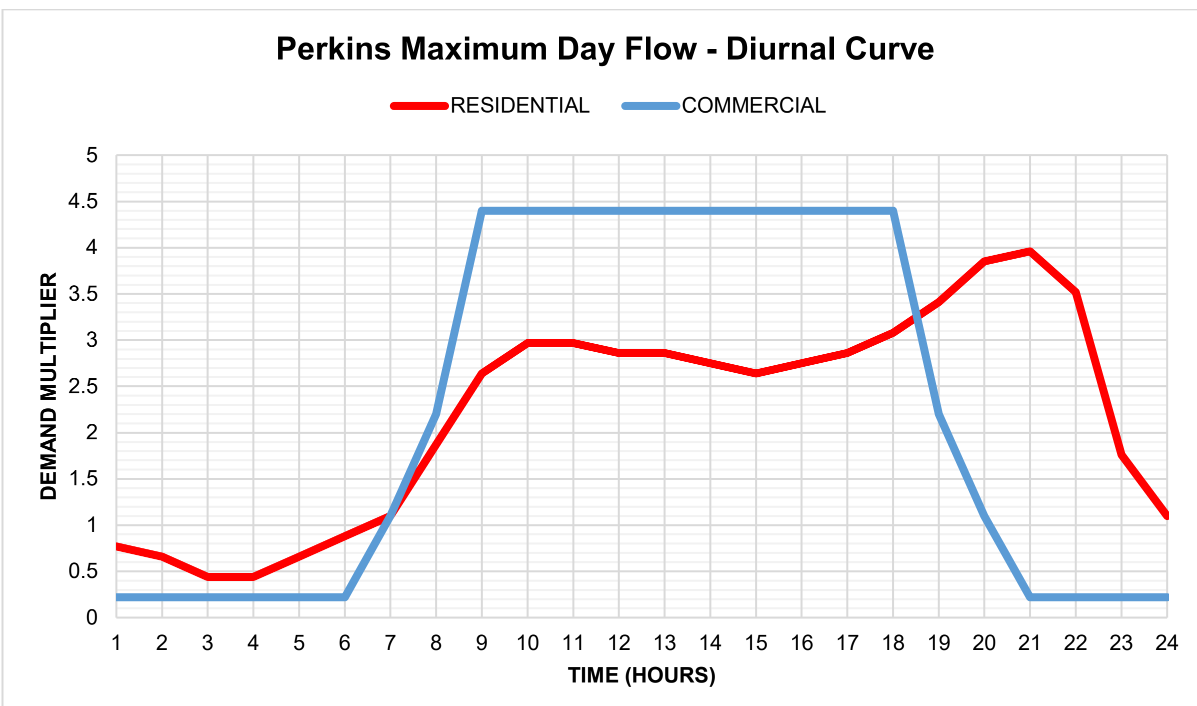

Figure 14. Maximum day flow diurnal curves for residential and commercial water use.

Customer meters were assigned to junctions in the water system by determining the zone of influence for each junction. The junction demand was then calculated by multiplying the number of residential meters or number of commercial meters by the average demand per meter as shown in Equation 4. Hydraulic analysis was performed on EPANET software, and residential and commercial demands were kept separate so the correct demand multipliers could be assigned in EPANET. The demand multipliers associated with commercial and residential meters were found on their respective diurnal curves and applied to the meters to model demand throughout the day. All demands and time usage patterns for each junction were assigned in EPANET before running the analysis on the system.

$$\text{Junction demand} = 0.115\ \frac{\text{gpm}}{\text{meter}} * \text{no. of associated meters} \qquad (Equation\ 4)$$

8.1.3 Future Development

The future development surrounding the new Health Center was approximated and applied to the existing network to ensure that the network had enough circulation in the case of a fire. The Kinder Wells developments were in the construction phase at the present time and are shown in the orange area of Figure 15. This development added 113 new residential meters to the system. In addition to the Kinder Wells project, it was estimated that there would be an additional 250 residential and 25 commercial developments for future analysis. The projected future residential homes are shown in the blue area of Figure 15. The areas in blue were drawn based on conceptual estimates and were only used as a representation of future growth. Future demands were assessed as discussed in Section 8.1.2 of this report, and Table 4 shows the summary of the water distribution system at future conditions.

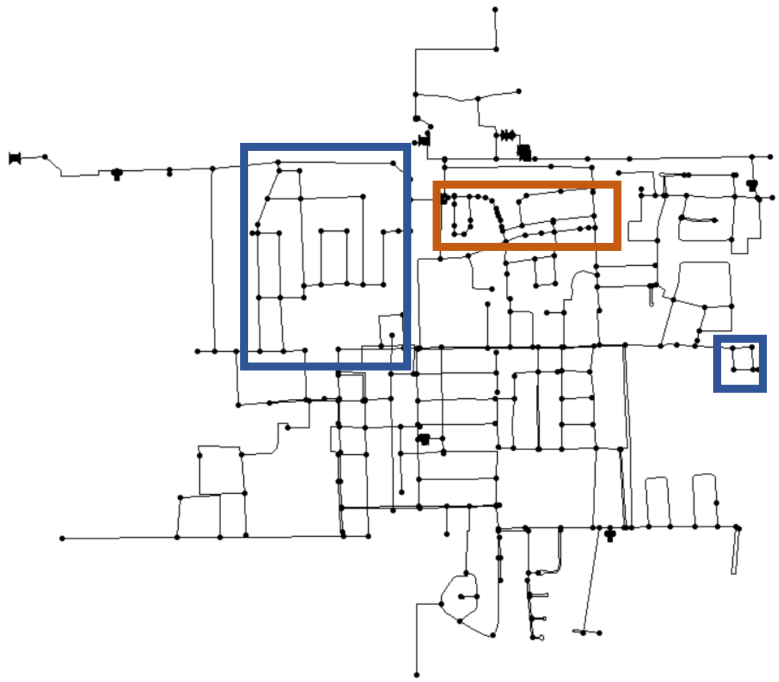

Figure 15. Image of new developments in the City of Perkins. Kinder Wells indicated by the orange and approximate future developments indicated by blue.

Table 4. Summary of water distribution system at future conditions.

Feature	Number
Residential Meters	1,782
Commercial Meters	118
Water Towers	5
Water Wells	4

8.1.4 Simulations without Fire Flow

The water system analysis was performed on EPANET. The following situations were assessed: present conditions at average day flow, present conditions at maximum day flow, future conditions at average day flow, and future conditions at maximum day flow. Each simulation showed that the water system, including the new tower and proposed Main Street crossing plus Ampride to Casey's connection, was able to meet ODEQ regulations. For each simulation, pressures in the system remained above 25 psi, and demands were met at each junction. Though ODEQ does not have specific water velocity regulations, it is generally advised that velocities remain under 5-6 feet per second. The velocities in the pipes did not exceed 6 feet per second, so it was determined that pipe sizes did not need to be increased.

Each simulation showed that the proposed alternative helped circulate water throughout the day. As the flow direction switched periodically, the pipe helped to move water between the east and west sides of the city. This was the case especially for future conditions where new residential developments on the west side of town would strain the system if there were fewer flow paths. The analysis showed that the Main Street crossing plus Ampride to Casey's connection and new water tower improved the functionality of the water distribution system by providing more flow and better water movement.

8.1.5 Fire Flow Simulations

Fire flow simulations were performed at maximum day flow for present and future conditions. A peaking factor of 2.2 was used for maximum day flow as discussed in Section 8.1.2 of this report. A total of five simulations were run at various points in the city. Four residential areas were chosen for fire flow analysis, and these included the proposed future developments, the Kinder Wells development, and an area near the south side of town. The health center was chosen as the only commercial building for fire flow analysis because this project came about due to the proposed Iowa Tribe health center.

Figure 16 shows the locations of the fire flow simulations. In Figure 16, the orange marker shows the location of the health center. This simulation used a fire flow of 1,500 gpm for two hours as calculated in Section 8.1.1 of this report. The green markers are residential connections, and the required fire flow for residential areas is 1,000 gpm for two hours per ODEQ. Table 5 summarizes the fire flow conditions.

Figure 16. Locations of fire flow simulations.

Table 5. Summary of conditions used for fire flow simulations.

Type of Connection	Fire Flow (gpm)	Duration (hrs)	System Demand
Health Center	1,500	2	Max Day
Residential	1,000	2	Max Day

Fire flow at each of the five marked locations was simulated using a dummy junction placed near an existing junction of interest. The dummy junctions were made to be similar in elevation to their adjacent existing nodes, and the existing and dummy junctions were connected using 10 feet of 6” pipe to represent a fire hydrant connection.

Each site chosen for analysis was tested individually. In order for the fire flow simulation to be a success, the water distribution system had to provide enough flow for the modeled fire plus maximum day demands while remaining above 25 psi across the system. These requirements were determined by ODEQ regulations. The alternatives were tested to see which ones maintained a minimum of 25 psi at the junctions. The results from the five simulations showed that the best alternative for fire safety was the Main Street crossing plus Ampride to Casey’s connection. At present conditions, Alternatives 1 and 3 were inadequate in two of the five simulations, and Alternatives 2 and 4 were sufficient for all scenarios. However, in future conditions, only Alternative 4 was adequate across all simulations; the other alternatives caused pressure at the junctions of fire flow to drop below 25 psi, deeming those alternatives unacceptable for the system. The future conditions models were prioritized per client preference and to provide future resiliency for the system. Table C1 in the appendix shows a summary of the fire flow simulation results that led to the decision for the final approach.

8.2 Structural

8.2.1 Dimensions

The dimensions of the tank were based on the requirement of a 250,000-gallon elevated water storage tank as discussed in Section 8.1.1 of this report. Tank capacity was chosen to meet the fire flow requirements for the 30,000 ft^2 health center and future residential developments in the area. The height of tank, diameter of steel tank bowl, plate thickness of steel tank, and diameter of concrete support walls (pedestal) were sized using AWWA D107-16 and reference drawings provided by Cowan Group Engineering and Caldwell Tanks, Inc.

The height of the water tank was based on a required water pressure, which ranged between 50 and 65 psi, at the base of the tower. This ensured the tower would match the pressure of Perkins’ current water system. Using Equation 5, the required high-water level (H.W.L.) elevation of the water tank was 150 ft.

$$\text{H.W.L Elevation} = 2.31\frac{\text{ft. of head}}{\text{psi}} * 65\text{ psi} = 150\text{ ft} \qquad (Equation\ 5)$$

The welded steel tank dimensions were calculated using reference drawings and design standards from AWWA D107-16, Section 5, "Steel Tanks". The diameter of the tank was determined to be 41 ft with a head range of 30 ft according to the design standards. The minimum plate thickness of steel in contact with water was ¼ in. However, to provide a safety factor, a plate thickness of ½ in was chosen. The roof cone angle was designed as 30 degrees, and the tank floor angle was designed as 42 degrees.

The structural concrete support walls for the pedestal were designed in accordance with the ACI 318-19 standards, AWWA D107-16 guidelines, and reference drawings. The diameter of the concrete pedestal was 23 ft. The guidelines stated that reinforced concrete had a minimum specified compressive strength of 4000 psi at 28 days and a maximum specified compressive strength of 6000 psi. A compressive strength of 4000 psi at 28 days was used for the concrete design. The stresses were limited to 25% of the specified compressive strength of concrete, approximately 1000 psi. For the concrete dome structure, the concrete supporting the steel tank floor needed to be at least 8 in. thick with the average compressive stress from the weight of the stored water and structure not exceeding 15% of the specified compressive strength, approximately 600 psi. The thickness of the concrete in the dome was, therefore, 8 in.

8.2.2 Axial Load Design

Dead and live loads were calculated to act on the base of the pedestal, otherwise understood as 150 ft below the hydraulic water line. Fluid load (F) was determined by multiplying the unit weight of water by the volume of storage for a total force of 2,085 kips. Dead load (D) included all forces created by the weight of steel and concrete acting in the direction of gravity. Thickness of concrete was assumed to be a typical 16 inches, and thickness of the steel tank was assumed to be ½ inch. Like the water load, both the concrete and steel volumes were calculated from the tower dimensions and multiplied by their respective unit weights, thereby creating a total dead load of 1,861 kips. In order to find the total factored load (P_{uw}), the applicable Load and Resistance Factored Design (LRFD) formulas were considered. The governing LRFD equation was recorded below. Finally, to obtain the nominal axial strength of the wall (P_{nw}) the factored load was divided by 0.7, the suggested phi factor from ACI 371, which yielded a value of 8,000 kips.

Table 6. Summary of material unit weights, volumes, and unfactored loads.

Material	**Volume (ft^3)**	**Unit Weight (lb/ft^3)**	**Load (kips)**
Water	33,420	62.4	2,085
Steel	161	490	133
Concrete	11,520	150	1,728

$$\text{Load Generated} = \text{Volume (ft}^3) * \text{Unit Weight } (\frac{\text{lb}}{\text{ft}^3}) \qquad (Equation\ 6)$$

$$\text{Govening Load (LRFD)} = 1.4\ (\text{D} + \text{L}) = 5{,}500\ kips \qquad (Equation\ 7)$$

$$P_{nw} \geq \frac{P_{uw}}{\Phi} = 8{,}000 \text{ kips} \qquad (Equation\ 8)$$

8.2.3 Concrete Thickness Based on Axial Load

To determine the thickness of concrete required to support the axial loads, the total factored axial load was divided by an assumed compressive strength of concrete (f'c) equal to 4,000 psi. This provided a minimum area of concrete equal to 2,000 in^2. Using the required area of concrete and the length of the pedestal circumference, it was determined that a minimum wall thickness of 11 inches was required. However, this value was not considered to be a final design specification. A thickness of 16 inches was used as the design concrete thickness due to further analyses described in section 8.2.4 and section 8.2.5.

$$\text{Area of Required Concrete} = \frac{P_{nw}}{f_c'} = 2{,}000 \text{ in}^2 \qquad (Equation\ 9)$$

$$\text{Minimum Thickness of Concrete} = \frac{\text{Area of Concrete}}{\text{Pedestal Circumference}} = 11 \text{ in}^2 \qquad (Equation\ 10)$$

8.2.4 Moment Design

The total moment accounted for in the design was a combination of wind acting on the naturally exposed part of the tower in combination with an eccentric dead load.

Wind calculations were performed using ASCE 7-22 guidelines. First, velocity pressure was determined using Equation 11. Using the velocity pressure and relevant factors, wind pressure was defined as seen in Equation 12.

$$\text{Velocity pressure } (q_z) = 0.00256 * k_z * k_{zt} * k_e * v^2 = 48 \frac{lb}{ft^2} \quad (Equation\ 11)$$

- Wind velocity (ASCE 7-22) = 121 mph
- Exposure Category = C
- Risk category = IV
- Exposure coefficient (k_z) = 1.32
- Topographic factor (k_{zt}) = 1
- Ground elevation factor (k_e) = 0.97

$$\text{Wind pressure (p)} = q_z * k_d \left[\left(GC_{pf}\right) \pm \left(GC_{pi}\right) \right] = 53 \frac{lb}{ft^2}, -34 \frac{lb}{ft^2} \quad (Equation\ 12)$$

- Wind directionality factor (k_d) = 1
- External pressure coefficient (GC_{pf}) = 0.2
- Internal external pressure (GC_{pi}) = 0.9

The maximum moment caused by wind was 20,545 kip•ft. After analyzing an eccentric dead load using one inch of eccentricity and the unfactored axial load from section 8.2.2, the total unfactored eccentric moment was 185 kip•ft. Using these two moments and the LRFD equations, the greatest design moment produced was 33,039 kip•ft.

$$Governing\ Load\ (LRFD) = 0.9D + 1.6W\ =\ 33{,}039\ kip \cdot ft (Equation 13)$$

Table 7. Summary of unfactored moments

Moment (kips • ft)	
Wind moment	20,545
Eccentric dead	329

8.2.5 Final Pedestal Design

The final challenge was to design the reinforced concrete pedestal. The pedestal itself was treated as a large hollow concrete column. An interaction diagram for the column was constructed using an estimated thickness of 16 inches and 139 #9 bars spaced approximately six inches apart. The interaction diagram can be found in Figure C2 in the appendix. This design met the requirements for the axial and moment loading, and for the purposes of this report, it was considered the final pedestal design for the tower. Despite these specifications meeting the required loading, there was concern that potential failure might be brittle failure as a result of inadequate compressive strength. In conclusion, it is highly recommended that a separate analysis be completed to improve the design suggestions provided by this report.

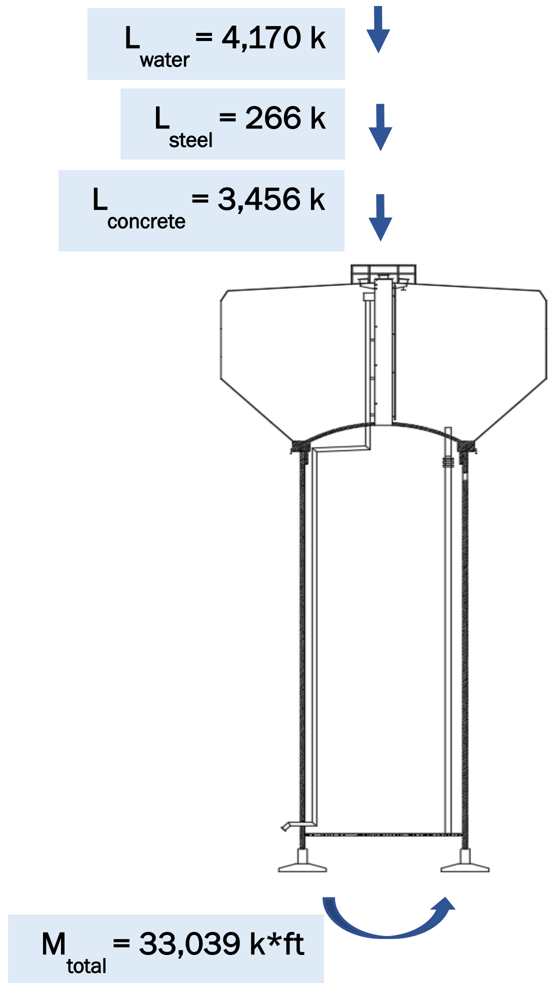

Figure 17. Visual of the applied loads and moments on the water tower. The numbers shown include the LRFD and phi factors.

9. Sustainability Analysis

Sustainability was an important factor in the overall project design. The Envision framework, a widely recognized system for awarding sustainably resilient civil infrastructure, was used as a checklist for the sustainability of the project. The five categories of the Envision checklist include quality of life, leadership, resource allocation, natural world, and climate and resilience.

The community wellbeing, mobility, and values were considered for the quality-of-life aspect. Health and safety guidelines were followed to ensure that the project would positively impact the community. The water system improvement design enhanced water distribution to the entire city, and the elevated water tank was designed to provide fire flow for the health center which increased health care access to the community.

Leadership entailed communication, planning, and economy. Due to a multi-party project, a hierarchy of communication between the stakeholders was created to ensure greater collaboration and satisfaction of all parties. Life-cycle maintenance was also a factor in the alternative decision process, and this further added to the leadership portion of the Envision framework.

Preserving water resources was a high priority for the resource allocation category. To perform the water system analysis and compute the volume of the elevated water tower, present water usage and future demands of the city were estimated. Both aspects of the project ensured improvement to the existing water infrastructure system.

The natural world category consisted of site location, conservation, and ecology. Due to the water system improvement design being largely underground, conservation and ecology were not applicable. However, the location was carefully considered for the elevated water tower. The area of interest was near a 100-year floodplain, so the water tower site was selected to avoid negative impacts to that floodplain.

Climate and resiliency focused on the emissions and integration of the project. Due to the nature of the project, integration of the elevated water tower into the water systems improvement was necessary.

After going through the Envision framework, the project showed good consideration of sustainability, especially with regards to water and the community of Perkins.

10. Risk and Uncertainty Considerations

An understanding of the risk and uncertainties in the design was of high importance to the project approaches. It was a priority that all the designs would have a low risk factor for any potential uncertainties.

10.1 Water System Improvements Design

The water infrastructure analysis was conducted on computer software with minimal coordinate data because there was a high uncertainty in the performance of the current system. The computer software did not include unknown pipe closures, faulty valves, and leaking pipes. Therefore, the analysis of the water system was placed under the assumption that all the pipes were open and functioning perfectly. If there were leaks or closed systems, the simulations performed in this project would not apply.

In addition to unknown conditions of the existing pipe network, there were also uncertainties with the future development conditions. The layout was created completely as a conceptual plan in order to model future demands on the network. Therefore, there is a high probability that the future demands will be different than how it was modeled in this project. There is some risk associated if the future conditions are not exactly as modeled in this project. For example, the Oklahoma Department of Commerce had originally estimated that the population of Perkins would be 2990 in 2030[14]. However, the 2023 population of Perkins currently exceeds this value, so it is difficult to accurately estimate what the future growth of Perkins will be. Thus, should the population exceed what was estimated in this analysis, the modeled performance of the solution will not hold true. Also, if the estimated growth was higher than what will occur, there will be a risk of an overdesign that will cause water to stay in the water towers and system for too long.

Furthermore, the model was run with the assumption that the well sources would not run out of water. In the event that a different water source must be used, the results of the water model simulations would not remain accurate.

10.2 Water Tower Design

As a crucial part of infrastructure, water towers carry an extreme amount of risk. In the event of a complete failure, there lies the potential inability to perform public services and in extreme cases loss of life. Such public services include fire suppression and the city's potable water supply. To minimize these risks, conservative estimates were used to complete the design of the new water tower.

The required fire flow analysis was performed using the following assumptions: first, the an automatic sprinkler system would be present in the new health center. Secondly, the material of the building was assumed since that information was not made readily available at the time of the water tower design. Therefore, there remains some risk that the fire flow calculations may not be an accurate representation of the future conditions, and thus, the water tower storage may be insufficiently designed. However, the tower storage ended up being overdesigned by a factor of 28% to account for any uncertainties as well as future development. Conversely, this overdesign might cause additional problems if the future conditions were not accurately estimated, and the time for tank turnover may become too long.

Due to a lack of geotechnical information, a foundation design was not feasible, and an accurate analysis of the overturning moment caused by the wind pressure on the foundation was not possible to compute. Therefore, additional analysis with foundation design is highly recommended. However, it was possible to calculate a moment caused by wind pressure acting on the pedestal and an eccentric dead and fluid load. The eccentric dead load calculation was defined as having a minimum eccentricity of 1 inch, so the moment caused by the eccentric load may be larger or smaller based on the true eccentricity of the tower.

It was determined that there may be a need for an additional pump, added in series, with the existing pump at the Ampride well. In this case, the price of the project would increase. This possibility stems from the uncertainty that the Ampride Well can supply enough pressure to reach the tower's high-water line. However, it may have been the case that the Ampride well could, indeed, supply 150 ft of head to the tower.

Finally, it was assumed that Perkin's Ampride well could supply enough water to support a 250,000-gallon tank. It is recommended that the Ampride well reservoir be assessed before to ensure the validity of this assumption. The worst-case scenario would result in a need for another well to help supply the future tower.

11. Project Cost Estimate

11.1 Water System Improvements Design

To estimate the cost of installing the water system improvements, the material and construction costs were found. Costs were estimated using Gordian's 2023 RSMeans data[15], and all unit costs from the RSMeans book included materials, labor, overhead, and profit (Total + O & P). The location for the costs was chosen to be Oklahoma City, OK.

Material costs for the proposed water system improvements were assessed based on the length of pipe and number of fittings that were required. To match the existing system, 6" PVC pipes were used. The Main Street crossing needed 440 linear feet (LF) of pipe, and the Ampride to Casey's connection needed 2,900 LF, so the total length of pipe required was 3,340 LF. The Main Street crossing needed two tees to connect to the current system, and the Ampride to Casey's connection needed one tee and two bends. Thus, the required pipe fittings were three tees in total and two 45° bends. Table 8 shows the material costs.

Table 8. Material costs for water systems improvements.

	Item	Unit Cost (Total + O&P)	Units	Quantity	Cost
Materials	6" PVC Pipe	$12	LF	3,340	$40,000
	6" PVC 45 Bend	$140	Each	2	$300
	6" PVC Tee	$280	Each	3	$800
				Total	**$41,000**

Per the client's advice and judgement, it was assumed that the Main Street crossing would be installed by boring under Main Street and open trenching the undeveloped land. An estimated 150 ft would need to be bored. The remaining 290 ft would be installed by open trenching. The Ampride to Casey's connection would be installed by open trenching only. Therefore, the Main Street crossing construction cost included the cost of boring underneath Main Street and all related equipment. From the RSMeans data, the cost of boring and pipe casing was found by doubling the cost of the line item for horizontal boring for a 3" pipe in sandy soil. The open trenching construction cost included the cost of excavation and cost of backfill. The amount to excavate was calculated by assuming a 3' x 5' x 3,190' trench. The amount to backfill was calculated by subtracting the volume of pipe from the excavation volume. Based on soil data and trench dimensions, the RSMeans line item that was selected for excavation costs was common earth excavation with a ½ cubic yard (CY) excavator. The line item chosen for backfill was trench backfill in 6" to 12" lifts using a dozer and compacting with a sheepsfoot roller. Table 9 shows construction costs.

Table 9. Construction costs for water system improvements.

	Item	Unit Cost (Total + O&P)	Units	Quantity	Cost
Construction	Boring Costs	$85	LF	150	$12,800
	Equipment	$12,300	Each	1	$12,300
	Excavation	$7	CY	1,770	$12,700
	Backfill	$4	CY	1,750	$7,000
				Total	**$44,800**

To find the total project cost, the material and construction costs were added together. An additional 15% was applied to the project cost to account for contingency. Table 10 shows the total cost of the waterline improvements.

Table 10. Total costs for water system improvements.

Materials	$41,000
Construction	$44,800
Sum	$86,000
Contingency	$13,000
Total Cost	**$100,000**

11.2 Water Tower Design

Estimating the cost of a 250,000-gallon composite elevated water tank (CET) required consideration of various factors that impacted the project cost. The cost estimate for the water tank design included the material, construction, and maintenance costs. Using data from the 2018 RSMeans Building Construction Costs book, an estimated construction cost was determined. The total cost was compared with a budget estimate from Landmark Structures and Gerard Tank & Steel, and the values are shown in Table 11.

Table 11. Total Cost Comparison for 250,000 CET Water Tower

Total Cost	
Tower, Inc. Estimate	**$1,517,000**
Gerard Tank & Steel	**$1,800,000**
Landmark Structures	**$3,100,000**

11.2.1 RSMeans Building Construction Costs

To calculate the estimated 2023 cost of materials and construction in 2023, a 9.13% interest rate was added to the costs from the 2018 RS Means book to account for inflation. The interest rate was calculated using Figure 18. To account for construction cost differences due to the location of the project, a location factor for Oklahoma City was applied to the unit costs, reducing the costs by 15.6% compared with the United States National Average Costs.

Figure 18. Building Cost Inflation Index 2001-2023

Material costs for the water tower design included a 250,000-gallon composite water tank, including paint, but it did not include pipe, pumps, or the foundation. The inlet and outlet pipes needed a 12-inch diameter, 300-ft long ductile iron pipe. An 8-inch, 150-ft ductile iron overflow was needed in case the tank overflowed. An altitude valve was included in the estimate to control the water pressure at the base of the water tower. Table 12 shows the detailed material costs, including the adjustments for materials in 2023.

Table 12. Materials Cost for 250,000 CET Water Tower

Item	Unit Cost RS Means 2018 with O&P	Projected Unit Cost RS Means 2023	Quantity	Units	Landmark Estimate CET 250,000-gallon		Cost
	Interest rate	9.13%			Low	High	
	Location Factor	84.40					
Materials							
Composite Elevated Tank incl painting	$ 697,566	$ 1,079,707	1	Ea.			$ 1,080,000.00
Ductile Iron Pipe 12"	$ 64	$ 99	300	ft	$ 25,000.00	$ 75,000.00	$ 30,000.00
Ductile Iron Pipe 8"	$ 43	$ 67	150	ft		-	$ 10,000.00
Altitude Valve	$ 5,000	$ 7,739	1	Ea.	$ 10,000.00	$ 50,000.00	$ 8,000.00
					Total Material Cost		**$ 1,128,000.00**

Construction costs for the water tank included excavation for a shallow ring foundation with a depth of 8 ft. The total volume of the foundation was approximately 123 bank cubic yards. The parking lot and surrounding areas were assumed to be covered in gravel. The Iowa Tribe of Oklahoma and the City of Perkins requested that their logos be presented on the side of the water tank, so an additional painting cost was added. RSMeans did not have a section that covered the scope of this task, so an average was taken from the high and low costs that Landmark Structures provided. The client also spoke about how aesthetically pleasing a composite water tank would be in the City of Perkins, so a concrete exterior aesthetic treatment was assessed in the construction costs. Some other costs that were included were grading the work area, which was approximately 5,000 sq. ft, and building a steel chain link fence around the new water tower, approximately 240 ft in length. Table 13 shows the detailed construction costs including adjustments for construction in 2023.

Table 13. Construction Cost for 250,000 CET Water Tower

Item	Unit Cost RS Means 2018 with O&P	Projected Unit Cost RS Means 2023	Quantity	Units	Landmark Estimate CET 250,000-gallon		Cost
	Interest rate	9.13%			Low	High	
	Location Factor	84.40					
Construction							
Excavation - shallow ring at 8 ft depth	$ 5	$ 7	123	B.C.Y			$ 1,000.00
Gravel Lot	$ 18	$ 27	389	SY	$ 20,000.00	$ 40,000.00	$ 30,000.00
Paint ~ Logo and special colors		$ -			$ 10,000.00	$ 50,000.00	$ 30,000.00
Concrete Exterior Aesthetic Treatmant	$ 5	$ 7	8700	ft^2	$ 25,000.00	$ 200,000.00	$ 64,000.00
Mass Site Grading		$ 3,237	1	Ea.			$ 4,000.00
Fence	$ 161.79	$ 250	240	ft.			$ 60,000.00
					Total Construction Cost		**$ 189,000.00**

To account for unforeseen expenses that may occur during the construction process, a 15% contingency was added to the total cost. The unit costs from the RSMeans book included overhead and profit which was approximately 10%. Table 14 shows the total estimated cost of the project.

Table 14. Total Calculated Cost for 250,000 CET Water Tower

Total Material Cost	**$1,128,000**
Total Construction Cost	**$189,000**
Contingency (15%)	**$200,000**
Total	**$1,517,000**

11.2.2 Maintenance Costs

The maintenance costs were determined by the Maintenance Cost from Landmark Engineering. This estimation included all the costs expected throughout a standard 60-year lifetime of a water tank. The exterior of the water tank requires an overcoat of paint every 30 years, and the interior of the water tank must be stripped and repainted every 15 years. This led to a total annual paint cost of $15,000 as shown in Table 15.

Table 15. Maintenance Cost for 250,000 CET Water Tower

Maintenance					
Item	**Unit Cost**	**Quantity**	**Units**	**Cost**	**Annual Cost**
Paint					
Overcoat					
Exterior (every 30 years)	$ 9.50	5000	ft^2	$ 48,000.00	$ 2,000.00
Removal and Replacement					
Interior (every 15 years)	$ 19.00	5700	ft^2	$ 108,000.00	$ 7,000.00
Exterior (every 30 years)	$ 19.00	5000	ft^2	$ 95,000.00	$ 6,000.00

AVG Annual Paint Cost	
Total	**$ 15,000.00**

12. Project summary and conclusion

The Iowa Tribe of Oklahoma planned to construct a new health center in the City of Perkins. This development could potentially stimulate future development on the west side of town. The City Manager was concerned that the existing water system was not adequate to provide fire flow for the health center or to support future development. Therefore, the scope of this project was to design a water tower to be placed on the west side of Perkins and analyze the existing water system to develop improvement plans.

For the water tower, three different types of water towers were considered. The types included a composite elevated water tower, a single pedestal water tower, and a fluted water tower. The alternatives were evaluated with a decision matrix, and the composite elevated water tower was selected as the final approach. The water tower will be 150 ft tall with a 30 ft steel tank. The steel tank will be ½ in thick and will be placed on a 16 in-thick hollow concrete pedestal with a diameter of 23 ft. The total cost of this project was estimated to be approximately $1.5 Million.

For the water system improvements design, four alternatives were considered. Each alternative included pipe installment that connected dead-ends within the network. The water usage data and the water system layout were collected from the City Manager. Using EPANET software, simulations of each alternative were run with present conditions and future conditions at average day flow, maximum day flow, and fire flow with maximum day conditions. After each simulation was run, alternative four was the only one that maintained a minimum of 25 psi under every condition. Therefore, alternative four was selected as the final approach. This plan consisted of 3,340 ft of 6” PVC pipe and had a total estimated cost $100,000.

The solutions to these two problems will improve water circulation and water pressure in the system and prepare the city for future growth.

13. Appendices

Appendix A. References Cited (codes, references, standards, guidelines, textbooks, web references)

References

1. Census Glossary. Accessed February 1, 2023. https://www.census.gov/glossary/
2. *Oklahoma Historical Society*. Accessed February 1, 2023. https://www.okhistory.org/publications/enc/entry?entry=PE015
3. “Water Towers in Perkins.”*Perkins, OK - Official Website*. Accessed February 1, 2023. https://cityofperkins.net/984/Water-Towers
4. *Minimum Design Loads and Associated Criteria for Buildings and Other Structures.* American Society of Civil Engineers, 2021.
5. *ACI 318: Building Code Requirements for Structural Concrete.* American Concrete Institute, 2019.
6. *Composite Elevated Tanks for Water Storage.* American Water Works Association, 2017.
7. *Distribution System Water Quality.* Environmental Protection Agency, 2022. Accessed February 26,2023. Distribution System Water Quality Protecting Water Quality Through Distribution System Flushing (epa.gov)
8. International Fire Code, 2022. Accessed February 26. 2023. Digital Codes (iccsafe.org)
9. *General Design.* Oklahoma Department of Environmental Quality, 2017.
10. Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at the following link: http://websoilsurvey.sc.egov.usda.gov/. Accessed [2/22/2023].
11. FEMA NFIP, FIRM Panel 410 of 525. Map number 40119C0410F, eff. May 16, 2007. https://www.cityofperkins.net/DocumentCenter/View/992/Floodplain-map-Perkins-half-size-January-2016-PDF?bidId=. (Accessed February 2, 2023).
12. Google Earth Pro v.7.3.6.9345. (2022). Perkins, Oklahoma 35°58'56"N. 97°1'45"W.
13. Caldwell Tanks. “Composite Elevated Storage Tank: Water Storage: Caldwell.” *Caldwell Tanks*, 17 Dec. 2021, https://www.caldwelltanks.com/tank_types/composite-elevated-storage-tank-cet.
14. Oklahoma Department of Commerce. “Population projects for Oklahoma 2000-2030.” *Digital Prairie.* https://digitalprairie.ok.gov/digital/collection/stgovpub/id/8376.
15. Gordian. “RSMeans Cost Data.” (2023).

16. *Construction inflation 2022*. Construction Analytics. (2023, February 9). Retrieved April 17, 2023, from https://edzarenski.com/2022/02/11/construction-inflation-2022/

Appendix B. Summary of discussions with client

Meeting Date: January 23, 2023

This was the first meeting with the client, Bob Ernst. The team and client discussed project expectations and scope. It was determined that a new water tower was needed to accommodate the new Iowa Tribe health center due to fire flow regulations. The team and client overviewed the water system in Perkins and briefly discussed expected challenges which included soil type and depth of water table. The location, size, and type of water tower were left to the team to decide. The team visited the proposed health center site and the 2018 Frank Eaton Water Tower. The client sent water system files and other helpful files to begin working.

Meeting Date: March 3, 2023

For this meeting, the team and client performed fire hydrant tests at two hydrants in the city. The team also obtained readings from water towers and valves along the system. The client and team discussed necessary water information such as water usage and well data.

Meeting Date: March 7, 2023

In this meeting, the client approved the conceptual future layout used to model future water demands. The client gave three recommendations for possible water system alternatives, which were used as the alternatives for the project, and the client approved the selected composite water tower alternative.

Meeting Date: April 7, 2023

The purpose of this meeting was to go over engineering design and calculations. This meeting was held after performing preliminary fire flow analyses, so combining alternatives was discussed in this meeting. The client stated that cost was not the biggest factor in the decisions for the water system analysis design, for he planned to use the results of the water model to apply for funding. It was determined that the performance of the system had priority over other factors. The client had no problems with the water tower design.

Email Correspondence

Much of the communication with the client was done through email for ease of communication. The client sent important files and information throughout the semester, and the team sent frequent updates to keep the client informed.

Appendix C. Data and Analysis

TABLE B105.1(2) REFERENCE TABLE FOR TABLES B105.1(1) AND B105.2

FIRE-FLOW CALCULATION AREA (square feet)					FIRE FLOW (gallons per minute)[b]	FLOW DURATION (hours)
Type IA and IB[a]	Type IIA and IIIA[a]	Type IV and V-A[a]	Type IIB and IIIB[a]	Type V-B[a]		
0–22,700	0–12,700	0–8,200	0–5,900	0–3,600	1,500	2
22,701–30,200	12,701–17,000	8,201–10,900	5,901–7,900	3,601–4,800	1,750	
30,201–38,700	17,001–21,800	10,901–12,900	7,901–9,800	4,801–6,200	2,000	
38,701–48,300	21,801–24,200	12,901–17,400	9,801–12,600	6,201–7,700	2,250	
48,301–59,000	24,201–33,200	17,401–21,300	12,601–15,400	7,701–9,400	2,500	
59,001–70,900	33,201–39,700	21,301–25,500	15,401–18,400	9,401–11,300	2,750	
70,901–83,700	39,701–47,100	25,501–30,100	18,401–21,800	11,301–13,400	3,000	3
83,701–97,700	47,101–54,900	30,101–35,200	21,801–25,900	13,401–15,600	3,250	
97,701–112,700	54,901–63,400	35,201–40,600	25,901–29,300	15,601–18,000	3,500	
112,701–128,700	63,401–72,400	40,601–46,400	29,301–33,500	18,001–20,600	3,750	
128,701–145,900	72,401–82,100	46,401–52,500	33,501–37,900	20,601–23,300	4,000	4
145,901–164,200	82,101–92,400	52,501–59,100	37,901–42,700	23,301–26,300	4,250	
164,201–183,400	92,401–103,100	59,101–66,000	42,701–47,700	26,301–29,300	4,500	
183,401–203,700	103,101–114,600	66,001–73,300	47,701–53,000	29,301–32,600	4,750	
203,701–225,200	114,601–126,700	73,301–81,100	53,001–58,600	32,601–36,000	5,000	
225,201–247,700	126,701–139,400	81,101–89,200	58,601–65,400	36,001–39,600	5,250	
247,701–271,200	139,401–152,600	89,201–97,700	65,401–70,600	39,601–43,400	5,500	
271,201–295,900	152,601–166,500	97,701–106,500	70,601–77,000	43,401–47,400	5,750	
295,901–Greater	166,501–Greater	106,501–115,800	77,001–83,700	47,401–51,500	6,000	
—	—	115,801–125,500	83,701–90,600	51,501–55,700	6,250	
—	—	125,501–135,500	90,601–97,900	55,701–60,200	6,500	
—	—	135,501–145,800	97,901–106,800	60,201–64,800	6,750	
—	—	145,801–156,700	106,801–113,200	64,801–69,600	7,000	
—	—	156,701–167,900	113,201–121,300	69,601–74,600	7,250	
—	—	167,901–179,400	121,301–129,600	74,601–79,800	7,500	
—	—	179,401–191,400	129,601–138,300	79,801–85,100	7,750	
—	—	191,401–Greater	138,301–Greater	85,101–Greater	8,000	

Figure C1. IFC fire flow values for buildings.

Table C1. Fire flow simulation results. Results below 25 psi do not meet requirements.

Alternatives	**Lowest Pressure at Junction of Fire Flow (psi)**							
	Health Center		**Kinder Wells**		**South Side**		**West Future Residential**	**East Future Residential**
	Present	**Future**	**Present**	**Future**	**Present**	**Future**	**Future**	**Future**
Alt 1	42.7	16.84	22.93	38.53	9.66	39.15	34.87	23.62
Alt 2	40.29	22.99	26.35	38.43	30.7	40.97	35.89	25.28
Alt 3	42.66	16.08	21.9	38.14	8.97	39.92	29.70	25.32
Alt 4	39.75	25.84	29.87	40.00	40.11	41.18	39.73	25.26

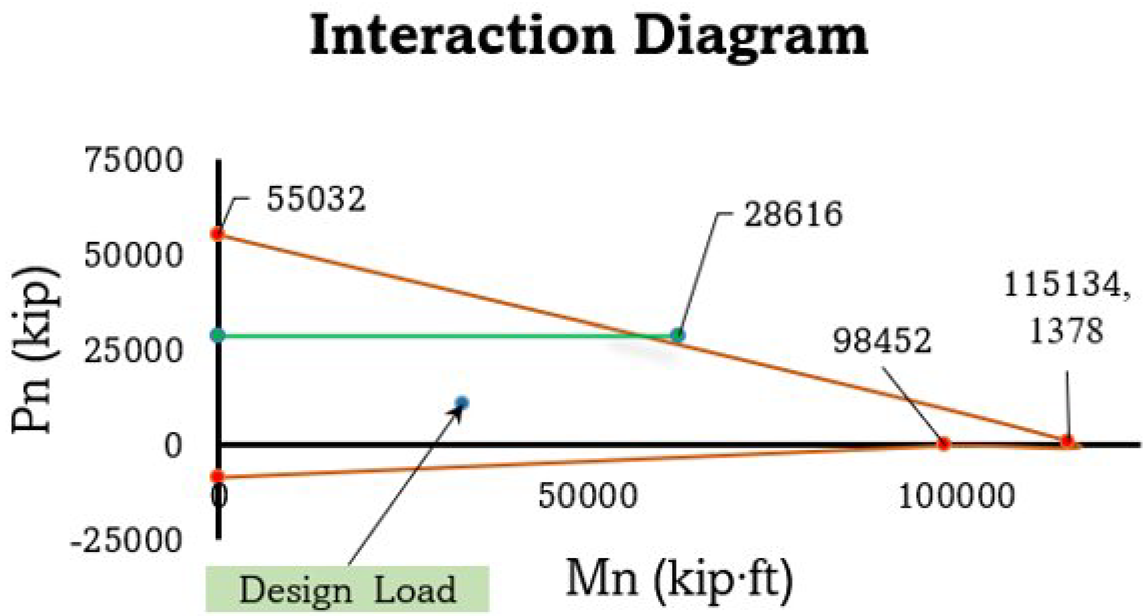

Figure C2. Interaction diagram used to design concrete pedestal.

Appendix D. Team Management Plan

Date – February 2, 2023

Team Name – Tower, Inc.

Team Members -

Ali Alfadhi – Ali took a soil stabilization class and stormwater class.

Josephine Lee – Josephine has taken an elective in Stormwater Management and Green Infrastructure. She is currently taking Geographic Information Systems and Civil Infrastructure Systems. She has experience with working with Civil3D, Matlab, and Excel.

Lela Merkel – Lela is an environmental student with a strong background in water resources involving two summer internships. The electives she has taken include Stormwater Management & Green Infrastructure and Water Treatment. She is familiar with Civil3D, GIS, HEC-HMS, and HEC-RAS.

Christian Pikett – Christian will provide knowledge he has acquired from land development and surveying internships, as well as classes such as GIS. He has experience with Civil3D and GIS.

Philip Thompson – Philip is a Civil student with a background in construction and management. He has taken an elective in Construction Business Practices course and is currently taking Construction Equipment Management Construction Contracts and

Specifications, and Advanced Steel Structure Design. He has worked with AutoCAD, SolidWorks, MATLAB and Revit.

Leadership Plan –

Our team will divide work as evenly as possible and split responsibilities of communication between members. Lela will be the main form of contact with Bob Ernst. Josephine will oversee documentation and turn in assignments on Canvas. Christian will communicate with Oklahoma State University professors for assistance. Philip will oversee communication with outside resources. Every member is expected to contribute to some degree in every aspect of the project.

This team will be split into two projects: water tower design and water system analysis. While all team members will be involved in both projects overall, the members will primarily focus on one or the other. Philip, Christian, and Ali will take charge of the water tower design. Josephine and Lela will focus on the water system analysis. As the projects are related, team members will assist on both projects as necessary.

Communication Plan –

We will be using GroupMe as the main form of communication for our project. We will ensure all team members are kept informed by enforcing a no mute policy. At meetings, a word document will be updated with main events and future actions to keep documentation.

Meeting Schedule -

All team members are available to meet after class on Wednesday. We are also available to meet on Tuesday or Thursday before 9:00, and Friday after 12. Meetings are preferred to be in person. These dates will be decided in GroupMe.

Preliminary Team Goals -

Our team goal is to design an exceptional water tower and accurately analyze the water distribution system to satisfy the client's needs. We want to gain valuable experience about the consulting process and apply our coursework to a real-life situation.

Tasks and Milestone Plan -

The team will establish milestones weekly during class and identify individual tasks at group meetings. We will identify tasks by determining what work must be prioritized each week, and we will set a target date to meet the milestone by estimating how much time it should take. If a milestone is not met, the situation will be assessed and modified to become a high priority and easier to complete. If a team member is not contributing enough, they will be given a verbal warning before alerting outside assistance.

Team Vision -

Collaboration and inclusivity will be encouraged, and all ideas will be acknowledged. Every member's input will be welcomed and valued. We want to design a solution that lasts. Our vision statement is, "Innovating creative, long-lasting water solutions by emphasizing coordination and striving for inclusivity."