QUANTITATIVE RISK ANALYSIS OF THE WAHSATCH GAS GATHERING PIPELINE SYSTEM

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Quest Consultants Inc. was retained by Union Pacific Resources Company (UPRC) to conduct a quantitative risk analysis of a natural gas gathering system located in southwestern Wyoming. The objective of the analysis was to determine the risk the pipeline and associated wells pose to the public population along the pipeline route. This required the completion of four major tasks.

Task 1. Determine potential pipeline and wellhead accidents that could create life-threatening hazards to persons located near the pipeline or well sites.
Task 2. Derive the frequency of occurrence (probability) of each accident identified in the first task.
Task 3. Determine the consequences of each accident identified in the first task.
Task 4. Combine the consequences and probability of occurrence of each accident to arrive at a measure of public risk created by the pipeline and well network.

The natural gas being produced and transported through the network varies in composition from one section of pipeline to another, according to the gas produced from each well. However, all pipeline sections transport natural gas containing some hydrogen sulfide. The pipeline creates no hazards for persons near the pipeline or well sites as long as the sour natural gas is contained within the pipeline.

Accidental releases of sour natural gas from the well/pipeline network could create potentially life-threatening hazards to persons near the location of the release. Due to the presence of hydrogen sulfide in the natural gas, the vapor cloud created by a release of gas to the atmosphere would be toxic as well as flammable. Persons inhaling air containing toxic hydrogen sulfide vapor could be fatally injured if the combination of hydrogen sulfide concentration and time of exposure exceeds the lethality threshold. If the cloud is ignited, persons in or very near the flammable vapor cloud could be fatally injured by the heat energy released by the fire.

The frequency of occurrence of each potential pipeline accident identified in Task 1 was estimated from historical pipeline failure rate data gathered by the U.S. Department of Transportation. Event trees were then used to estimate the percentage of releases of various sizes that would create a toxic or fire hazard. For example, it was estimated that 50 percent of moderate-sized releases of sour natural gas from the pipeline do not ignite but do create a toxic cloud; 10 percent ignite immediately upon release and create a torch fire; and 40 percent ignite after some delay, thus creating a toxic cloud followed by a torch fire.

The frequency of sour gas well blowouts was derived from sour gas well historical data. The largest documented database covers wells in the Province of Alberta, Canada. According to the data, an uncontrolled sour gas well blowout would occur with a frequency of 3.55×10^{-6} blowouts per well per year. This failure rate is for wells equipped with subsurface safety valves (SSSVs). All the wells in the Wahsatch network will be equipped with SSSVs.

Computerized consequence models were used to calculate the extent of potentially lethal hazard zones for toxic vapor clouds and/or gas fires created by each potential accident identified in Task 1. Calculations were repeated for numerous combinations of wind speed and atmospheric stability conditions in order to account for the effects of local weather data.

When making these calculations, it was assumed that large releases of gas (ruptures and punctures) from underground pipelines were capable of blowing away the soil overburden because of the pipeline's high operating pressure. As a result, the released gas enters the atmosphere with high velocity, resulting in rapid mixing with air near the point of release. For corrosion holes, it was assumed that the gas being released from an underground pipeline was incapable of blowing away the soil overburden. As a result, the released gas enters the atmosphere with little momentum after passing through the soil above the pipeline.

The number of persons expected to receive fatal injuries due to exposure to each of the toxic or fire hazard zones was determined as a function of wind direction. The risk was then calculated by summing the potential exposures to each of the hazards for all accidents identified in Task 1, and modifying the exposures to each potential hazard zone by its probability of occurrence. For example, the probability of a specific flash fire is the product of the following probabilities.

- Probability of the accident that releases sour natural gas.
- Probability that the release creates a flammable vapor cloud under a unique combination of wind speed, wind direction, and atmospheric stability conditions.
- Probability that the flammable vapor cloud is not ignited immediately but is ignited after some delay.

The number of persons potentially exposed to a specific hazard zone is a function of the population density and distribution near the accident location. The population density varies along each pipeline section, and many of the sections do not have any permanent dwellings or population close enough to the pipeline to be affected by a pipeline release. In addition, some of the physical aspects of the pipeline (e.g., pipe diameter and operating pressure) and the composition of the gas in the pipeline also vary with location. Therefore, the pipeline/well network was divided into twelve pipeline sections and six well sites on the basis of pipeline diameter, operating pressure, and local population density. A drawing of the proposed pipeline/well system is presented in Figure 1. Calculations of expected failure rates and exposures were performed for each of the twelve pipeline sections and six well locations.

For each pipeline section or well site, one particular accident will create the largest potentially lethal hazard zone for that section. As an example, along Section L9 (the portion of the pipeline crossing Interstate 80), this accident is a full rupture of the pipeline without ignition of the flammable cloud, thus resulting in a possible toxic exposure downwind of the release. Under "worst-case" atmospheric conditions, the toxic hazard zone extends 2,600 feet from the point of release. Under the worst-case conditions, it takes about 11 minutes for the cloud to reach its maximum extent. The hazard "footprint" associated with this event is illustrated in two ways in Figure 2. One method presents the footprint as a "hazard corridor" that extends 2,600 feet on both sides of the pipeline for the entire length of Section L9. This presentation is misleading since everyone within this corridor cannot be simultaneously exposed to potentially lethal hazards from any single accident. A more realistic illustration of the maximum potential hazard zone along Section L9 of the pipeline is illustrated by the shaded area in Figure 2. This shaded area illustrates the hazard footprint that would be expected IF a full rupture of the pipeline were to occur, AND the wind is blowing perpendicular to the pipeline at a low speed, AND worst-case atmospheric conditions exist, AND the vapor cloud does not ignite. The probability of the simultaneous occurrence of these conditions is about 1.87×10^{-7} occurrences/pipeline mile-year, or approximately once in 5,330,000 years.

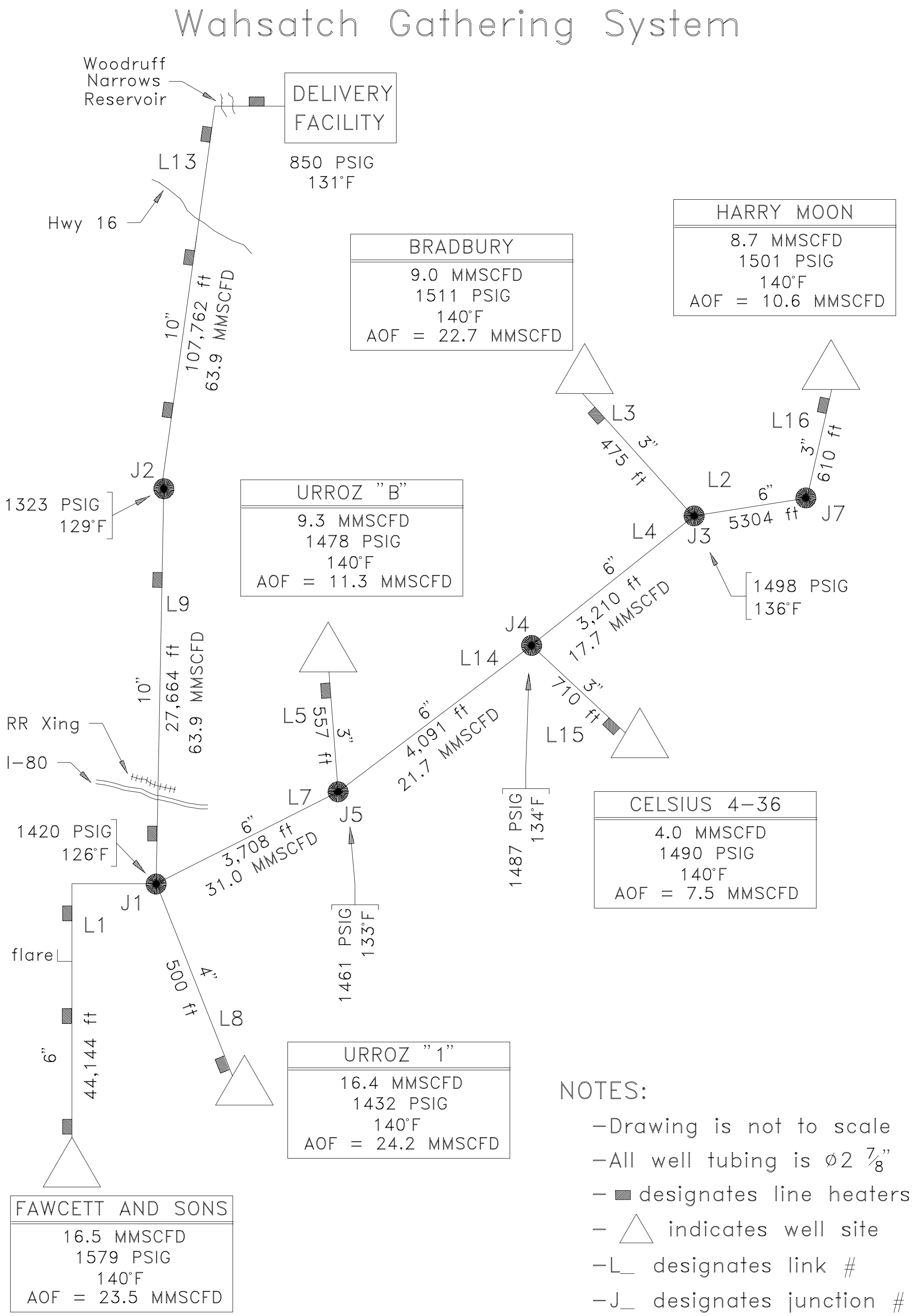

Figure 1
Proposed Wahsatch Pipeline/Well System

Figure 3 presents the results of the risk analysis of the four pipeline sections and two wells located near the southwestern city limits of Evanston. This is the only portion of the pipeline/well network that has a resident population within 2,000 feet of the pipeline. The hazard corridor for this portion of the pipeline/well network is represented by the dashed line, marked "hazard corridor," on Figure 3. The results of the risk analysis are presented in Figure 3 as individual risk contours. Each contour illustrates the annual risk the pipeline/well network poses to persons near the pipeline or wells as a function of their distance from the pipeline and wells. As can be seen in Figure 3, the highest risk along this section of the pipeline network is to persons located immediately above the pipeline. The maximum risk posed by this portion of pipeline is about 5.0 x 10^{-6} chances of fatality per year. This is for an individual located directly above the pipeline 24 hours per day for 365 days. In other words, an individual in this area of the pipeline network would have one chance in 200,000 of being fatally injured by some release from the pipeline for an entire year, if this individual remained directly above the pipeline for an entire year. An individual in this same area, but located 50 meters from the pipeline, would have about one chance in one million of being fatally injured by a release from the pipeline, if the individual were present at that location for the entire year.

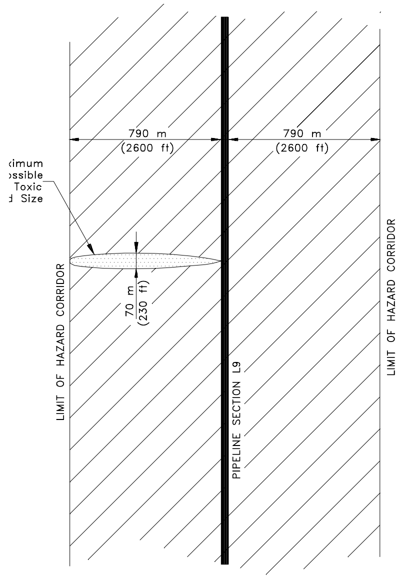

Figure 2
Maximum Hazard Corridor for Section L9

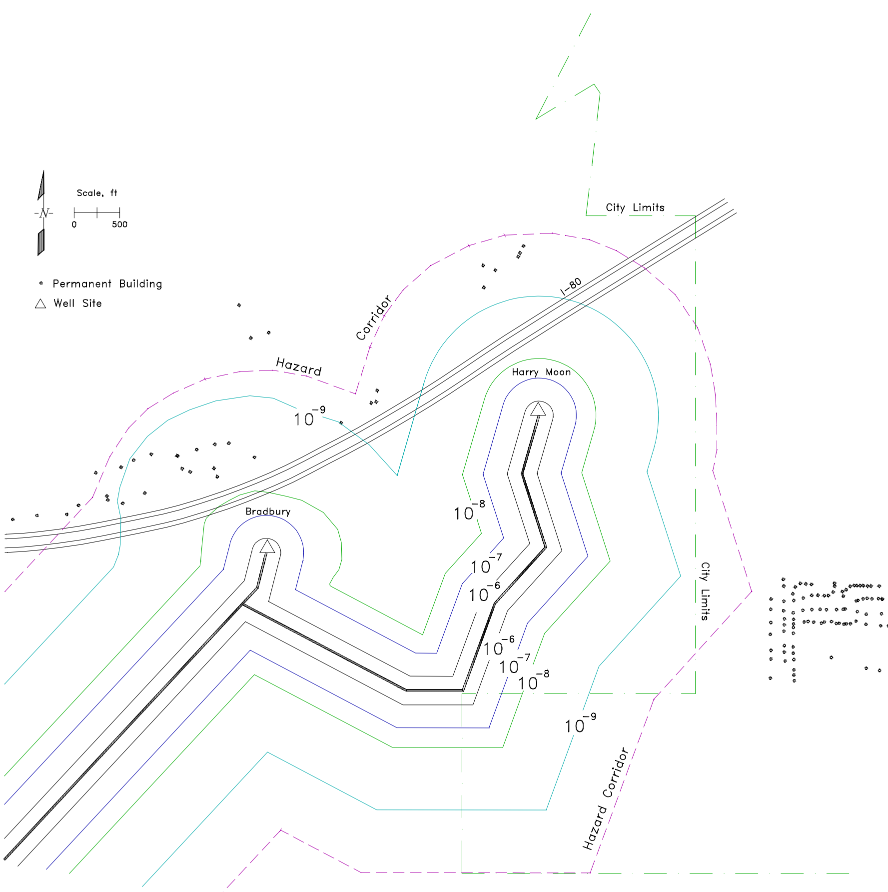

Figure 3
Individual Risk Contours for Bradbury and Harry Moon Wells and Associated Pipeline

The risk posed to the population within the appropriate hazard corridor for the pipeline/well network can also be presented in the form of *f/N* curves. This type of risk presentation, often called societal risk, is a plot of the frequency, *f*, at which *N* or more persons are expected to be fatally injured. Figure 4 is the *f/N* curve for the pipeline/well network. The *f/N* curve for UPRC's Wahsatch Gas Gathering System (twelve pipeline sections and six wells) shows the frequency of accidents that would affect one or more persons, on average, is less than 6.0 x 10^{-7} chances/year, or one chance in 1.7 million.

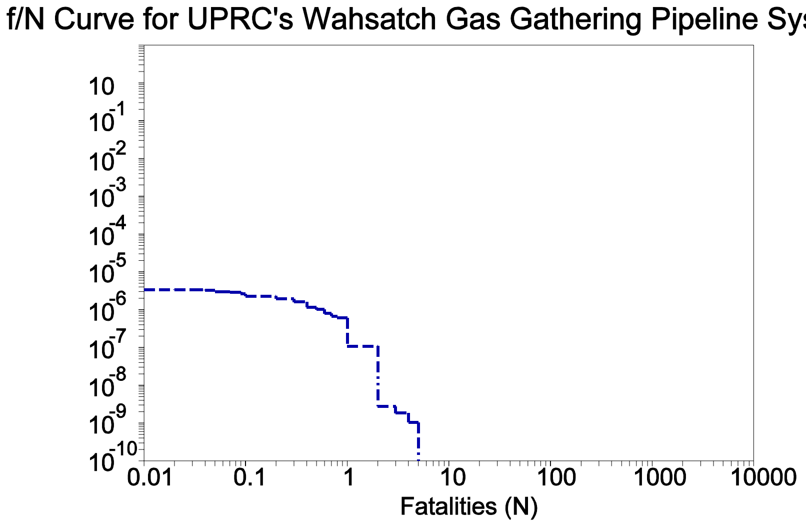

Figure 4

Figure 5 plots the *f/N* curve for the pipeline/well network against the Off-Site Risk Guidelines proposed by the County of Santa Barbara (California) System Safety and Reliability Committee. As shown in Figure 5, the societal risk posed by the Wahsatch Gathering System is well within the *De Minimis* (acceptable) region.

Historical data on fatal accidents involving natural gas gathering and transmission pipelines have been compiled by the Department of Transportation (DOT). During the 14.5 years for which summary data are available, the maximum number of fatalities due to any single accident was six, and only two accidents caused six fatalities. For the pipeline/well network involved in this study, the maximum expected number of fatalities for any single accident is five on average. Figure 6 compares the *f/N* curve for all the pipeline sections to the *f/N* curve derived from the DOT historical data. (In order to make this comparison, the accident frequencies are presented as accidents per mile of pipeline per year.) As shown in Figure 6, the predicted *f/N* curve for the Wahsatch pipeline network is less than the *f/N* curve derived from the DOT's historical data. This is primarily due to the sparse population along the pipeline route.

To put this type of evaluation into perspective, it is instructive to look at the types of risks people are ordinarily exposed to during day-to-day life. Table 1 lists the risks a citizen of the Evanston area might be exposed to each and every day. As can be seen in the table, there are voluntary activities (driving a car) and involuntary activities (being hit by lightning) that involve risks higher than those due to the Wahsatch pipeline/well network.

A second pipeline/well network was evaluated in this work. The second network is identical to that presented in Figure 1, with the addition of two wells (Champlin 375 C and Kindler-Reese), 15,400 feet of 6-inch pipeline, and 500 feet of 3-inch pipeline (Sections L10, L11, and L12). This pipeline/well network is presented in Figure 7. The two additional wells and associated pipeline are located in remote areas, with no permanent residents or businesses within the 2,000 foot hazard corridor; thus, they do not contribute to the societal risk (as presented on the *f/N* curve) of the pipeline/well network.

Comparison of the f/N Curve for UPRC's Wahsatch Gas Gathering Pipeline System and the Proposed Off-Site Risk Guidelines for the County of Santa Barbara

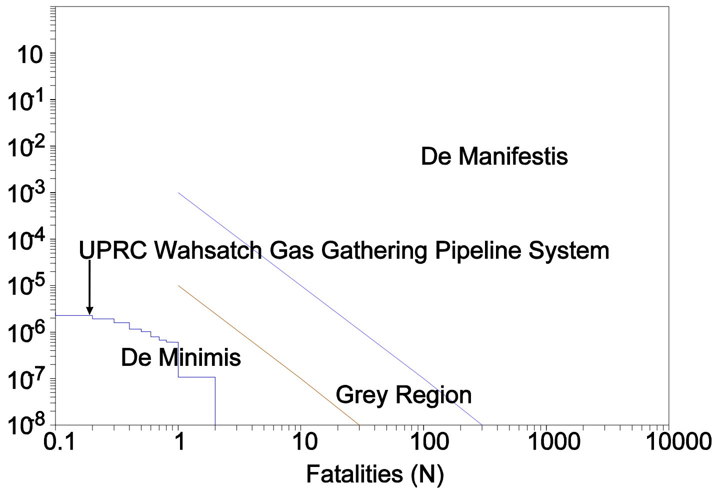

Figure 5

Comparison of the f/N Curve for UPRC's Wahsatch Gas Gathering Pipeline System and the Historical f/N Curve for U.S. Natural Gas Gathering and Transmission Pipelines

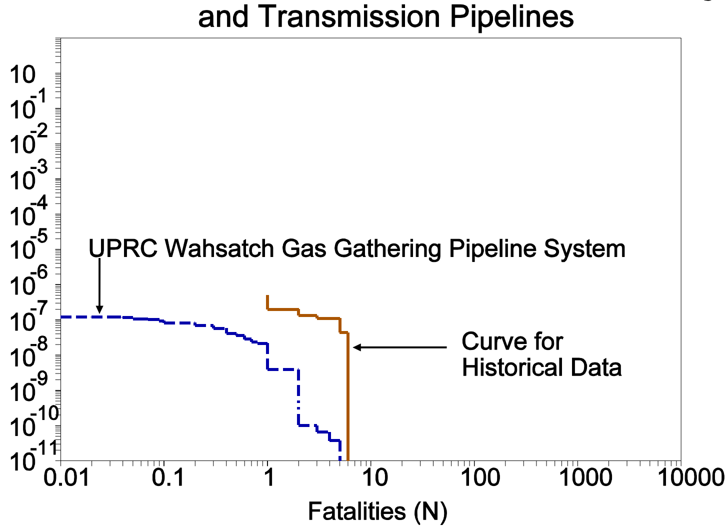

Figure 6

Table 1
Individual Risk of Early Fatality by Various Causes

Hazard	Approximate Individual Risk of Early Fatality	
	Probability/Year	One Chance in
Heart disease	3.12×10^{-3}	320
Cancer	1.96×10^{-3}	510
All accidents	3.90×10^{-4}	2,560
Motor vehicles	1.98×10^{-4}	5,030
Homicides	8.66×10^{-5}	11,500
Drowning	2.09×10^{-5}	47,600
Fires, burns	1.93×10^{-5}	51,600
Release of gas from Wahsatch pipeline/well network (maximum risk level – on pipeline center or wellhead)	5.20×10^{-6}	192,300
Civil aviation	5.19×10^{-6}	192,600
Water transport	3.90×10^{-6}	256,000
Railroads	2.56×10^{-6}	389,000
Lightning	4.06×10^{-7}	2,454,000
Bites and stings	2.79×10^{-7}	3,570,000
Release of gas from Wahsatch pipeline/well network (risk level - 100 meters either side of pipeline or wellhead)	2.00×10^{-7}	5,000,000
Release of gas from Wahsatch pipeline/well network (risk level - 300 meters either side of pipeline or wellhead)	2.50×10^{-9}	400,000,000

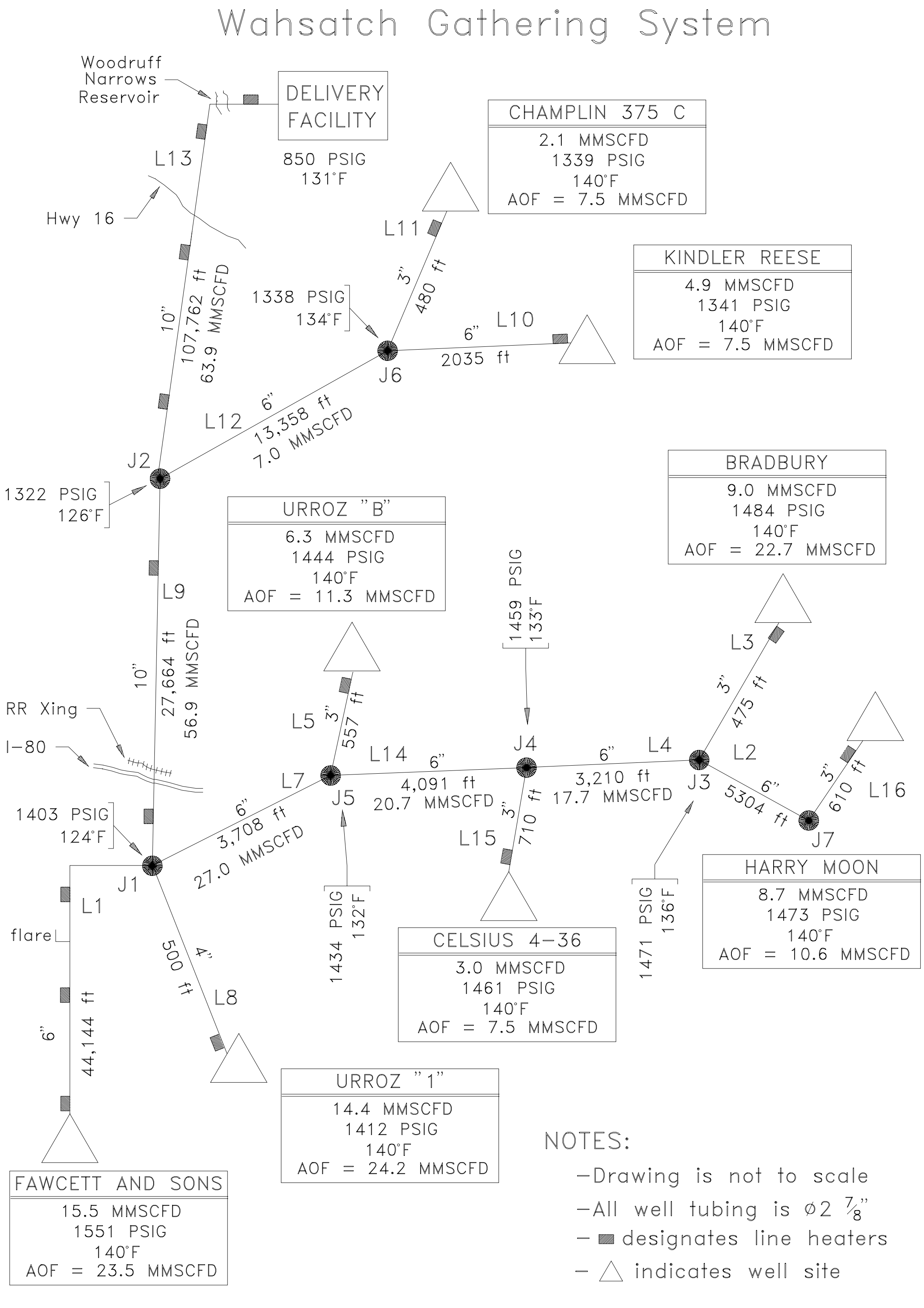

Figure 7
Proposed Wahsatch Pipeline/Well System with Champlin 375 C and Kindler-Reese Wells Added