COLORADO STATE UNIVERSITY MOUNTAIN CAMPUS FIRE SUPPORT SYSTEM

Hotshot Engineering
9 April 2021

Ms. Susanne Cordery
Environmental Engineer
Colorado State University Facilities Management
2545 Research Boulevard
Colorado State University
Fort Collins, Colorado, 80526

November 20th, 2020

Subject: Colorado State University Mountain Campus Fire Protection Upgrade

Dear Ms. Cordery,

Hotshot Engineering is excited to have the privilege of being chosen to take on Colorado State's Mountain Campus Fire Protection System Upgrade. Hotshot Engineering has been working vigorously to present you with a final report that entails designs to help improve the campus. Below is a report outlining the designs and steps that Hotshot Engineering took to better CSU's Mountain Campus Fire Support System. Mountain Campus's upgrade includes a design for a new fire line, a Plan of Action, and a fuel reduction plan. Upgrading the system will provide a safer campus for faculty, students and visitors to the mountain campus. It could also potentially save valuable research collected by Mountain Campus researchers, thousands of dollars in property damage, and lives of other Rams. To accomplish these goals, Hotshot Engineering carried out the general approach detailed in the proposal.

Working on this project for Colorado State University was an honor for Hotshot Engineering. Hotshot Engineering consists of six future engineers that range from Civil, Environmental and Structural backgrounds. This variety of knowledge allowed for the team to come up with the best solution possible for CSU's Mountain Campus. Please feel free to contact the team with any questions or concerns.

Sincerely,

Stephen Agenbroad

Stephen Agenbroad, Senior Project Engineer

Hotshot Engineering
Walter Scott, Jr. College of Engineering
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Introduction and Background

Colorado State University is known for its research in wildlife conservation, botany and many other natural sciences. Although the main campus of CSU is located in Fort Collins, the school also has another campus, known as the Colorado State Mountain Campus. This campus has been a staple in the CSU community for the research and field studies it hosts. Located about two hours west of Fort Collins the campus boasts over 1,600 acres. Using this land and knowledge gained from CSU, students and professors have gained valuable research in fields like wildlife biology, agriculture and hydrology of snow. Below figures display a geographical location of the campus.

Figure 1. CSU Mountain Campus relative to Fort Collins

Historically, the Mountain Campus was home to Native Americans, then George Pingree opened a logging camp that brought valuable timber to the expanding country. In the late 1890's, two brothers, Hugh and Charles, opened a ranch and it was passed down throughout generations of the family for almost one hundred years. By an act of congress in 1914, Colorado State was allowed to select a piece of land in the Roosevelt National Forest, and the Mountain Campus was born.

Hugh and Charle's ranch still remained on the land and in 1972 Colorado state bought the ranch. In an effort to preserve history, Colorado State maintains many of the buildings that were once on the ranch. Currently, the campus has a walking tour of the ranch and a museum to help commemorate the pioneers. This museum mimics what a home on the ranch would have looked like. Figures below display the museum, which is inside one of the original homes.

Figure 2. CSU mountain Campus Museum Interior

Visiting the Mountain Campus can be an amazing experience but it is not open to the public. Many undergraduate students in the Warner College of Natural Resources are required to take a four-week summer session at the mountain campus. Along with students, the Campus also allows business conferences, fundraisers and other camp programs. Mountain Campus has 52 buildings which include classrooms, labs, dormitories and eating halls. Also on the property is a challenge ropes course that is used primarily for team building exercises.

Wildlife biology also plays an important role at the Mountain Campus. Being surrounded by beautiful landscape, and watersystems many species choose to make their homes nearby. Doctors Kate Huyvaert and Paul Doherty alongside one undergraduate student from the Department of Fish, Wildlife, and Conservation Biology have teamed up to study calcium effects on nesting Tree Swallows (*Colorado State University*, 2). Figures 3 and 4 represent some wildlife seen on the Mountain campus.

Figure 3. Marmot

Figure 4. Pika

Although this campus has many natural beauties and is home to adorable wildlife, the area is prone to heavy snow and wildfires. Most recently, the Cameron Peak wildfire aimed its blaze on the campus. Cameron Peak burned through over 208,913 acres starting in early 2020 (*Cameron Peak Fire* n.d.). Starting in Chambers Lake in Northern Colorado the fire blew Southwest approaching Pingree Park and the Mountain Campus. Figures below show the map and blaze of the fire over nearby Estes Park.

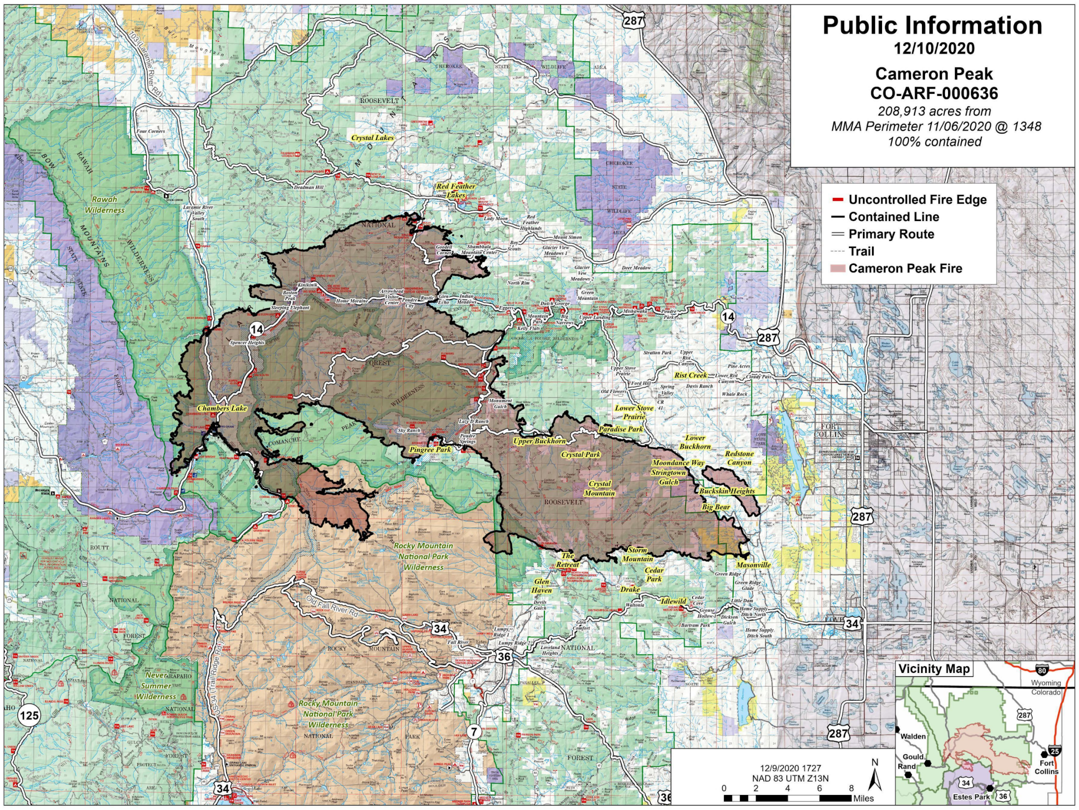


Figure 5. Cameron Peak Fire Map

Figure 6. Cameron Peak Fire Approaching Estes Park

As of December 2nd, 2020 the fire had been completely extinguished. Although the fire came extremely close to the campus, it was saved. This was due in part to the tireless efforts of local and nonlocal firefighters. Hotshot engineering had the privilege of interviewing two of the firefighters Jesse Whitt and Joe Murray. The interview gave insight to the equipment and methods used, along with valuable recommendations on how the project can aid in their efforts against future fires.

Working over 16 hours daily the men gave their all to support the campus. Prepping the campus was the first step, they cleared a 100 yard perimeter outside the campus removing brush and trees, this process is also known as fuel reduction (Murray & Whitt, phone interview, February 9, 2021). They also did a dig perimeter a half mile outside of campus. Dig perimeters are used to stop initial flames from entering, essentially another barrier. This was the first step in their efforts, the firefighters then moved on to implement a water distribution system. This distribution system would serve as the last barrier for the campus buildings before flames swallowed them up.

Given the optimal location of the campus, the South Fork of the Poudre river served as a water source for the system. Using the fire crews pumps they were able to pump directly from the river. Five Mark 3 pumps were used, these pumps can push 38-98 gallons per minute (Murray & Whitt, phone interview, February 9, 2021). Due to the extent of the fire the men estimated millions of gallons of water were used to delineate any threats. Piping and sprinklers for the distribution system was brought in from around the country and took a few weeks to get.

Once the piping was brought in, the pumps were hooked up to the piping and into sprinklers. Sprinklers were strategically placed around the historic and high value buildings. A four point system was used for the sprinklers, this means two sprinklers on each building end. One head was just a foot off the ground while the other head was twenty feet off the ground, covering the entire perimeter. Buildings not covered by the sprinkler system were housed down manually or wrapped in structure rap. Structure rap resembles a thicker tin foil and is used to reflect heat off the building.

Currently, the campus is coming back to life. Through the efforts of Jesse, Joe and other fire personnel the campus did not suffer any damage. Cameron peak never fully reached the campus, it did reach the dig barrier but never surpassed it. Moving forward Hotshot Engineering created a plan to aid firefighters in their efforts and help the Mountain Campus if another wildfire were to occur.

Purpose and Objective

Colorado has experienced the two largest fires in state history this past year: The East Troublesome fire and The Cameron Peak fire. Burning over 300,000 acres, these two fires caused massive environmental damage as well provoking entire cities to evacuate. Thankfully, The Colorado State University Mountain Campus managed to survive the 2020 Cameron Peak Fire with minimal damage. Before the fire blew past, the campus served as a launch location for the brave firefighters who fought the fire. Mountain campus had little to offer when it came to tools for fighting the wildfire. As explained above, the firecrews brought in all of their own equipment, some of which took weeks to reach the campus (Murray & Whitt, phone interview, February 9, 2021). If the fire crews had had access to more efficient fire suppression equipment then they would have stood a better chance at containing the fire. With this in mind, CSU Mountain Campus intends to be proactive in its preparedness for the next fire season.

One main job of the HotShot Engineering team was to provide an updated fire support system to replace the Mountain Campus's outdated system. With this in mind, the objective of the project involved researching and developing the new system. Requirements for the project involved redesigning the water distribution system, recommending a fuel reduction plan and a Plan of Action. Within the redesign of the water distribution system, product suggestions and cost estimates were made based on the firefighters recommendations. A fuel reduction plan was recommended in an effort to reduce fire risk surrounding the campus. Lastly, a Plan of Action will be provided to aid the firefighters in operating the system in a safer manner and steps to take incase of system failure. The optimum goal is to provide the mountain campus with a safe and updated fire support system that is user friendly to firefighters when another wildfire occurs.

General Approach

Throughout the project, the goal of the system has shifted from a self sustaining, fire suppression system to a fire support system that allows wildland firefighters to integrate with the system. This new goal was accomplished in a four phase plan, starting with a data collection and research phase, followed by determining the alternatives, designing the alternatives, and finally the completion of the deliverables. The overall approach of the project can be summarized in Table 1 below.

Phase One was data collection and research. It consisted of three major tasks, with an objective to provide enough information to determine the alternatives in the next phase. Research entailed identifying water sources surrounding the campus and to ascertain the maximum, allowable water usage for fighting fires. Legal issues and regulations were researched to understand to what extent the South Fork Poudre River could be utilized. Highly valuable information was gathered from an interview with wildland firefighters that were on duty during the Cameron Peak Fire. Additional tasks entailed researching possible solutions for fires on the campus including possible detection systems, current methods for fighting fires, and systems being currently used by other isolated, mountain communities.

Phase Two is when the team developed design criteria, different alternatives, and decided on a singular alternative to fully design. Initial design criteria entailed the storage capacity, power capability, and distribution ease. These design criteria were then compared amongst five different alternatives which were building an extra storage tank, designing a new well, rehabilitating the old fire well, building precipitation catchments, and finally using foam dispensers. After communicating with the client and wildland firefighters, it was determined that the goal of the project would be to integrate with firefighting personnel and support them in their duties. With recommendations from the firefighters, it was decided that a new fire distribution system in combination with a Plan of Action would be the best alternative moving forward. The Plan of Action would also entail a fuel reduction plan along with a flowchart that would explain how firefighting personnel would react if the system were to fail.

Phase Three entailed the development and designing of the chosen alternative, along with a cost analysis, and a Plan of Action. Initial tasks involved drawing the new fire distribution system using both AutoCAD and Fathom. AutoCAD was utilized to display the layout of the system, while Fathom was used to analyze the physical properties of the system. Both softwares were used to get an accurate cost analysis of all the material being used. A cost analysis was made to evaluate the construction and material costs for the system. Lastly, a Plan of Action was made to help inform firefighters on how to integrate with the systems. In addition to the Plan of Action, there are suggested fuel reduction plans that the campus should follow.

During Phase Four, a presentation was made to display final designs and considerations. The presentation will also be conducted at the virtual E-Days event hosted by the Colorado State University College of Engineering. A final report was made for Colorado State Mountain Campus along with the Civil/Environmental Engineering senior design professor.

Table 1. Summary of the phases and tasks of the project

Phase I	Data Collection and Research
Task 1	Determine Water Sources
Task 2	Research Other Wilderness Fire Protection Programs
Task 3	Collect Firefighting Experience and Needs
Phase II	Determine Alternatives
Task 1	Develop Alternatives
Task 2	Develop Design Criteria
Task 3	Choose Preliminary Design
Phase III	Develop Design
Task 1	Develop and Design Recommended Alternatives
Task 2	Provide a Cost Benefit Analysis of the Alternatives
Phase IV	Presentation and Deliverables
Task 1	Compile Final Report
Task 2	Create Presentation Materials
Task 3	Present at Virtual E-Days

Designs

After communicating with wildland firefighters about the issues they deal with and the equipment they use, it was decided that the overall goal of this design is to support the firefighters in their fight against forest fires. A common issue that the firefighters faced was setting up equipment and fuel reduction (Murray & Whitt, phone interview, February 9, 2021). It was explained that it took almost two weeks before the firefighters were able to set up temporary sprinkler systems. In addition, it took five workers five days to clear fuel 100 ft beyond the campus (Murray & Whitt, phone interview, February 9, 2021). Therefore, an updated, semi-permanent fire distribution system was developed to cut down on the wait time for equipment that firefighters use. A Plan of Action is included in the final design to inform firefighters on how to react in case the system encounters malfunctions. In addition to this, a year round fuel reduction plan for the campus is included in final designs.

Fire Distribution System

A primary goal of the design process was to develop a new fire line for the campus that is semi-permanent. In designing the distribution system, it was assumed that the system would be made of two parts: permanent and temporary equipment. Temporary equipment would consist of cloth piping and sprinkler heads. This method was utilized by the firefighters stationed at the campus during the fire. They positioned sprinkler heads around the critical buildings designated by the campus (Murray & Whitt, phone interview, February 9, 2021). The rankings of importance for the buildings can be seen in Figure 7 below.

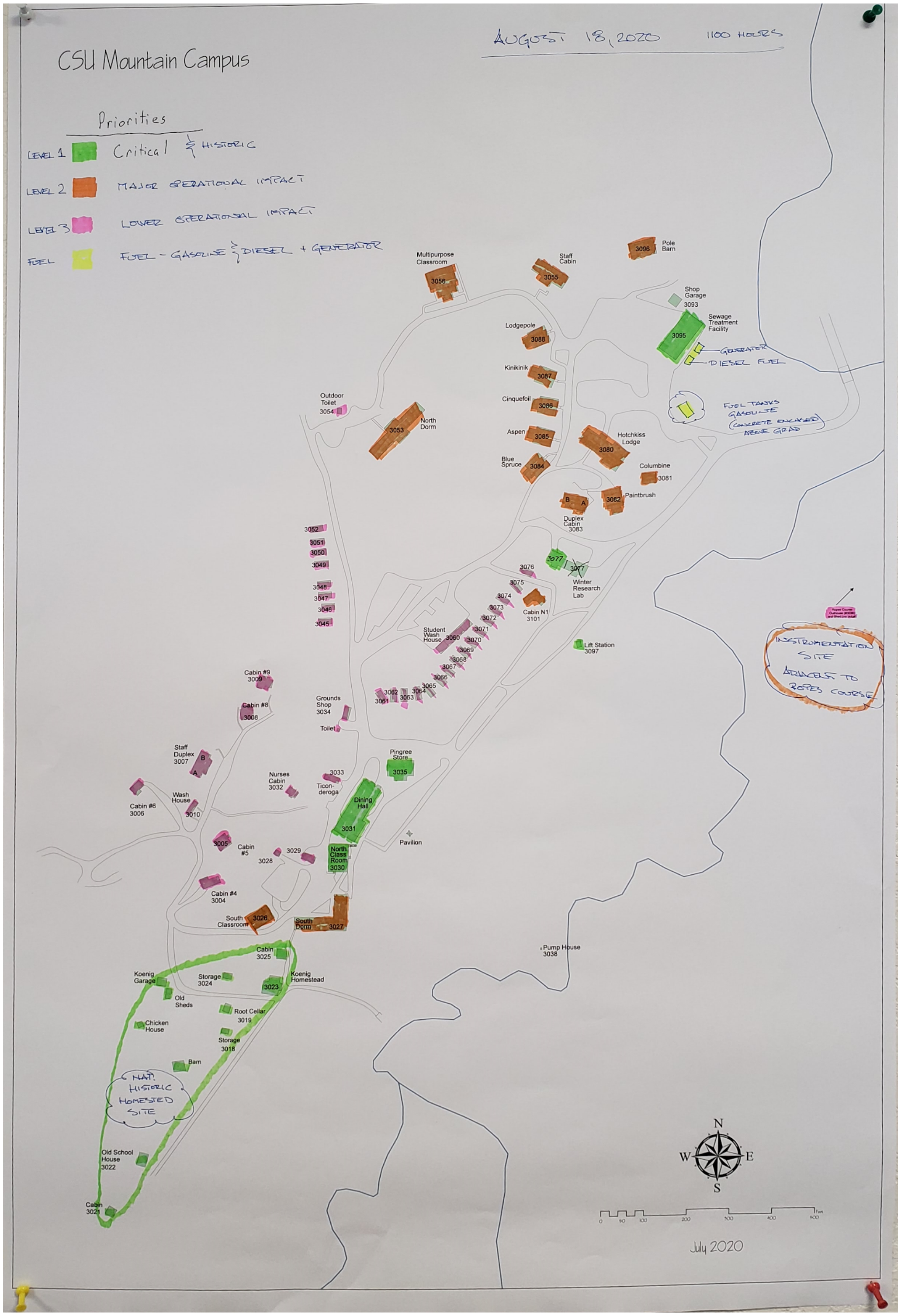


Figure 7. Building importance layout provided by the campus to aid firefighters during the Cameron Peak Wildfire (Cordery, phone interview, February 25, 2021)

Sprinkler heads were laid in a pattern with four per building, two were positioned 20 ft in the air to cover the roofs, while the other two were positioned closer to the ground (Murray &

Whitt, phone interview, February 9, 2021). A similar method was incorporated in the overall design of the system. Sprinklers will be positioned around critical buildings shown above, but instead sprinkler heads will be minimized. After simulating the system, it was discovered that the sprinklers will have enough pressure to spray at a 60 ft range. Therefore, only two sprinklers are required per building, and if placed between buildings they can cover multiple buildings. Sprinkler heads and clothed piping would be stored in a safe location on campus so that they can be rolled out when needed.

Permanent portions of the system are made up of a piping system that will aid in the transportation of water. An assumption was made that the permanent portion of the system would be six inches below the ground at all locations. Exceptions were made for valve controls and connections. Layouts of the distribution can be seen in Figures 8 and 9 below. The distribution system was split into two different sections: the historic and the northern section. This was done to aid in both costs and calculations for the system. Referring to Figures 8 and 9 below, each pipe segment was measured using Google Earth due to the lack of surveying equipment owned by Hotshot Engineering. In addition to the pipe lengths, valves can be seen in both figures in the form of circles along the pipeline with hatched centers.

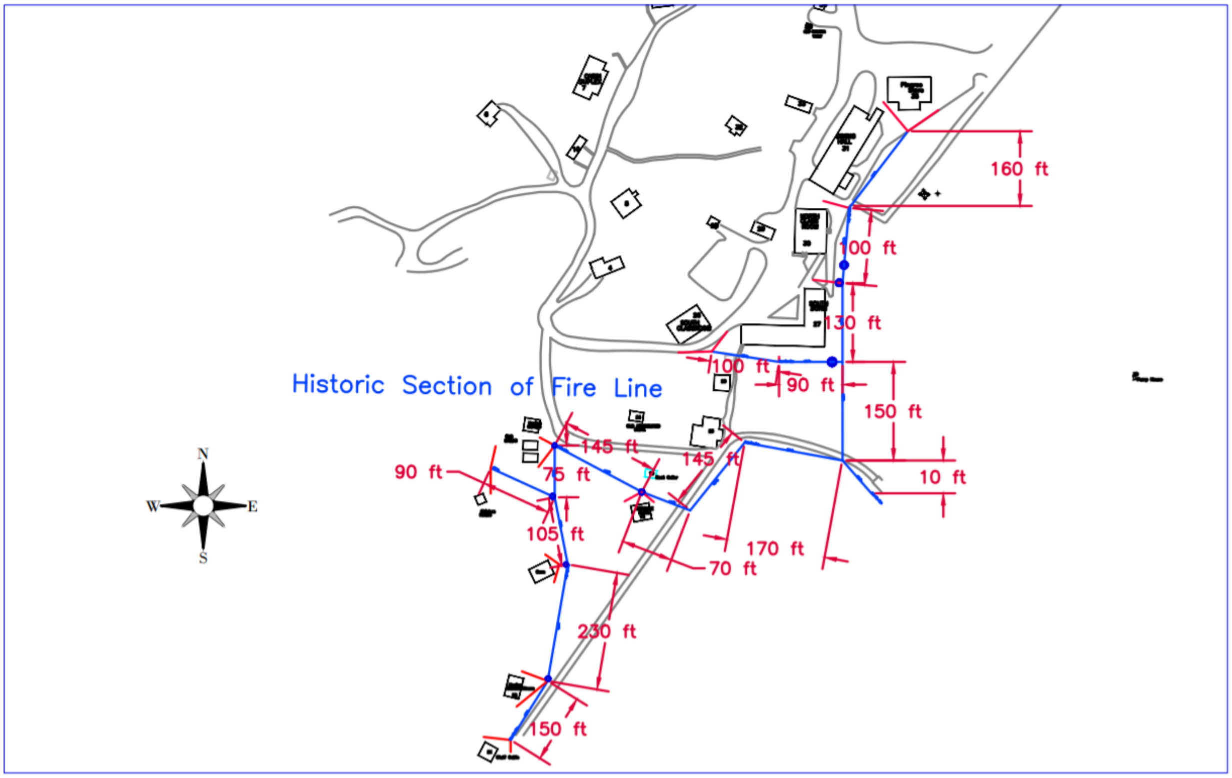


Figure 8. Historic (Southern) Section of the new fire line.

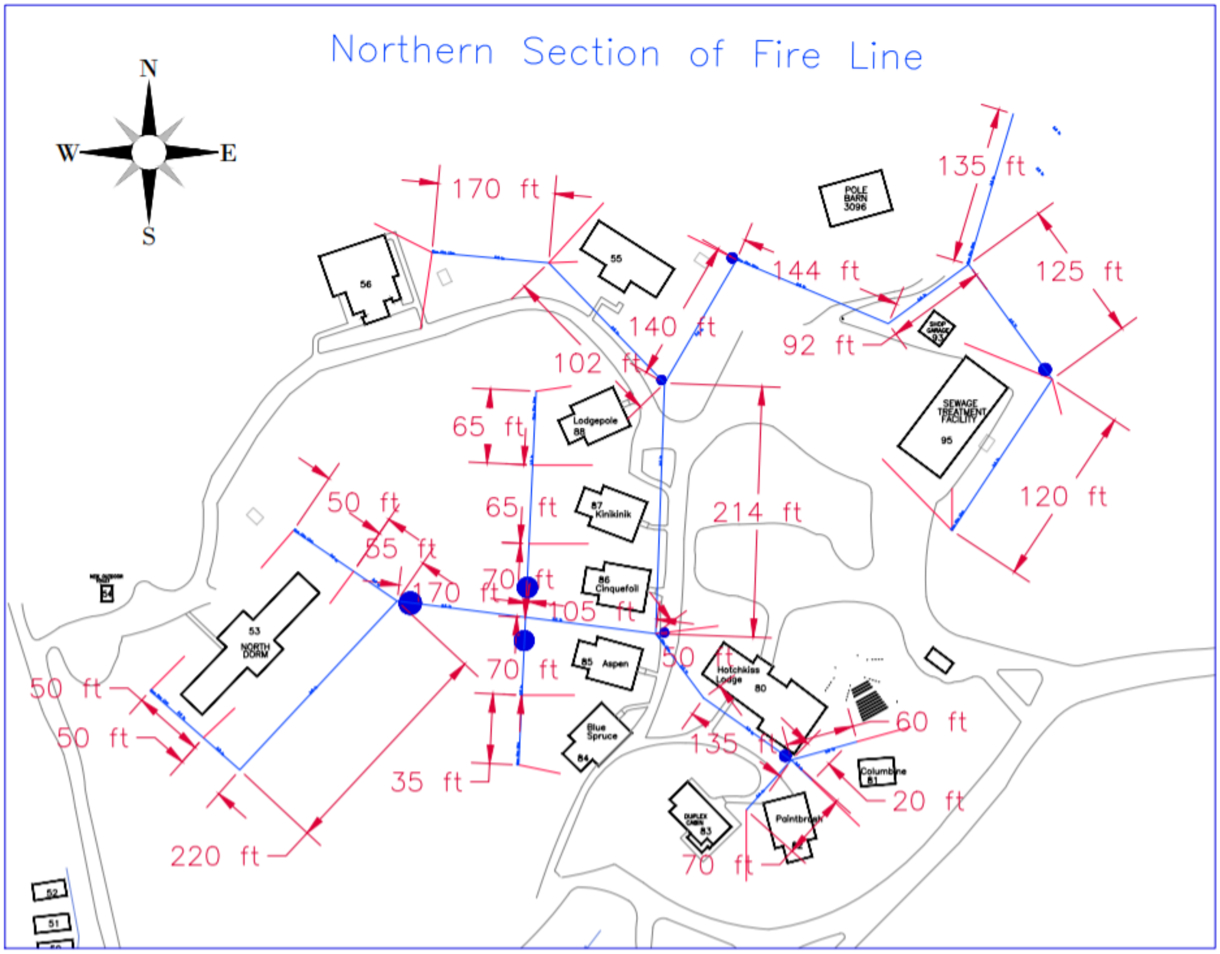


Figure 9. Northern Section of the new fire line.

CSU Mountain Campus does not have water rights to the South Fork Cache La Poudre portion of the river; therefore, the distribution system will not pull directly from the river (Colorado Water Law, 2016). Instead, firefighters will integrate with the system, using their own pumps and cloth piping to pull from the river. Firefighting crews should use standard Mk. III pumps in addition to 3.5 inch, 100ft long cloth piping to pull water from the river on the north and south end of campus (Murray & Whitt, phone interview, February 9, 2021).

Due to the volumetric flow of the river, the system cannot have all sprinklers run at the same time. Therefore, the system will be automated to minimize the involvement of the firefighter crews. Figures 10-19 outline the different zones that will be activated individually by the automated system. A program would be made so that the automated system would transition from zone to zone every 20 minutes. This will ensure that the buildings remain wet throughout the day and will minimize the chance of the buildings catching fire.

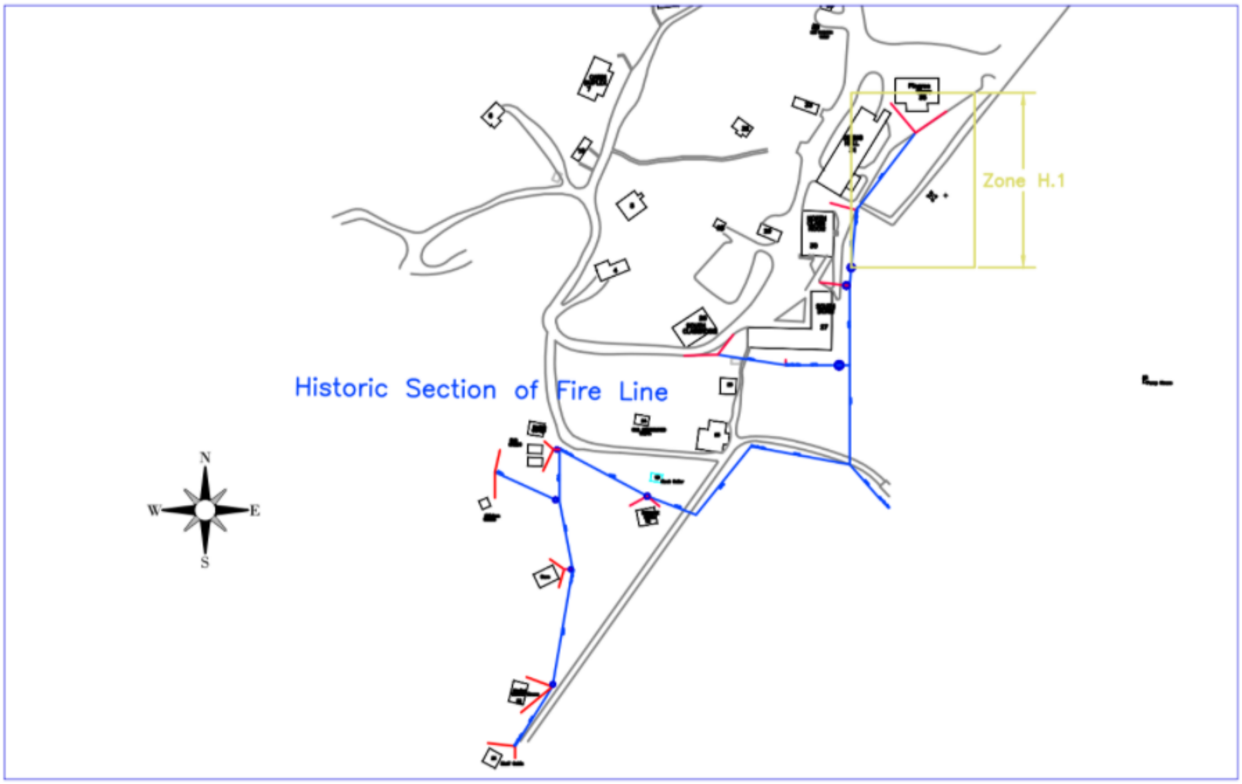


Figure 10. Historic Section Zone 1 (Zone H.1).

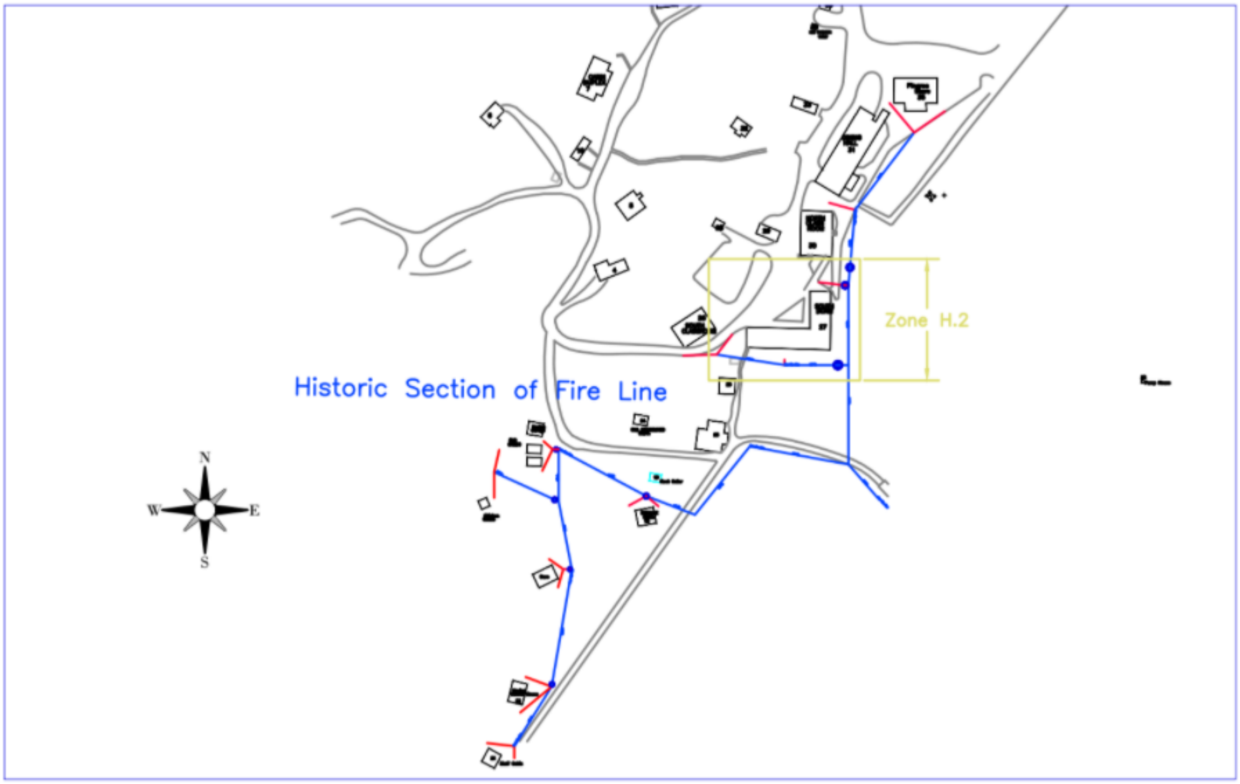


Figure 11. Historic Section Zone 2 (Zone H.2).

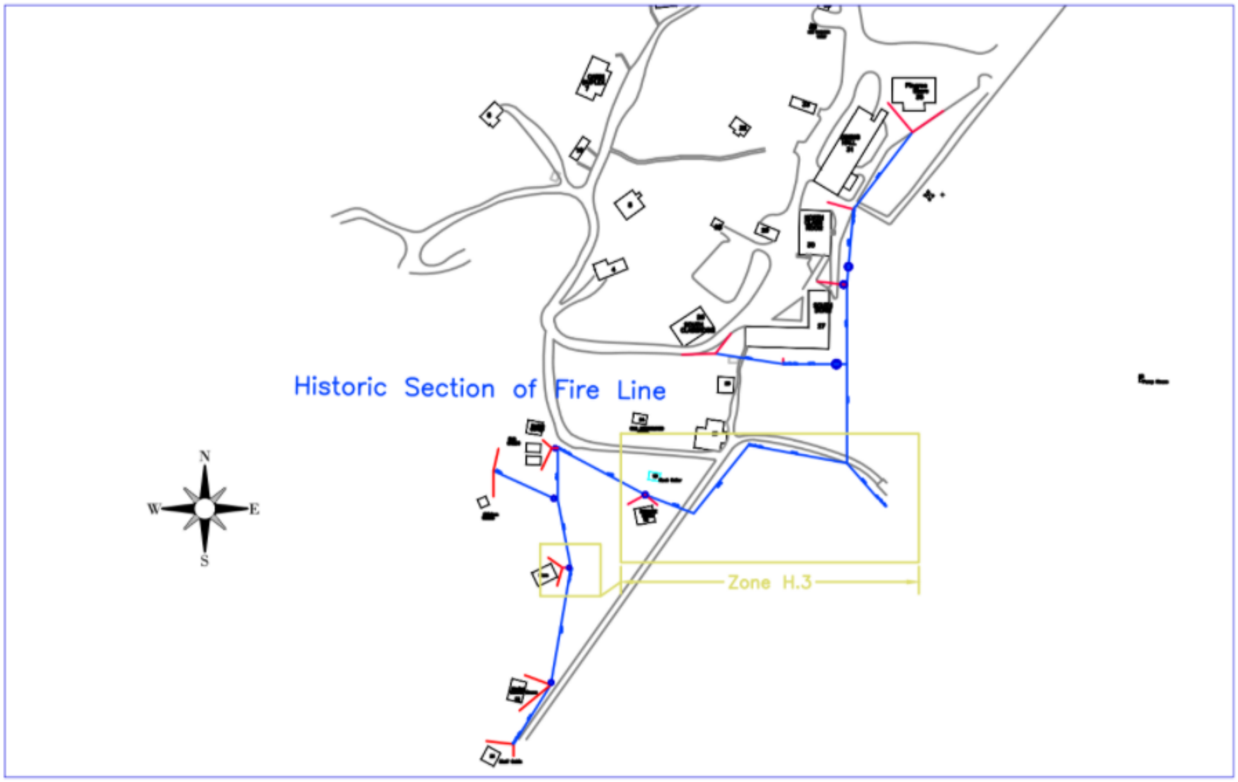


Figure 12. Historic Section Zone 3 (Zone H.3).

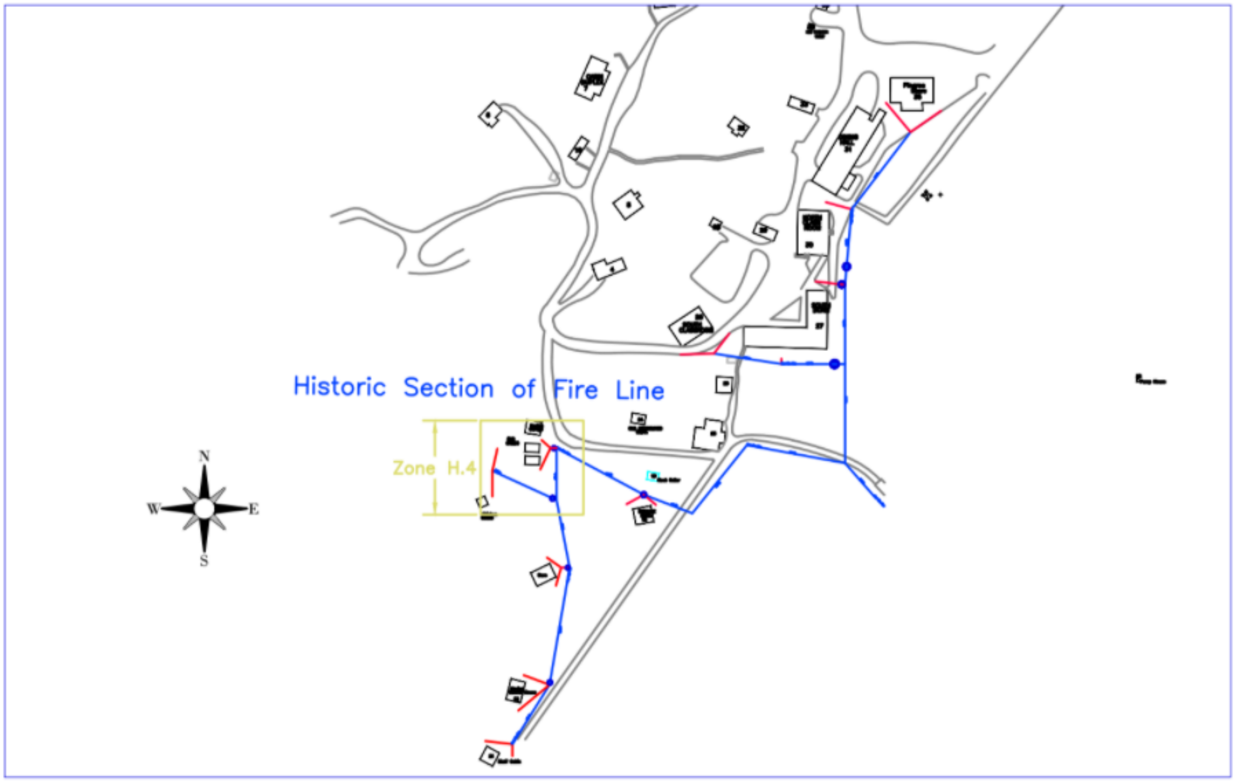


Figure 13. Historic Section Zone 4 (Zone H.4)

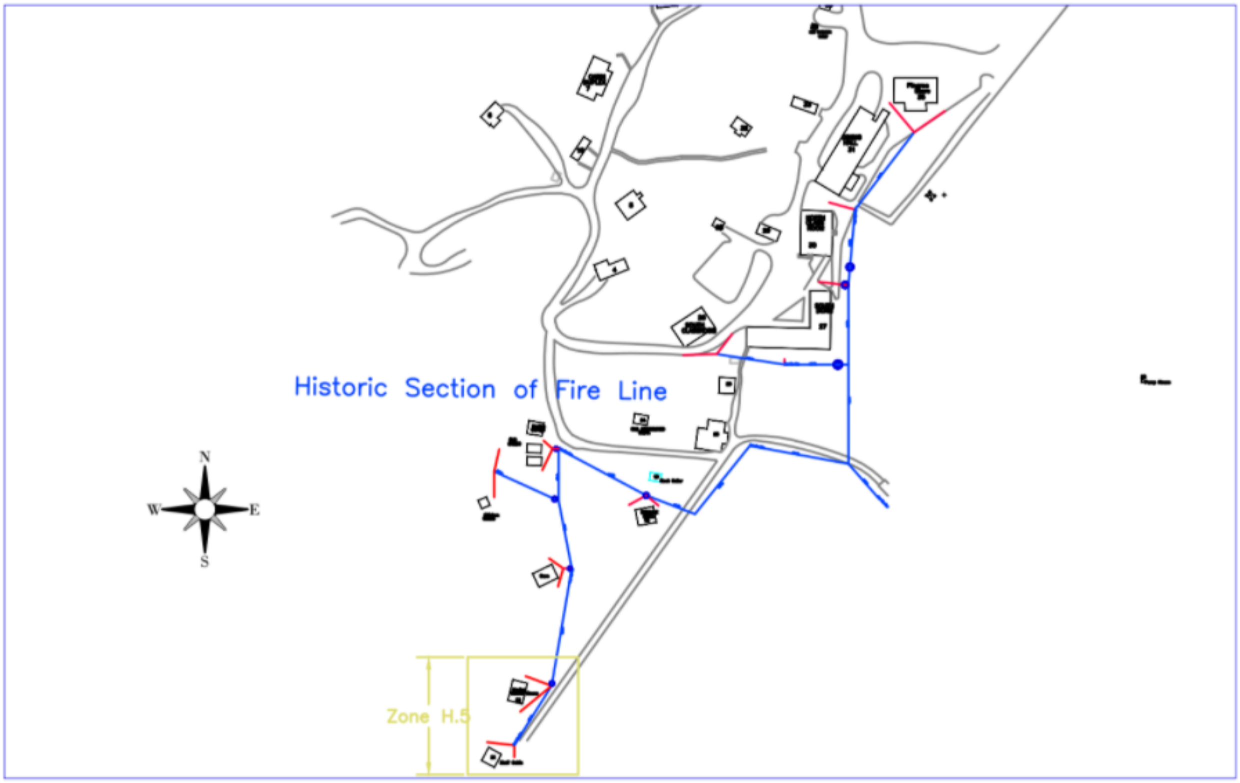


Figure 14. Historic Section Zone 5 (Zone H.5).

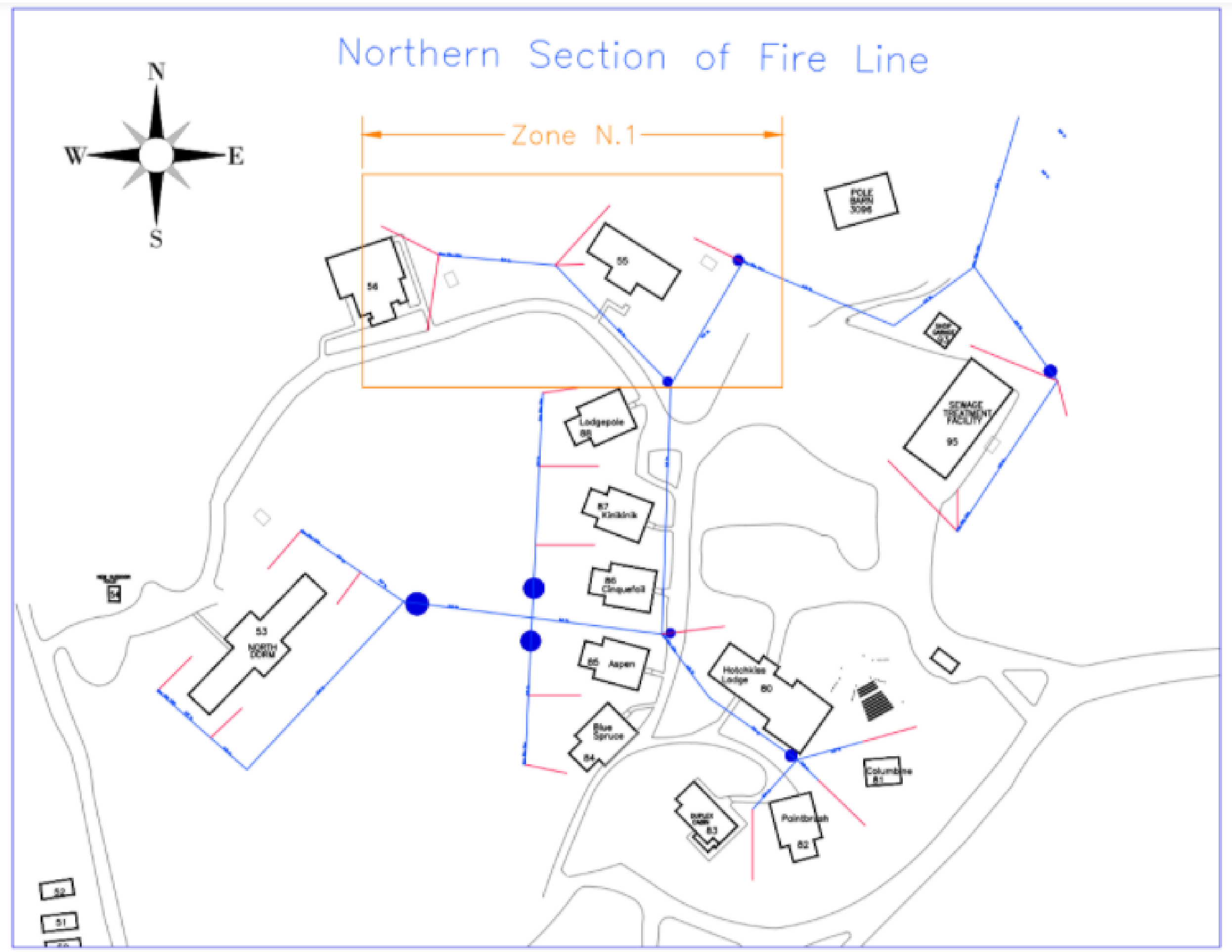


Figure 15. Northern Section Zone 1 (Zone N.1).

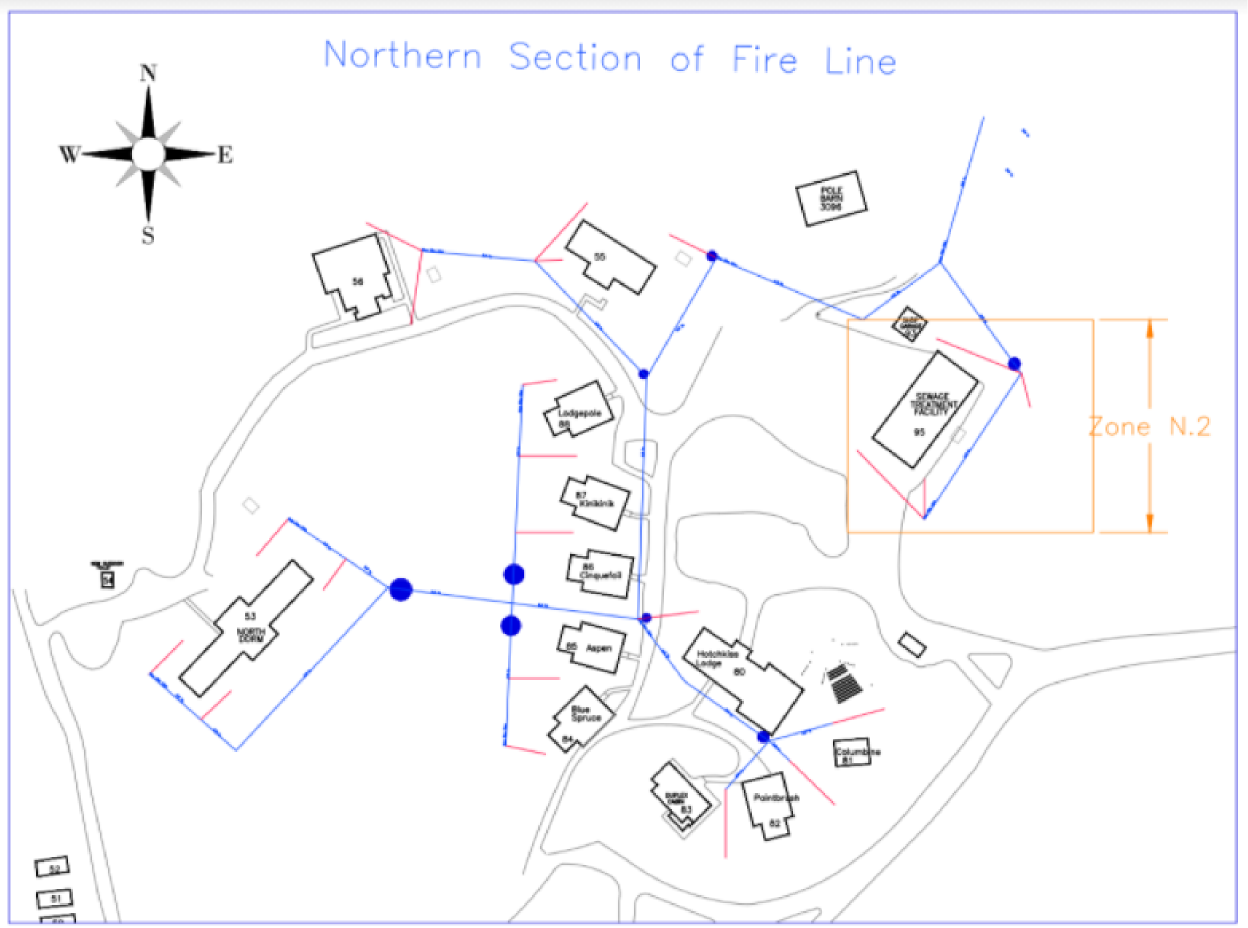


Figure 16. Northern Section Zone 2 (Zone N.2)

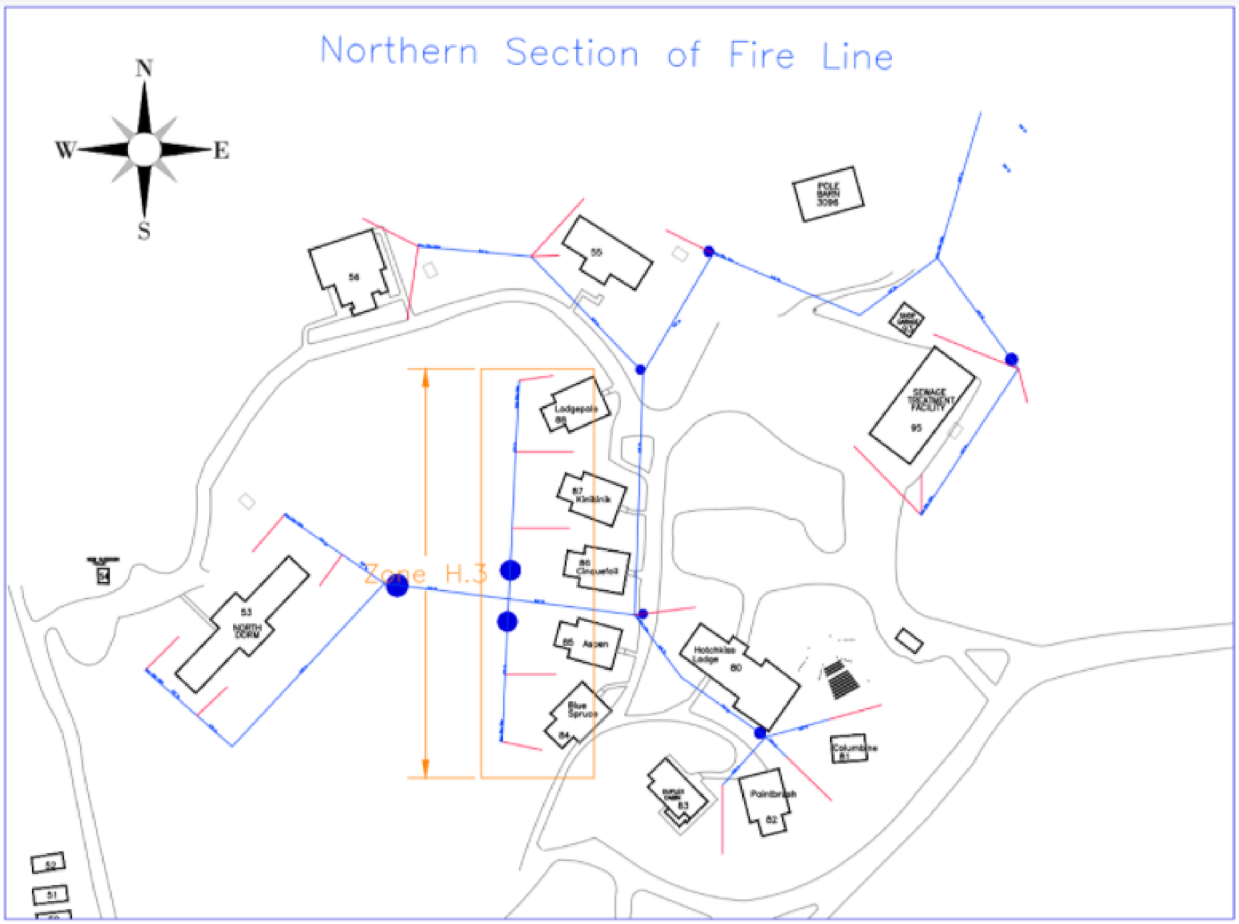


Figure 17. Northern Section Zone 3 (Zone N.3)

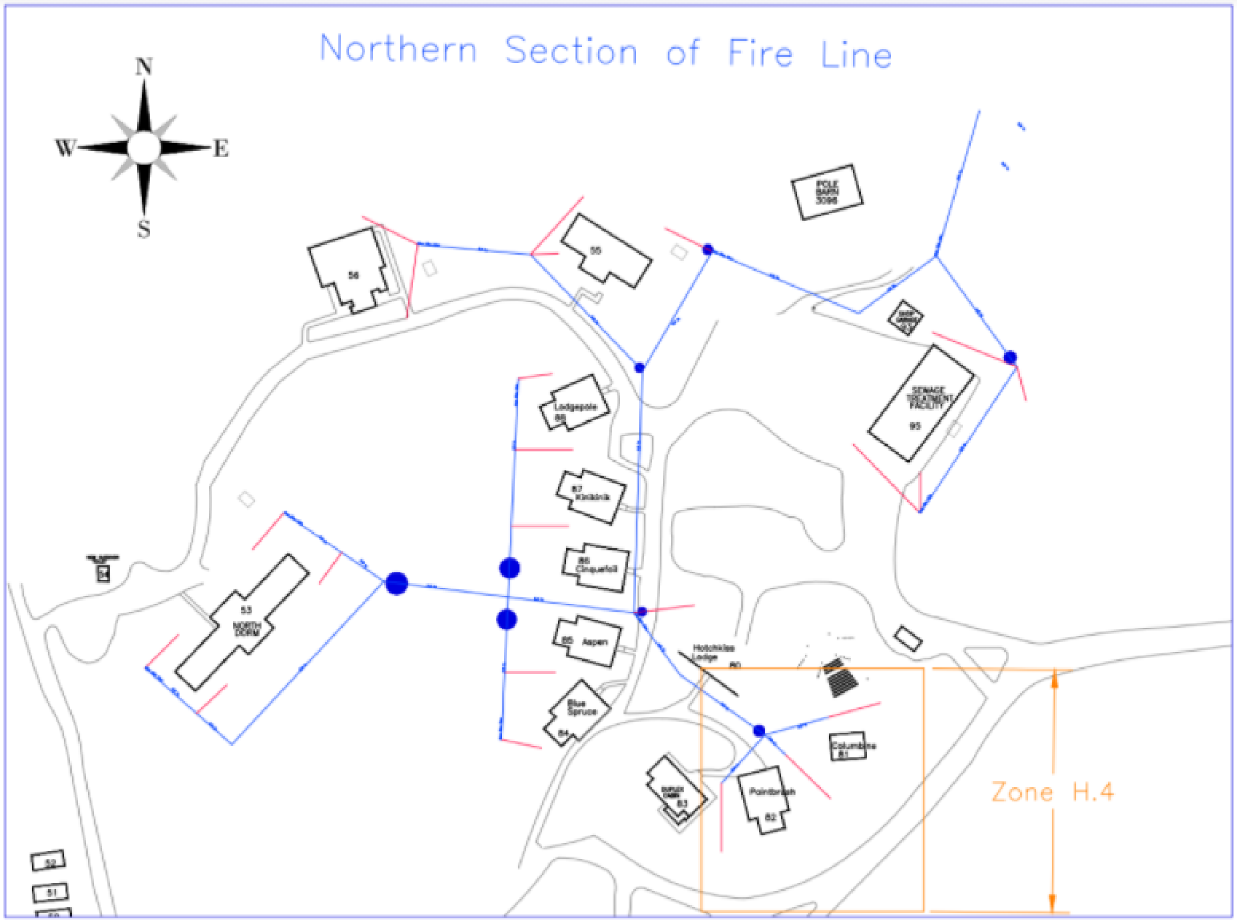


Figure 18. Northern Section Zone 4 (Zone N.4)

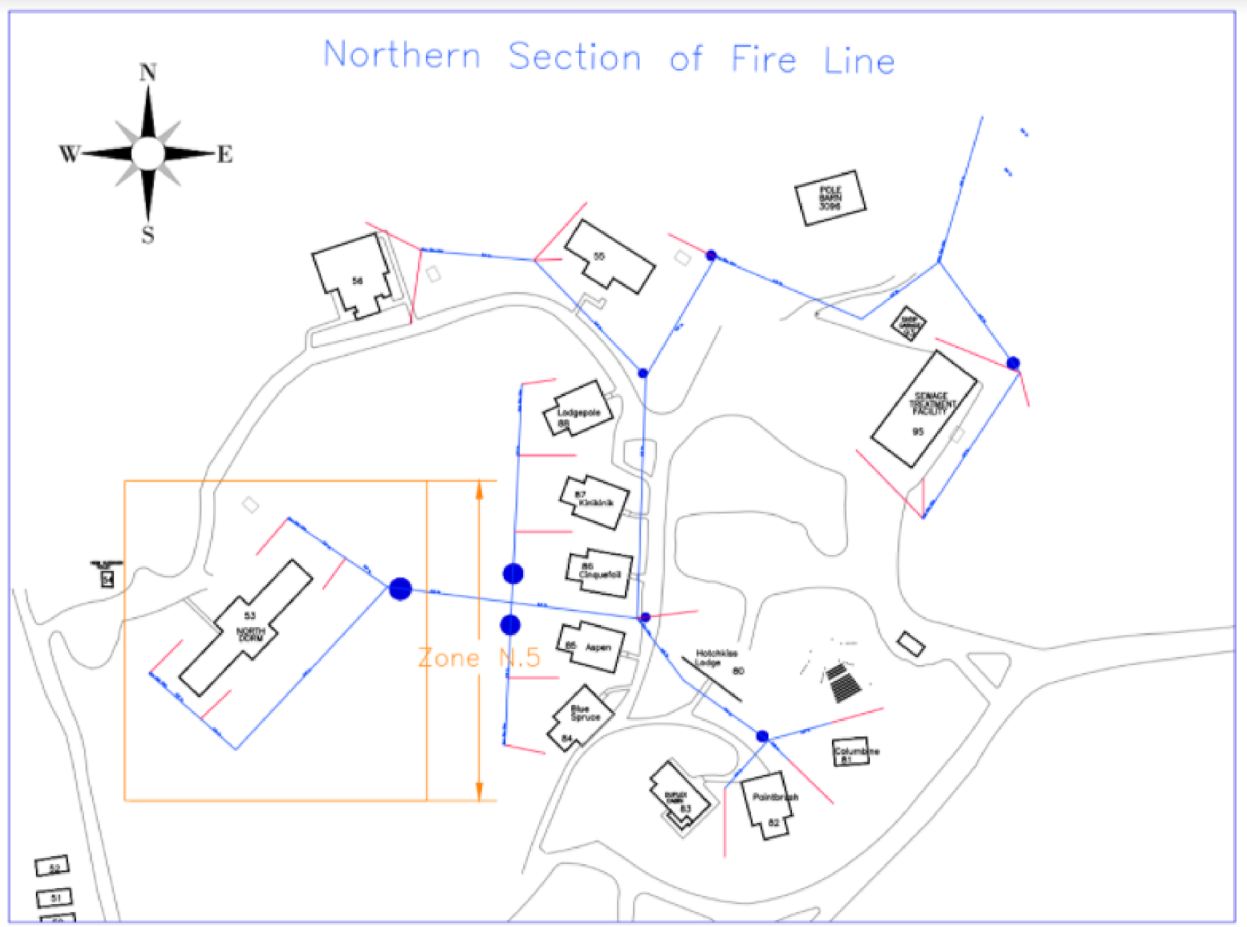


Figure 19. Northern Section Zone 5 (Zone N.5).

AFT donated Fathom for the use of this project with the understanding that it will be used solely for this senior design project. AFT's Fathom was used to simulate the pipe system, along with sizing the pump or pumps necessary to ensure at least a 40 GPM flow rate through each sprinkler. For both the northern and the historic portions of campus sprinklers were grouped together to reduce the number of valves needed. A total of 6 valves were used to control 19 sprinklers for the historic section and 8 valves were used to control 23 sprinklers in the northern section. A simulation was performed for each section with both an optimum and a suboptimal pipe roughness to create an envelope of operation for a required pump. Drawings of the simulations can be found below in Figures 20 and 21. Individual zones were also drawn using Fathom, and are included in the appendices.

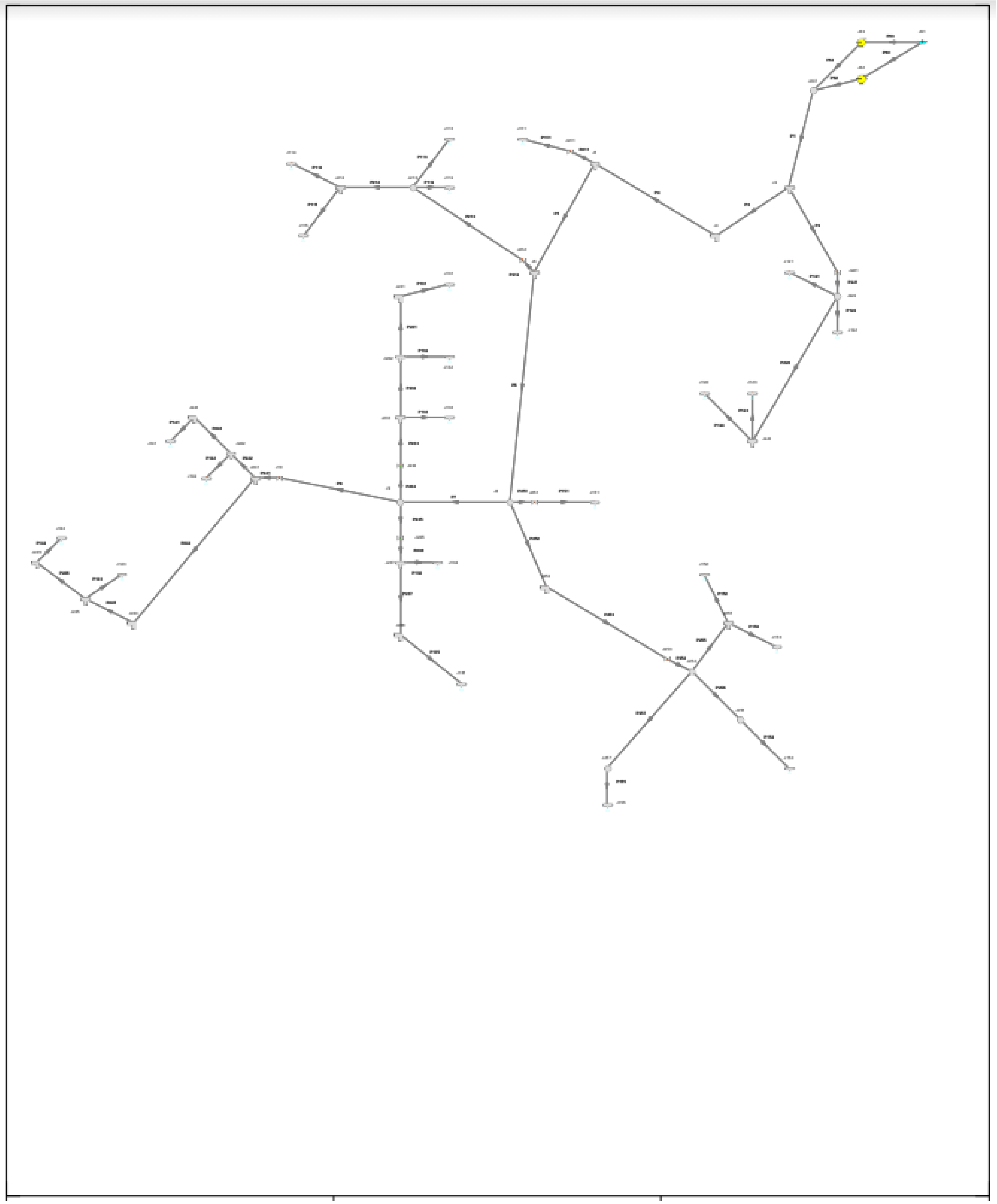


Figure 20. Northern Section of the new fire line made in ATF Fathom.

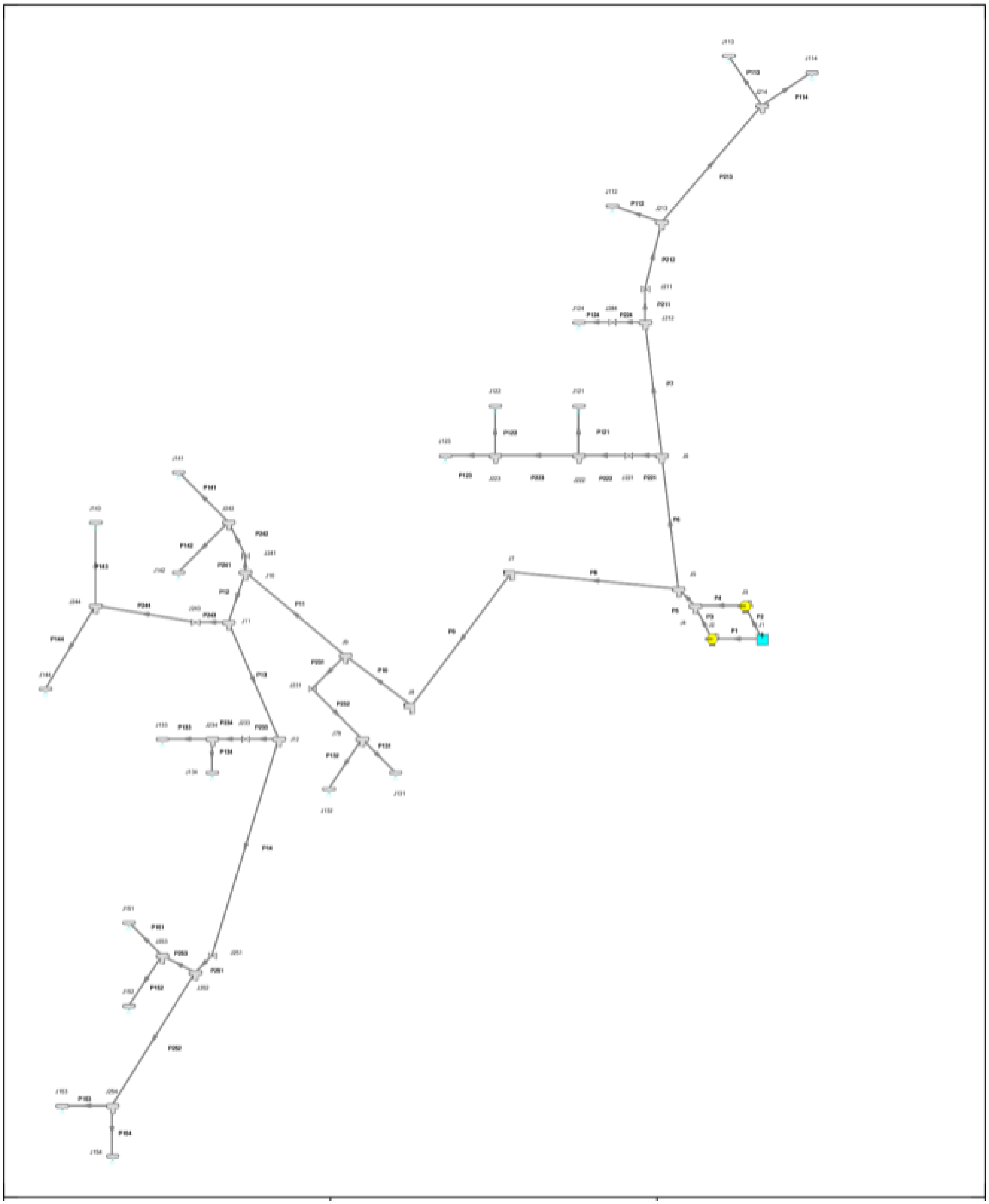


Figure 21. Historic (southern) Section of the new fire line.

AFT’s Fathom uses a number of assumptions that had to be accounted for. These assumptions are that the flow through the pipes is in a steady state, the fluid being used is incompressible and is liquid, all the pipes are full, and that there are no chemical reactions. Each of these assumptions are acceptable for the use of this project. Initial filling of the system could not be simulated inside Fathom. However, any complications that could arise can be ignored by starting with all of the valves open while each system is being filled. Additionally, the water sources for each of these sprinkler systems is the South Fork Cache La Poudre river. Another assumption was that the quantity of water being used by the system was assumed to be infinite for the normal duration of the system's use, because less than half of the stream flow will be used in the system. Next, most of the minor head losses that result from bends have been accounted for; however, the minor losses from junctions with multiple outlets were neglected but were accounted for in the sizing of the pumps with a 15% inefficiency. Finally it was assumed that the water hammer in the system could be ignored. This assumption is acceptable because of the operation plan to slowly close all valves and to open the next group of sprinklers before closing the current group of sprinklers.

Using Fathom's workspace, the modeling of this system was made to resample the AutoCAD drawing of the system. However, due to Fathom's requirements to account for every break in the system with a junction and pipe, some portions of piping and junction positions are exaggerated to increase the readability of the design.

Valves for each system are expected to be automated, with the addition of manual valves to build redundancy in the system. Electronic automation is used to decrease the amount of time and attention the firefighters need to spend working on the system. Each valve would be electronically controlled from a watertight container near the initial connection point. This system would open and close valves in a predetermined order to ensure the regular wetting of each of the buildings while requiring very little input from the firefighters.

Due to the requirement for the water connections to be temporary and flexible in their placement, all of the hoses connecting the system to the sprinklers are temporary cloth fire fighting hoses with a nominal diameter of 1.5 inches The pumps and their hoses will have to be manually connected and placed in the river by the firefighters themselves. It is recommended to use a 3-inch diameter hose from the river to the pumps.

Plan of Action

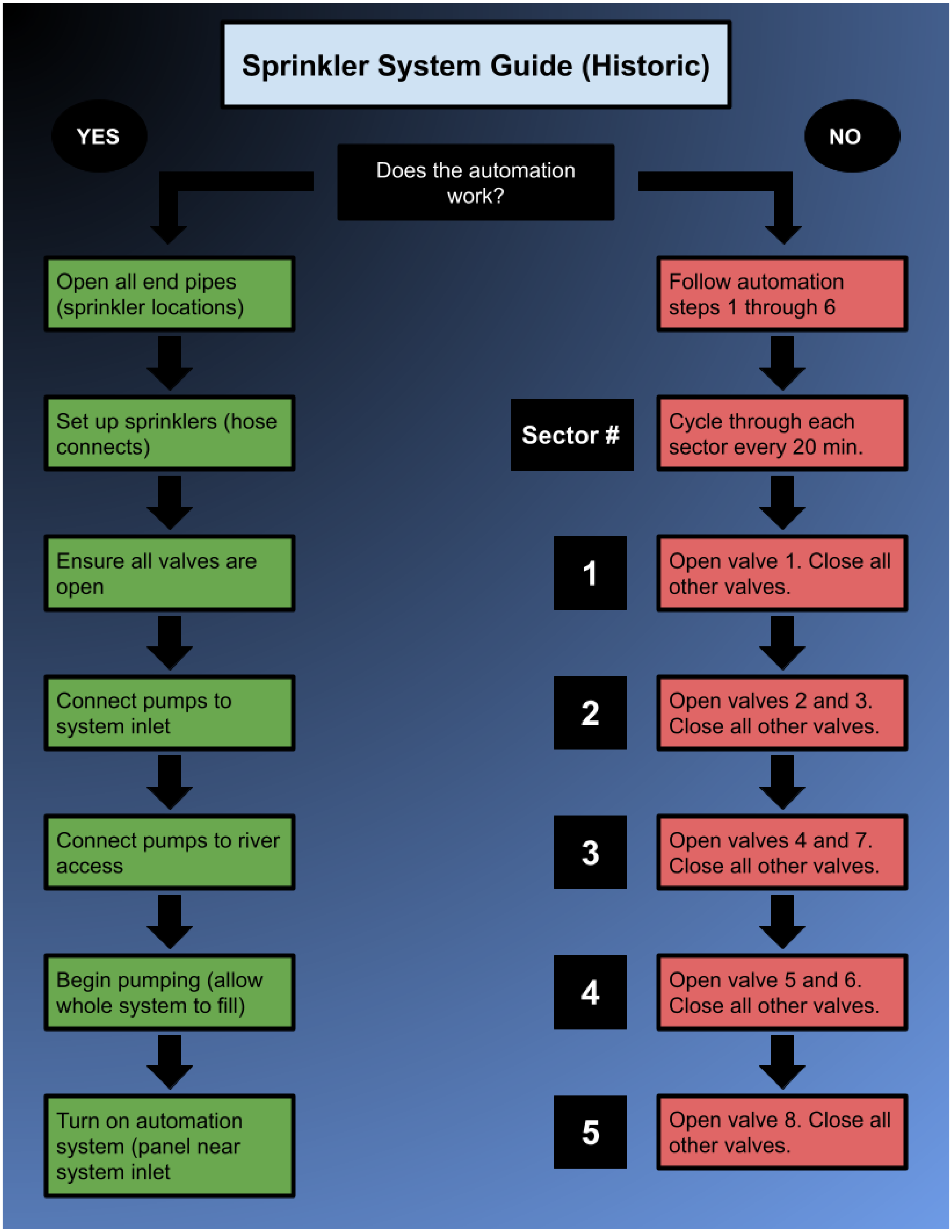
Protecting high value buildings is the main objective of the fire support system and the ability to mobilize this structure quickly is imperative. If the system functions as designed, minimal oversight by the firefighters will be needed, however, if the automation fails a more hands on approach will be required. In either case, good communication and coordination will assist in making sure the fire support system runs smoothly.

Best Case Scenario

In the best case scenario, system engagement, following the initial setup, will be largely minimal. Computer automation will ensure that the system is cycling between each of the five zones (per district) every 20 minutes. Refer to Figures 10-19 for zone outline. Firefighters should inspect the system approximately every hour to make sure that all sprinklers are operating adequately and that no problems have arisen. Shutting off the system is equally as simple, automation can be suspended by using the control panel located next to the system inlet.

Worst Case Scenario

There are many possibilities that could make up a “worst case” scenario, but the most likely is that automation will have failed and the system will need to be cycled manually. Increased personnel involvement will be required. Initial setup of the fire support system will be the same as in the best case scenario, but since cycling will not be automatic, firefighters will have to manually open and close the valves to direct flow to the correct sector. Two handouts have been created (Figure 22 and 23) to instruct firefighters which valves must be opened and shut to manage which sprinklers receive water. These handouts will include a basic map of each district with locations of all the valves and their manual turn wheels. It is imperative when manually shutting valves to do so slowly, this will help avoid creating sudden pressure changes that could damage the pipes. If the issue is not with the automation but has to do with pipes, open all of the valves and allow water to come through all sprinklers. If water is not flowing through one of the sprinklers, firefighters can manually close the valve leading to that sector and allow the rest of the system to operate. Any complications with the fire mains for either of the two districts will prove to be problematic as they are underground and not easily maintenanced.


Sprinkler System Guide (Historic)

Does the automation work?

YES

Open all end pipes (sprinkler locations)

Set up sprinklers (hose connects)

Ensure all valves are open

Connect pumps to system inlet

Connect pumps to river access

Begin pumping (allow whole system to fill)

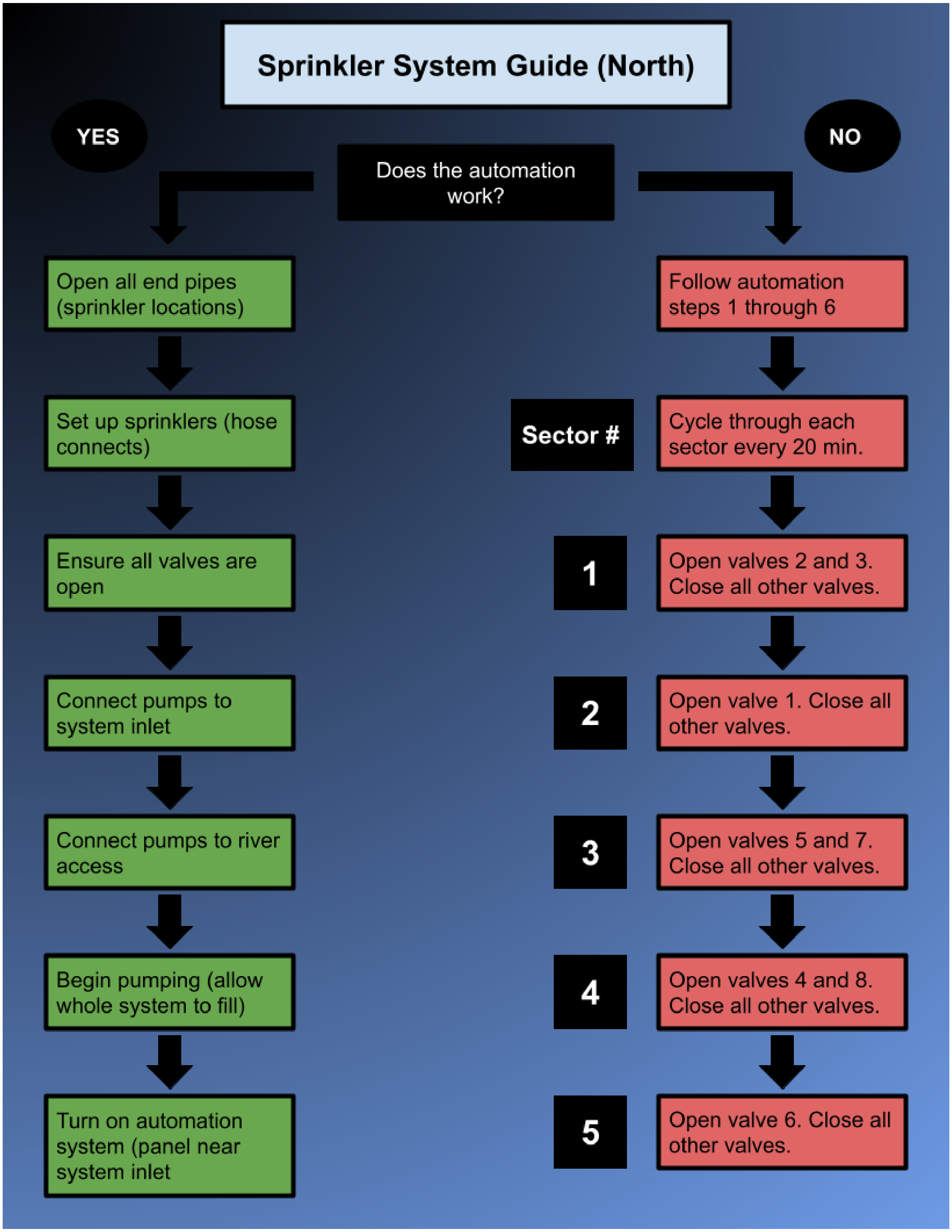
Turn on automation system (panel near system inlet

NO

Follow automation steps 1 through 6

Sector #	Cycle through each sector every 20 min.
1	Open valve 1. Close all other valves.
2	Open valves 2 and 3. Close all other valves.
3	Open valves 4 and 7. Close all other valves.
4	Open valve 5 and 6. Close all other valves.
5	Open valve 8. Close all other valves.

Figure 22. Sprinkler system handout for the historic district.



Sprinkler System Guide (North)

Does the automation work?

YES

Open all end pipes (sprinkler locations)

Set up sprinklers (hose connects)

Ensure all valves are open

Connect pumps to system inlet

Connect pumps to river access

Begin pumping (allow whole system to fill)

Turn on automation system (panel near system inlet

NO

Follow automation steps 1 through 6

Sector #	Cycle through each sector every 20 min.
1	Open valves 2 and 3. Close all other valves.
2	Open valve 1. Close all other valves.
3	Open valves 5 and 7. Close all other valves.
4	Open valves 4 and 8. Close all other valves.
5	Open valve 6. Close all other valves.

Figure 23: Sprinkler system handout for the north district.

Fuel Reduction

Fuel reduction is critical to fire mitigation and consists of reducing or removing anything around the campus that would allow a fire to spread. Not only will this reduce the spread of the fire, it will also give firefighters more time to prepare. Fuel reduction is a crucial component to fire mitigation and supporting firefighters. One method that has been used in the past is the use of volunteers from the Forestry Service (USDA). These volunteers will manually clear out the fuel sources around and outside of the campus. This method will need an allowance of at least 5 days to complete clearing and should occur annually and if a wildfire threatens the campus. Volunteers should only be used to complete the clearing if they have adequate time and can do so safely. Another option is to have livestock, such as rams, goats, etc., that live on the campus and will reduce the fuel sources through consumption. Living on campus, they will roam around and outside of campus in their efforts to reduce fuel sources like brush, grass, and other vegetation. This may still require additional fuel reduction efforts from volunteers to clear bigger items such as logs or fallen trees. Volunteers will not be required for as long as the first option since the clearing will be very minimal. Implementation of either option will adequately reduce fuel in the surrounding area.

Cost Analysis

Colorado State's Mountain Campus fire protection system will consist of a water distribution piping network of 4,482 feet of permanent piping and 2,100 feet of temporary piping. Galvanized iron, stainless steel, copper, and aluminum were evaluated for the piping material in the permanent system with their prices shown in Table 2 below. Prices of each piping material were calculated using McMaster-Carr. Galvanized iron was the least expensive material that was evaluated, however, galvanized iron tends to rust when their zinc coating erodes and they need to be replaced frequently. Copper was evaluated because it is not harmful to the environment and because of its durability. Stainless steel was evaluated for its high quality, strength, and resistance to corrosion. The last material that was evaluated was aluminum. Aluminum has a high resistance to heat, is durable, and resists corrosion.

Hotshot Engineering recommends the use of stainless steel piping for the water distribution system. Although it is more expensive than copper piping, it is stronger and more resistant to corrosion. This will allow the material stay intact and function longer than copper.

Table 2. Prices of Permanent Distribution System for Different Piping Material

	Galvanized Iron	Stainless Steel	Copper	Aluminum
Historic	$13,648.23	$61,172.50	$36,371.81	$65,390.83
North	$16,738.53	$74,191.89	$34,962.13	$70,467.30
Total	$30,386.76	$135,364.39	$71,333.93	$135,858.14

Temporary piping used for the system consists of discharge hoses that will be attached to the water distribution system and activated in the case of a fire. A total of 19 hoses at 50 feet long will be needed for the historic part of campus and 23 hoses at 50 feet long for the northern part of campus. These two types of hoses were evaluated for a 1-½" x 50' Single Jacket Discharge Hose and a 1-½" x 50' Double Jacket Mill Hose, their prices shown in Figure 3 below. Both of the hoses mentioned above can be found on the *FireHoseDirect* website. Double Jacket Mill Hose is recommended by Hotshot Engineering because it operates at a service pressure of 150 psi and has a maximum pressure of 450 psi, where the Single Jacket Discharge Hose has a maximum pressure of 125 psi.

Figure 3. Price of Temporary Distribution System for Different Hoses

	Single Jacket Discharge Hose	Double Jacket Mill Hose
Historic	$1,284.02	$1,909.50
North	$1,554.34	$2,311.50
Total	$2,838.36	$4,221.00

In order to convey enough water at a pressure of 280-320 psi and a flow rate of 98 gpm, 4 pumps will need to be utilized. A high quality water pump that could be used is the "Honda WH15XTA - 98 gpm (1.5") high pressure water pump". This pump can be found on the Water Pumps Direct website. It is important to use a pump like the one described above because of its high reliability if an unexpected fire were to occur around the campus. Hotshot Engineering determined that the "SIME Duplex 2" Partial Circle Impact Sprinkler w/ Nozzles" should be used to protect the outside of the buildings. This sprinkler system provides flow at 42-220 gpm, pressure at 22-90 psi, and a throw radius of 65.6-152.6 feet. With the sprinkler, comes four nozzles to adjust the parameters mentioned above. This sprinkler can be found on the Irrigation King website. Using this sprinkler system will be ideal in protecting the outside of buildings and keeping them wet to reduce burning. Prices of the water pumps and sprinkler kits needed for the campus are shown below in Table 4.

Table 4. Cost of Water Pumps and Sprinkler Kits

	Amount	Cost per	Total
Water Pumps	4	$669.00	$2,676.00
Sprinkler Kits	42	$234.65	$13,650.00

According to the Colorado Real Estate Journal, the average cost of commercial construction in Colorado is $241 per square foot. Water lines in Colorado must be at least three feet below the ground surface. With 4,482 feet of piping needed for the CSU Mountain Campus fire suppression system, it is estimated that the construction cost of this project would be at least $3.24 million. If all of the recommendations from Hotshot Engineering mentioned above are taken, the total cost of the project is projected to be just under $3.4M as shown in Table 5 below.

Table 5. Total Cost of the Project

Permanent System Cost	$135,364.39
Temporary System Cost	$4,221.00
Water Pumps Cost	$2,676.00
Sprinkler Kits Cost	$13,650.00
Construction Cost	$3,240,486
TOTAL COST	$3,396,397.39

Conclusion

Designs and considerations were based off of interviews with firefighters who served on the CSU Mountain Campus during the Cameron Peak Fire. These interviews lead to a conclusion that the system should allow firefighters to integrate with the system to minimize their set up period. In addition to this, a fuel reduction plan and a Plan of Action were developed to help minimize the amount of debris a fire can consume and to reduce confusion when integrating with the system. This project is expected to cost approximately $3.4 million due to the expensive construction costs in Colorado.

These considerations were vital to prepare the campus for the next potential disaster. Forest fires are both a natural and common occurrence in the state of Colorado. A distribution system that integrates with firefighting equipment will both by-pass the water rights required to pull from the South Fork Cache La Poudre, and will also protect the most crucial buildings from catching fire. Confusion on the system will be minimized by the Plan of Action which details how firefighters should react if the automated system were to fail. Lastly, the fuel reduction plan will minimize the amount of fuel the fire can draw from, and will thereby reduce the potential for fires to reach the campus

Appendix

Appendix A: Extra Figures and Tables

The following section contains extra figures referenced in text, but not included.

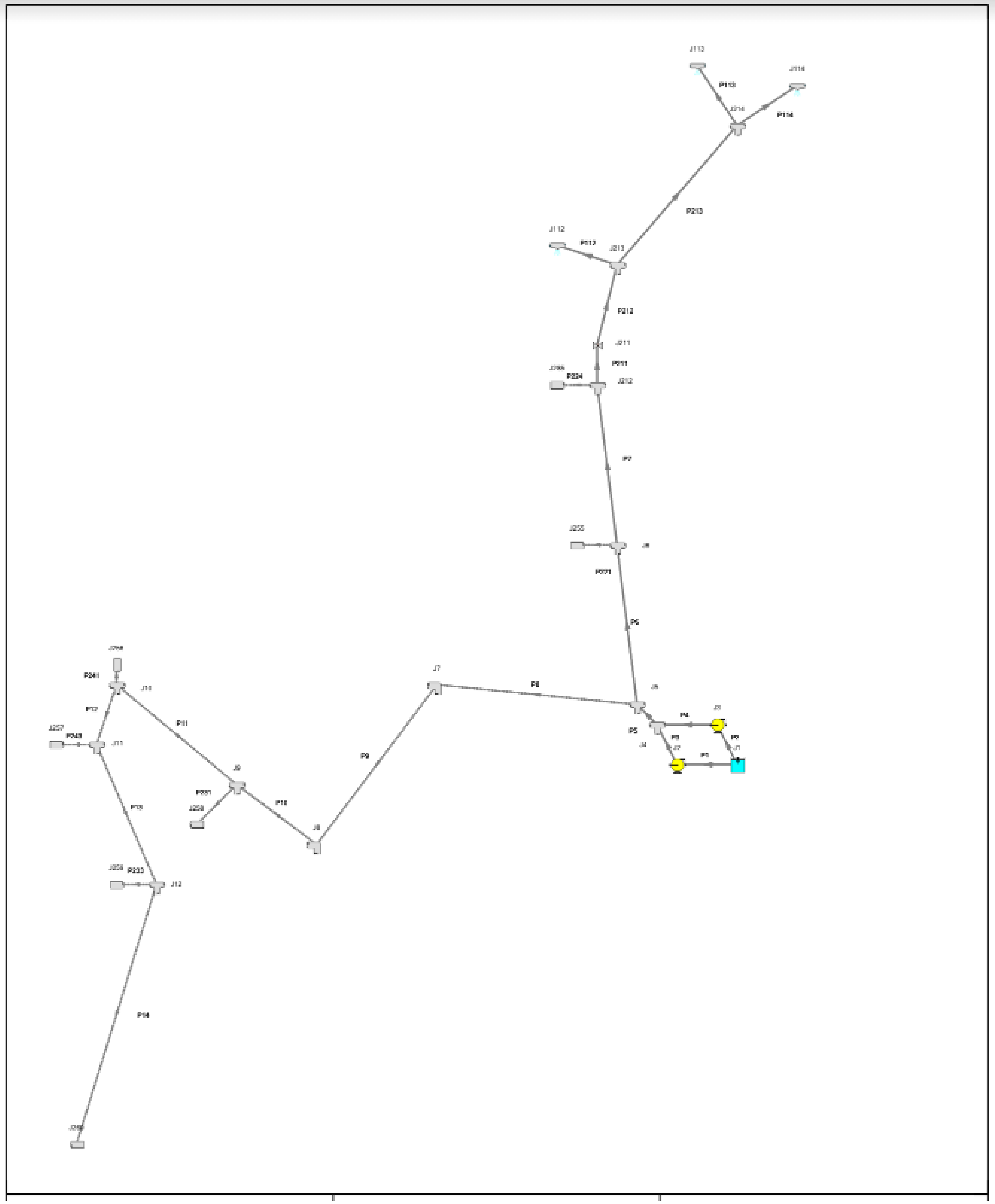


Figure 24. Zone H.1 simulated in Fathom.

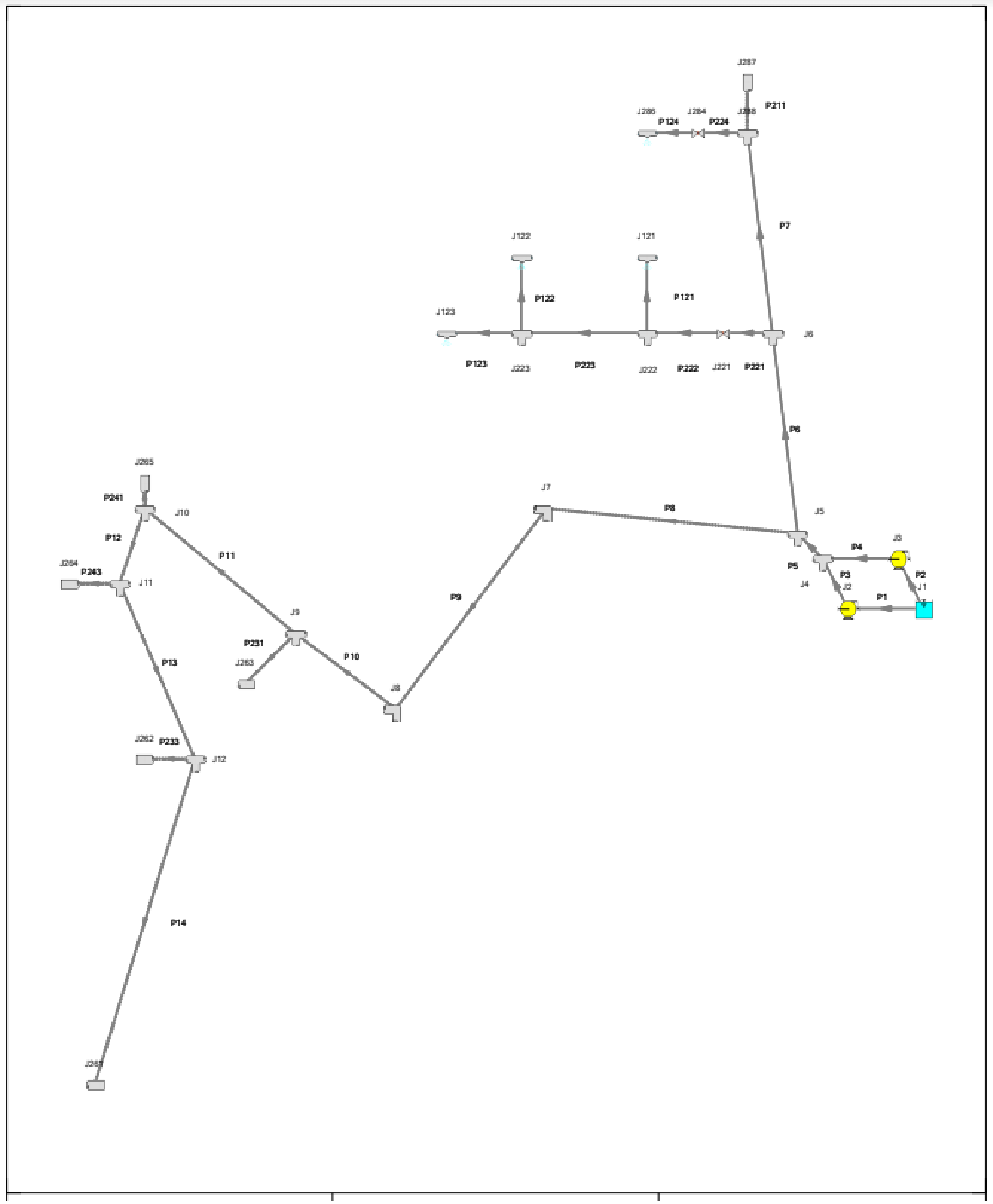


Figure 25. Zone H.2 simulated in Fathom.

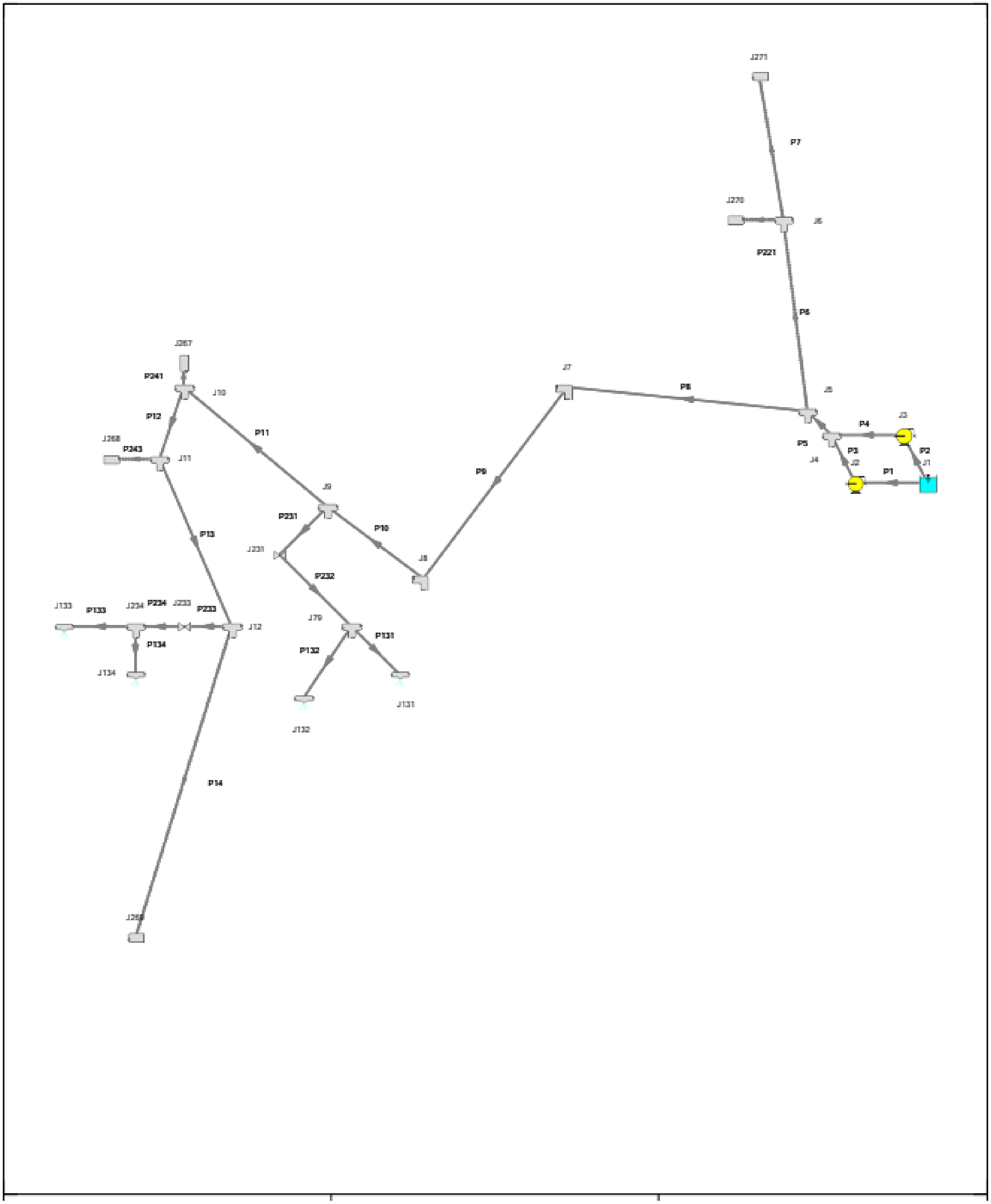


Figure 26. Zone H.3 simulated in Fathom.

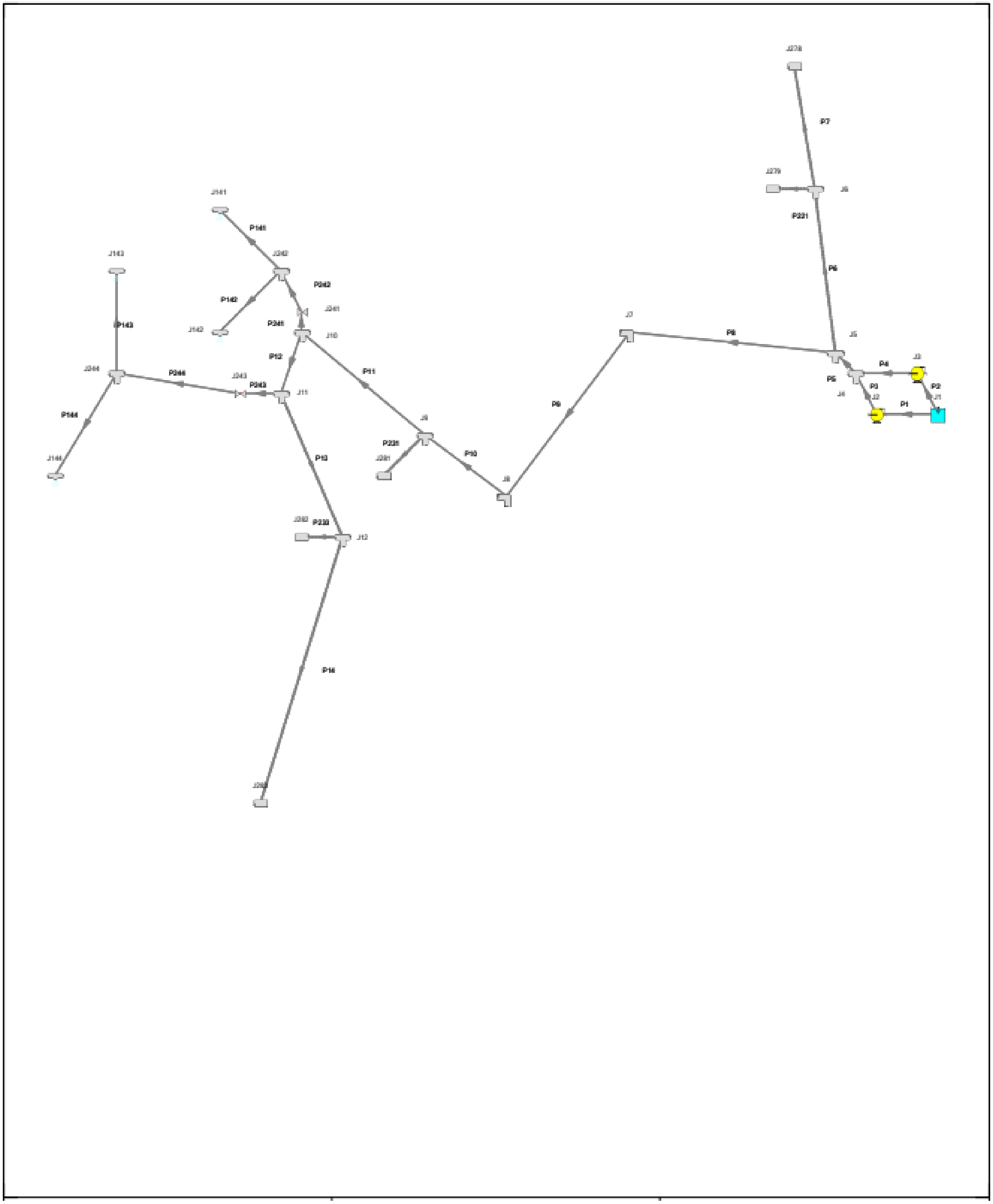


Figure 27. Zone H.4 simulated in Fathom.

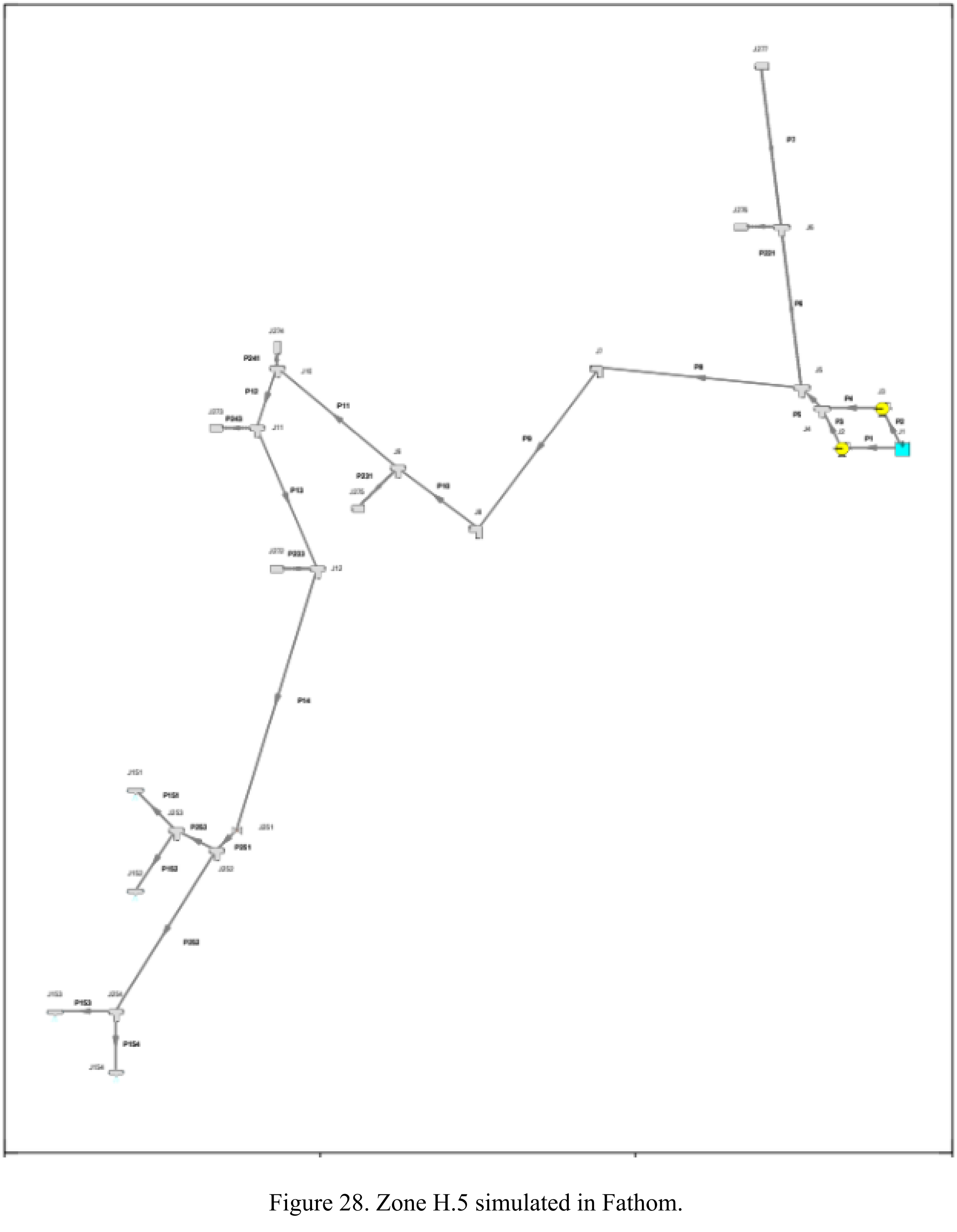


Figure 28. Zone H.5 simulated in Fathom.

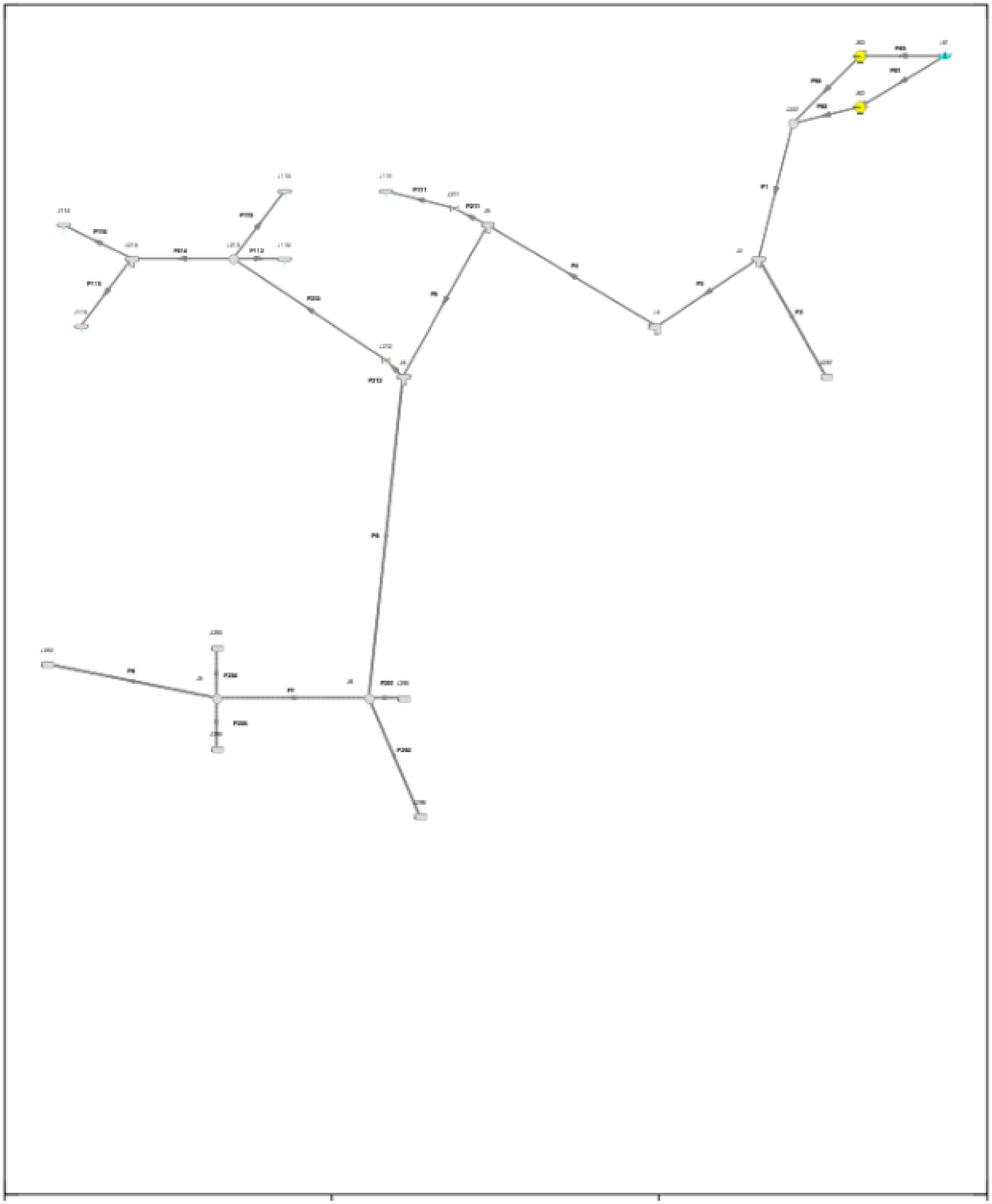


Figure 29. Zone N.1 simulated in Fathom.

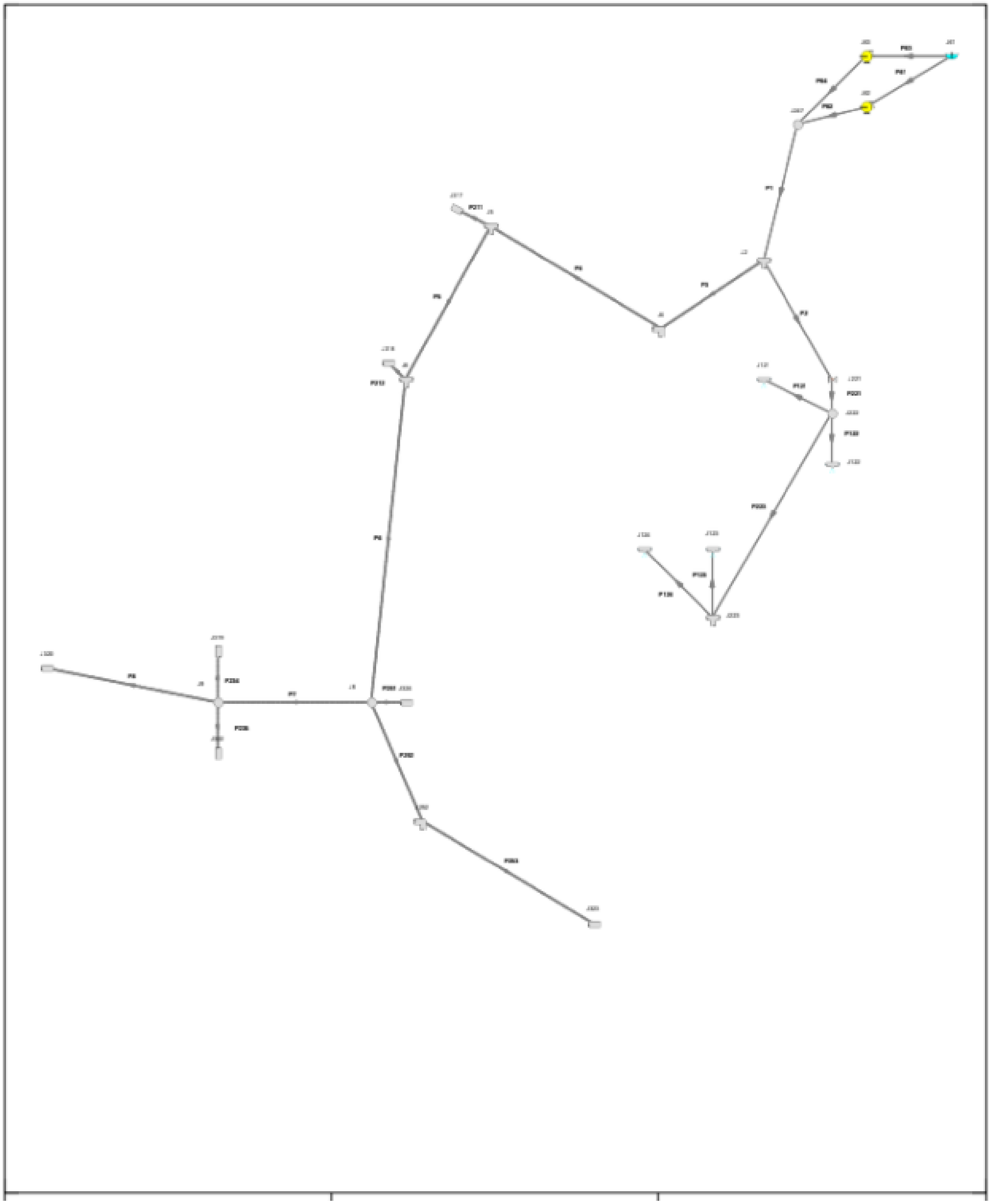


Figure 30. Zone N.2 simulated in Fathom.

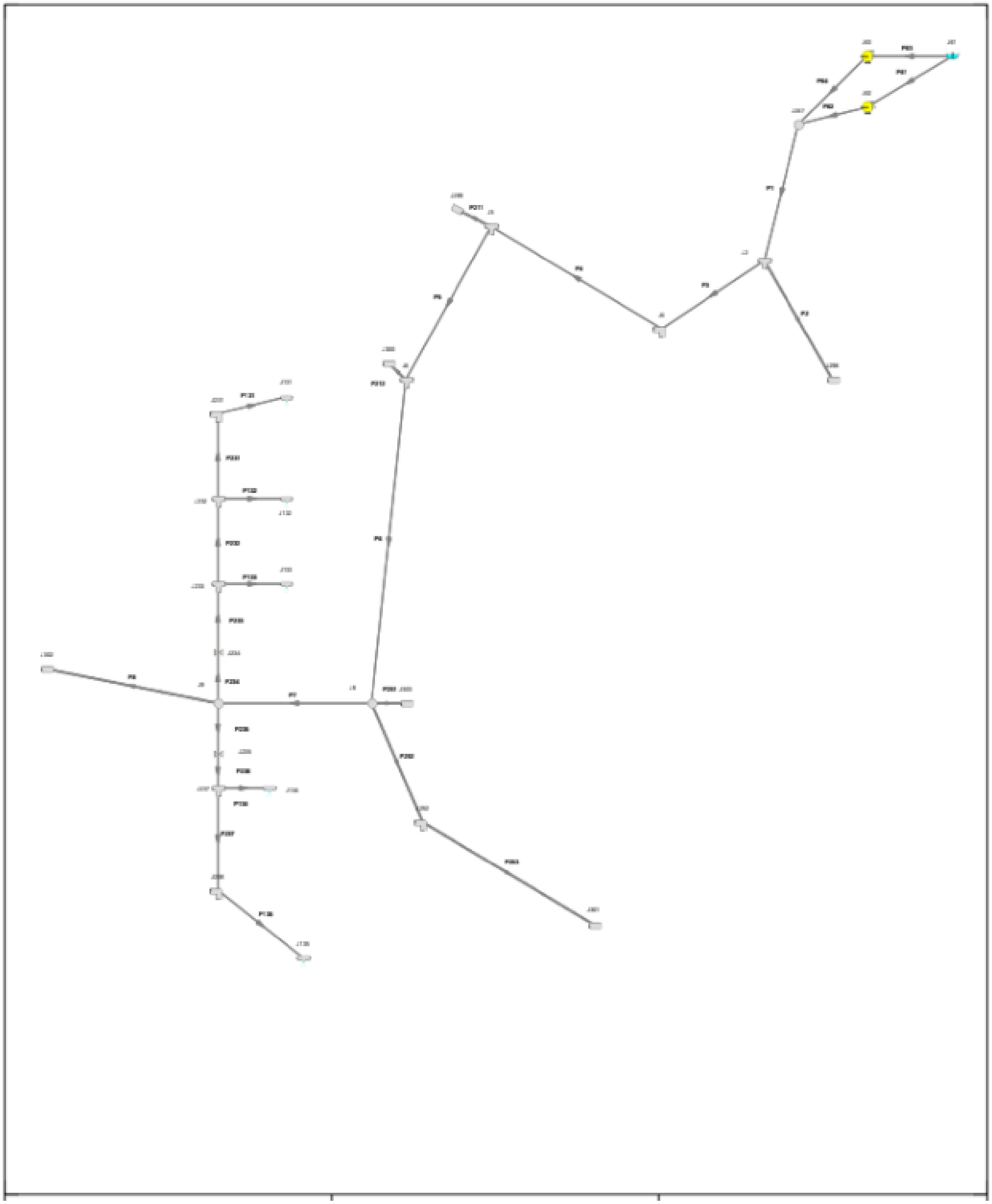


Figure 31. Zone N.3 simulated in Fathom.

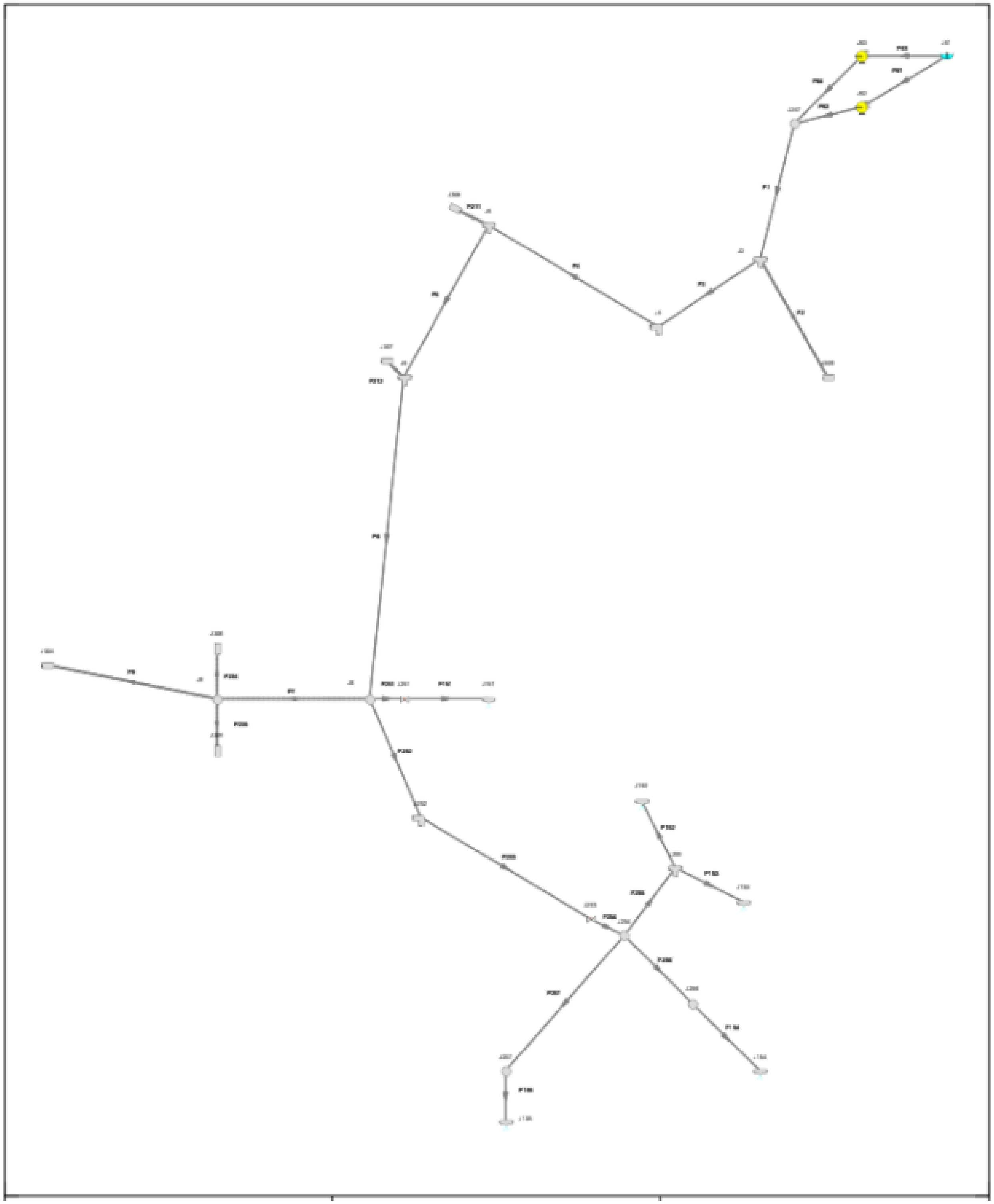


Figure 32. Zone N.4 simulated in Fathom.

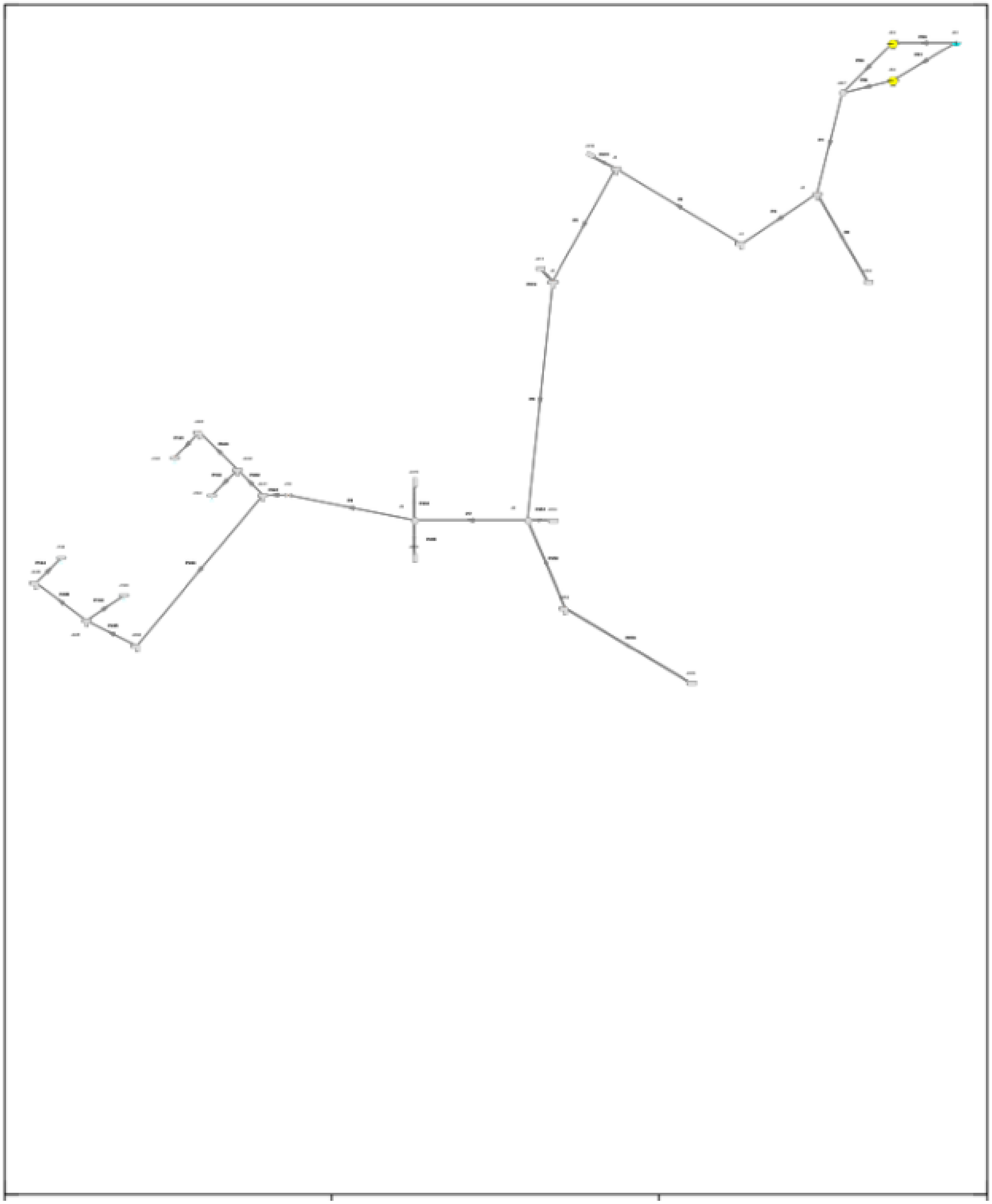


Figure 33. Zone N.5 simulated in Fathom.

Table 6. North Pipe Pressure Data

SCUMC North Pipe Pressure Data							
Pipe	Senario	Vol. Flow Rate (gal/min)	P Static Max (psia)	P Static Min (psia)	dP Stag. Total (psid)	dP Static Total (psid)	dH (feet)
1	Common	196	189.04	182.81	6.23	6.23	11.38
2	2	196	144.47	138.6	5.87	5.87	10.54
3	Common	196	182.37	176.84	5.53	5.53	7.76
4	Common	196	176.73	170.6	6.13	6.13	12.14
5	Common	196	170.16	164.18	5.98	5.98	11.80
6	Common	196	164.18	156.79	7.39	7.39	18.04
8	4	196	155.12	148.91	6.21	6.21	14.33
7	Common	196	156.79	155.12	1.67	1.67	8.85
61	Common	98	18.09	11.64	6.46	6.46	1.89
62	Common	98	18.09	11.64	6.46	6.46	1.89
63	Common	98	194.61	189.46	5.16	5.16	1.89
64	Common	98	194.61	189.46	5.16	5.16	1.89
111	1	42.11	105.37	90.54	14.83	14.83	12.20
112	1	39.46	95.54	81.31	14.23	14.23	10.82
113	1	39.46	95.54	81.31	14.23	14.23	10.82
114	1	37.48	88.6	74.79	13.80	13.80	9.84

115	1	37.48	88.6	74.79	13.80	13.80	9.84
121	2	49.92	137.22	121.29	15.92	15.92	16.73
122	2	49.92	137.22	121.29	15.92	15.92	16.73
123	2	48.08	125.98	113.58	12.40	12.40	15.60
124	2	48.08	125.98	113.58	12.40	12.40	15.60
131	3	38.19	88.43	77.08	11.35	11.35	10.18
132	3	38.25	88.65	77.29	11.37	11.37	10.22
133	3	38.95	88.93	79.58	9.35	9.35	10.56
134	3	40.28	95.92	84.11	11.81	11.81	11.24
135	3	40.33	96.09	84.27	11.82	11.82	11.27
141	4	50.53	138.69	123.91	14.79	14.79	17.11
142	4	50.75	141.04	124.89	16.15	16.15	17.25
143	4	47.51	126.53	111.25	15.29	15.29	15.26
144	4	47.21	123.5	110.02	13.47	13.47	15.08
151	5	42.28	105.58	91.15	14.43	14.43	12.30
152	5	38.13	87.35	76.88	10.47	10.47	10.15
153	5	38.13	87.35	76.88	10.47	10.47	10.15
154	5	38.83	89.39	79.2	10.19	10.19	10.51
155	5	38.64	88.26	78.55	9.71	9.71	10.41
211	1	42.11	105.96	105.96	0.00	0.00	0.01

212	1	153.89	100.15	100.06	0.08	0.08	0.19
213	1	153.89	97.09	95.59	1.51	1.51	5.48
214	1	74.97	95.54	88.64	6.91	6.91	16.93
221	2	196	137.29	137.28	0.01	0.01	0.02
223	2	96.16	137.2	125.92	11.28	11.28	19.02
231	3	38.19	89.48	88.67	0.81	0.81	1.87
232	3	76.44	89.95	89.21	0.74	0.74	6.71
233	3	115.39	98.38	89.44	8.94	8.94	15.62
234	3	115.39	100.72	100.7	0.02	0.02	0.06
235	3	80.61	101.14	101.13	0.01	0.01	0.03
236	3	80.61	100	96.54	3.46	3.46	7.98
237	3	40.33	96.84	96.35	0.48	0.48	1.11
241	4	196	147.6	147.59	0.01	0.01	0.02
242	4	101.28	147.45	141.48	5.97	5.97	7.77
243	4	50.53	141.45	139.11	2.34	2.34	2.40
244	4	94.72	147.43	130.13	17.30	17.30	33.89
245	4	94.72	129.82	126.48	3.34	3.34	7.70
246	4	47.21	126.51	123.86	2.65	2.65	2.12
251	5	42.28	106.18	106.18	0.00	0.00	0.01
252	5	153.72	104.84	95.65	9.19	9.19	19.20

253	5	153.72	96.36	90.5	5.87	5.87	7.53
254	5	153.72	89.69	89.69	0.01	0.01	0.01
255	5	76.25	89.63	87.39	2.24	2.24	6.17
256	5	38.83	89.89	89.63	0.26	0.26	0.59
257	5	38.64	89.89	88.5	1.39	1.39	2.21

Table 7. Historic Pipe Pressure Data

SCUMC Historic Pipe Pressure Data							
Pipe	Senario	Vol. Flow Rate (gal/min)	P Static Max (psia)	P Static Min (psia)	dP Stag. Total (psid)	dP Static Total (psid)	dH (feet)
1	Common	98	15.492	14.24	1.25	1.25	1.89
2	Common	98	15.71	14.24	1.47	1.47	1.89
3	Common	98	141.97	140.718	1.25	1.25	1.89
4	Common	98	141.97	140.718	1.25	1.25	1.89
5	Common	196	140.19	139.92	0.27	0.27	0.62
6	Common	196	153.95	141.53	12.42	12.42	12.65
7	Common	196	157.92	153.17	4.75	4.75	10.96
8	Common	196	143.34	131.06	12.28	12.28	14.33
9	Common	196	117.8267	112.5267	5.30	5.30	12.22
10	Common	196	112.2667	107.1067	5.16	5.16	5.90
11	Common	196	119.71	109.21	10.50	10.50	12.22
12	Common	196	108.77	106.03	2.74	2.74	6.32
13	3	96.49	91.97	89.1	-2.87	-2.87	2.38
14	5	196	106.1	100.29	5.80	5.80	19.39
112	1	65.67	146.06	128.71	17.35	17.35	19.02
113	1	65.37	145.39	127.68	17.71	17.71	18.86

114	1	64.96	143.86	126.24	17.62	17.62	18.64
121	2	57.52	120.7	102.17	18.53	18.53	21.75
122	2	54.48	111.65	93.16	18.50	18.50	19.66
123	2	54.9	112.98	94.37	18.62	18.62	19.94
124	2	29.1	125.02	113.24	11.77	11.77	6.16
131	3	49.75	94.61	80.14	14.47	14.47	11.38
132	3	49.75	94.61	80.14	14.47	14.47	11.38
133	3	48.25	89.13	76.23	12.90	12.90	10.75
134	3	48.25	89.13	76.23	12.90	12.90	10.75
141	4	50.23	90.76	81.41	9.36	9.36	11.58
142	4	50.23	90.76	81.41	9.36	9.36	11.58
143	4	47.77	83.49	75.01	8.48	8.48	10.55
144	4	47.77	83.49	75.01	8.48	8.48	10.55
151	5	49.83	96.13	80.35	15.79	15.79	11.41
152	5	49.83	96.13	80.35	15.79	15.79	11.41
153	5	48.17	91.51	76.03	15.48	15.48	10.71
154	5	48.17	91.51	76.03	15.48	15.48	10.71
211	1	196	153.17	153.16	0.01	0.01	0.02
212	1	196	151.85	148.2	3.65	3.65	8.43
213	1	130.33	148.45	146.14	2.30	2.30	6.31

221	2	166.9	124.83	124.82	0.01	0.01	0.02
222	2	166.9	123.87	121.44	2.44	2.44	5.62
223	2	109.38	120.8	112.91	7.88	7.88	20.18
224	2	29.1	125.3	125.3	0.00	0.00	0.00
231	3	99.51	96.47	96.45	0.02	0.02	0.04
232	3	99.51	94.72	94.69	0.04	0.04	0.08
233	3	96.49	90.88	90.86	0.02	0.02	0.04
234	3	96.49	89.24	89.21	0.03	0.03	0.08
241	4	100.47	93	92.98	0.02	0.02	0.04
243	4	95.53	91.71	91.7	0.02	0.02	0.04
244	4	95.53	90.11	83.56	6.54	6.54	14.09
251	5	196	97.1	97.03	0.07	0.07	0.15
252	5	96.33	98.83	91.59	7.24	7.24	16.70
253	5	99.67	96.95	96.22	0.73	0.73	1.70

Table 8. North Pump Requirements

North Pump Requirements								
Pump	Senario	Name	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)	Vol. Flow Rate Thru Jct (gal/min)	Mass Flow Rate Thru Jct (lbm/sec)
62&63	1	Pump	11.64	129.64	11.71	129.71	98	13.631
62&63	2	Pump	11.64	156.28	11.71	156.35	98	13.631
62&63	3	Pump	11.64	140.54	11.71	140.62	98	13.631
62&63	4	Pump	11.64	194.61	11.71	194.69	98	13.631
62&63	5	Pump	11.64	143.63	11.71	143.7	98	13.631
		Max	11.64	194.61	11.71	194.69	98	13.631
		Min	11.64	129.64	11.71	129.71	98	13.631
		Delta	0	64.97	0	64.98	0	0

Table 9. Historic Pump Requirements

Historic Pump Requirements								
Pump	Senario	Name	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)	Vol. Flow Rate Thru Jct (gal/min)	Mass Flow Rate Thru Jct (lbm/sec)
2&3	1	Pump	14.24	172.58	14.31	172.65	98	13.631
2&3	2	Pump	14.24	139.8	14.31	139.88	98	13.631
2&3	3	Pump	14.24	121.97	14.31	122.04	98	13.631
2&3	4	Pump	14.24	129.92	14.31	129.99	98	13.631
2&3	5	Pump	14.24	145.58	14.31	145.66	98	13.631
		Max	14.24	172.58	14.31	172.65	98	13.631
		Min	14.24	121.97	14.31	122.04	98	13.631
		Delta	0	-50.61	0	-50.61	0	0

Appendix B: References

Colorado State University. (n.d.). Retrieved November 12, 2020, from http://www.mountaincampus.colostate.edu/history

Colorado State University. (n.d.). Retrieved November 12, 2020, from http://www.mountaincampus.colostate.edu/nature\

Colorado Water Law, CRS 37-92-103 (2016)

Google Maps, Map of Northern Colorado, 12 November, 2020.

Honda WH15 Xta - 98 GPM 1.5-Inch high pressure water pump. (2016, November 08). Retrieved April 06, 2021, from https://www.waterpumpsdirect.com/Honda-WH15-Water-Pump/p6629.html

InciWeb developed and maintained by USDA Forest Service, F. (n.d.). Cameron peak fire. Retrieved April 08, 2021, from https://inciweb.nwcg.gov/incident/map/6964/0/111376

McMaster-Carr. (n.d.). Retrieved April 06, 2021, from https://www.mcmaster.com/tubing/material~steel/

Nicholson, K. (2020, October 21). Cameron peak Fire: Strong winds and dry Weather fuel the Fire Tuesday. Retrieved April 08, 2021, from https://www.denverpost.com/2020/10/20/cameron-peak-fire-update-october-20/

SIME duplex 2. (n.d.). Retrieved April 06, 2021, from https://www.irrigationking.com/duplex-2-partial-circle-impact-sprinkler-w-nozzles.html

"Volunteer Opportunities." *Volunteer Opportunities | US Forest Service*, www.fs.usda.gov/working-with-us/volunteers/opportunities.

White 1 1/2" x 50' Double JACKET MILL HOSE (Alum npsh couplings). (n.d.). Retrieved April 06, 2021, from https://www.firehosedirect.com/White-1-5-x-50-Double-Jacket-Mill-Hose-Alum-NPSH-Couplings?feed=Froogle&gclid=Cj0KCQjwmIuDBhDXARIsAFITC_56g_9KpFYE8DHuub-Awp9QQD4nrQkYE2Cr0Btriwt9cdp7as4RRhAaAuY5EALw_wcB

White 1 1/2" x 50' Single JACKET Discharge Hose. (n.d.). Retrieved April 06, 2021, from https://www.firehosedirect.com/White-1-5-x-50-Single-Jacket-Discharge-Hose?feed=Froogle&gclid=Cj0KCQjwmIuDBhDXARIsAFITC_4gKiU-IlxQlY21WHiqSne_AcUFd4QfQMFp7BP4ilvzElVJ2SCV-lkaAk7KEALw_wcB