Appendix G

Accidental Release Dispersion Reports and Summary of PHMSA Regulations

Summary of PHMSA Regulations:
CO2 Pipelines
January 2024

Appendix G
Summary of PHMSA Regulations: CO_2 Pipelines

G.1 Is the project regulated by the Pipeline and Hazardous Materials Safety Administration, and if so, how is the project regulated?

Yes, the Otter Tail to Wilkin Carbon Dioxide (CO_2) Pipeline Project (project) is regulated by the Pipeline and Hazardous Materials Safety Administration (PHMSA) under Title 49 Code of Federal Regulations (CFR) Parts 190 and 195–199 concerning engineering, design, construction, safety, and operation of the project.

G.2 What is PHMSA, and what does it regulate?

PHMSA is a federal agency within the United States Department of Transportation (USDOT) that has statutory authority over pipeline engineering, design, construction, safety, and operation (see 49 CFR Parts 190, 195-199). PHMSA establishes the federal regulations for pipeline safety. It was created under the Special Programs Improvement Act (Public Law 108-426) of 2004. The mission of PHMSA is to protect people and the environment by advancing the safe transportation of energy products and other hazardous materials that are essential to our daily lives. There are two safety offices within PHMSA: the Office of Pipeline Safety and the Office of Hazardous Materials Safety.

PHMSA regulates the construction, operation, and maintenance of CO_2 pipelines. PHMSA defines CO_2 as "a fluid consisting of more than 90 percent carbon dioxide molecules compressed to a supercritical state" (49 CFR Section 195.2). Proposed rules and regulations (discussed below) will extend the regulations to pipelines transporting liquid and gas CO_2 as well. Extending PHMSA oversight to cover all forms of CO_2 will ensure that no new CO_2 pipelines lack safety standards and regulations.

G.3 Why does PHMSA regulation apply to the project?

In 1979, Congress enacted comprehensive safety legislation governing the transportation of hazardous liquids by pipeline, the Hazardous Liquids Pipeline Safety Act of 1979 (HLPSA; 49 United States Code 2001 et seq.). The HLPSA expanded the existing statutory authority for safety regulation. It also added civil penalty, compliance order, and injunctive enforcement authorities to the existing criminal sanctions. The HLPSA provides for a national hazardous liquid pipeline safety program with nationally uniform minimal standards and with enforcement administered through a federal-state partnership.

The HLPSA leaves to exclusive federal regulation and enforcement the "interstate pipeline facilities," or those used for the pipeline transportation of hazardous liquids in interstate or foreign commerce. For the remainder of the pipeline facilities, denominated "intrastate pipeline facilities," the HLPSA provides that the same federal regulation and enforcement will apply unless a state certifies that it will assume those responsibilities. A certified state must adopt the same minimal standards but may adopt additional more stringent standards so long as they are compatible. Therefore, in states that participate in the hazardous liquid pipeline safety program through certification, it is necessary to distinguish interstate and intrastate pipeline facilities.

Concerning the proposed CO_2 project, USDOT would consider this project to be an interstate pipeline facility and thus subject to PHMSA regulation.

G.3.1 Current PHMSA CO_2 Pipeline Regulations

Transportation of Hazardous Liquids by Pipeline (49 CFR Part 195) is broken down into the following subparts:

- Subpart A – General. This subpart prescribes safety standards and reporting requirements for pipeline facilities used in the transportation of hazardous liquids or carbon dioxide.
- Subpart B – Annual, Accident, and Safety-Related Condition Reporting. This part prescribes requirements for periodic reporting and for reporting of accidents and safety-related conditions.
- Subpart C – Design Requirements. This subpart prescribes minimum design requirements for new pipeline systems constructed with steel pipe and for relocating, replacing, or otherwise changing existing systems constructed with steel pipe. However, it does not apply to the movement of line pipe covered by 49 CFR Section 195.424.
- Subpart D – Construction. This subpart prescribes minimum requirements for constructing new pipeline systems with steel pipe and for relocating, replacing, or otherwise changing existing pipeline systems that are constructed with steel pipe. However, this subpart does not apply to the movement of pipe covered by 49 CFR Section 195.424.
- Subpart E – Pressure Testing. This subpart prescribes minimum requirements for the pressure testing of steel pipelines. However, this subpart does not apply to the movement of pipe under 49 CFR Section 195.424. Provisions include risk-based alternatives to pressure testing, test pressure, testing of components, test medium, pressure testing aboveground breakout tanks, testing of tie-ins, and records.
- Subpart F – Operation and Maintenance. This subpart prescribes minimum requirements for operating and maintaining pipeline systems constructed with steel pipe.
- Subpart G – Qualification of Pipeline Personnel. This subpart prescribes the minimum requirements for operator qualification of individuals performing covered tasks on a pipeline facility.
- Subpart H – Corrosion Control. This subpart prescribes minimum requirements for protecting steel pipelines against corrosion.

G.3.2 Status of Pending PHMSA Regulations for CO_2 Pipelines

On February 22, 2020, the Denbury Green Pipeline, a CO_2 pipeline in Satartia, Mississippi, experienced a rupture that caused 48 people to seek medical attention and many others to evacuate the release area (further discussed Chapter 8 of this Environmental Impact Statement [EIS]). As a result of this CO_2 pipeline failure, PHMSA announced in May 2022 that the agency will be taking various measures to strengthen CO_2 pipeline safety and steps to implement new safety and oversight measures to prevent future failures and/or mishandling of CO_2 pipeline failures (Docket No. PHMSA-2023-0013).[1]

On December 13–15, 2022, PHMSA held an informational public meeting addressing multiple safety topics. Among other things, PHMSA discussed with the public and industry how it is improving CO_2 pipeline safety by issuing advisory bulletins based on lessons learned from events like the pipeline failure that threatened the community of Satartia. This included discussion about calculating the potential impact radii for CO_2 pipeline releases. The overall purpose of the informational public meeting was to share safety information with the public and industry as well as gather input to inform future rulemaking decisions.

PHMSA received a letter from the Pipeline Safety Trust on February 17, 2023 (Docket No. PHMSA-2022-0125), formally requesting that PHMSA hold a public meeting on CO_2 pipeline safety and the announced rulemaking under RIN 2137-AF60.[2]

On May 31 and June 1, 2023, PHMSA held a public meeting and webcast on CO_2 pipeline safety.[3] The purpose of the May–June 2023 public meetings was to serve as an opportunity for pipeline stakeholders to help inform pipeline safety-related rulemaking decisions and share information surrounding CO_2 pipeline safety. Key stakeholders included the public, states, Tribal governments, other federal agencies, industry, and international regulators and/or organizations. Topics included the following:

- Safety expectations for pipeline operators
- General state of CO_2 pipeline infrastructure – current mileage and forecasts
- Federal and state jurisdictions and authorities
- Public awareness, engagement, and emergency notification
- Emergency equipment, training, and response
- Dispersion modeling
- Safety measures to address other constituents besides CO_2 in CO_2 pipelines
- Leak detection and reporting
- Geohazards
- Conversion to service
- Environmental justice

Speakers/participants included the following

- Public advocacy groups
- Pipeline operators
- Federal regulators
- Tribal governments
- States through the National Association of Pipeline Safety Representatives
- Other United States government agencies

Comments were allowed to be submitted for the meeting.

PHMSA intends to publish a Notice of Proposed Rulemaking by June 2024.[4] A first draft of the new regulations from the agency is not expected before October 2024.[5] No date has been set for a prediction as to when the agency will have finalized rules in place.

G.4 What are CO_2 pipeline project mitigation strategies and measures to ensure public safety?

G.4.1 Measures Consistent with Proposed and Final Federal Rules

Since PHMSA has not formally initiated the Notice of Proposed Rulemaking process, proposed, new, or amended rules to current CO_2 pipeline regulations under 49 CFR Part 195 are not known at this time. PHMSA indicates the new rules and regulations will extend the regulations to pipelines transporting liquid and gas CO_2 as well, and that extending PHMSA oversight to cover all forms of CO_2 will ensure that no new CO_2 pipelines lack safety standards and regulations. As indicated above, PHMSA plans to publish a Notice of Proposed Rulemaking by June 2024, and first drafts of any new regulations are not expected before October 2024. Therefore, discussion of mitigation strategies and measures to ensure public safety associated with any newly proposed (or final) PHMSA rules is not possible at this time. Chapter 3 of this EIS also discusses this topic.

Safety mitigation strategies and measures are further discussed and summarized in Chapter 8 of this EIS and in this Appendix G.

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[1] See PHMSA Announces New Safety Measures to Protect Americans From Carbon Dioxide Pipeline Failures After Satartia, MS Leak | PHMSA (dot.gov).

[2] See Federal Register :: Pipeline Safety: Carbon Dioxide Pipeline Safety Public Meeting. Accessed January 19, 2024.

[3] See Regulations.gov. Accessed January 19, 2024.

[4] See IN12169 (congress.gov). Accessed January 19, 2024.

[5] See https://www.eenews.net/articles/midwest-co2-pipeline-rush-creates-regulatory-chaos/#:~:text=PHMSA%E2%80%99s%20existing%20regulations%20cover%20pipelines%20carrying%20carbon%20dioxide%20in%20a%20%E2%80%9Csupercritical%E2%80%9D%20phase.

Aerial and Thermal Dispersion Analysis:
Otter Tail to Wilkin CO2 Pipeline Project
January 11, 2024
(Allied Solutions)

Aerial and Thermal Dispersion Analysis: Otter Tail to Wilkin Carbon Dioxide Pipeline Project

MN Docket No.: PL-22-422

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Prepared by:

ALLIED SOLUTIONS

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1. Executive Summary

Allied Solutions verified the aerial dispersion analysis that Summit Carbon Solutions (the applicant) conducted on the Otter Tail to Wilkin CO_2 Pipeline by duplicating their input data and running the analysis in CANARY, a software package used specifically for calculating aerial dispersion impact of a product release from a pipeline. We also created our own assumptions and input data and ran our own analysis using CANARY, then we compared our results to the applicant's results.

Our analysis generated larger impact areas than the applicant's analysis (11.1 feet greater at 15,000 parts-per-million (ppm) and 107.9 feet greater at 40,000 ppm). We investigated the reasons for the differences and concluded that the applicant's process was valid, but we used more conservative assumptions and more targeted levels of concern.

The applicant also conducted an analysis of the effects of terrain using a software package called FLO-2D, which did not materially impact their CANARY-generated results. FLO-2D, however, does not account for windbreaks. Furthermore, engineers at FLO-2D reported that the software cannot account for gaseous mixing—a key component in aerial dispersion—and is not intended to be used for aerial dispersion analyses. Therefore, we recommend using computational fluid dynamics (CFD) software to determine if windbreaks and terrain would materially affect the aerial dispersion impact area of a potential release from the potential Otter Tail to Wilkin CO_2 Pipeline and determine how long impacted areas would remain hazardous.

2. Introduction

Allied Solutions (hereinafter referred to as "Allied," "us," "we," or "our") created this report for HDR Engineering, Inc. (hereinafter referred to as "HDR," "the client," or "client"), on behalf of the State of Minnesota, Department of Commerce, Environmental Review and Analysis (EERA) unit. In it, we describe our methodology for completing an aerial and thermal dispersion analysis for the Otter Tail to Wilkin CO_2 Pipeline project and summarize the results.

We also validated a previous aerial dispersion analysis conducted by the applicant, Summit Carbon Solutions (hereinafter referred to as "the applicant"). The applicant submitted the inputs and outputs of said aerial dispersion as part of an effort to gain a permit from the State of Minnesota to build the Otter Tail to Wilkins pipeline.

3. Definitions

Table 1. Definition of Terms

Acronym or Term	Definition
CANARY	Software used to determine the impact of various HVL releases on the surrounding area. CANARY integrates multicomponent thermodynamics into a time-varying fluid release simulation. These simulations account for two-phase flow, flash vaporization, and aerosol formation, as well as liquid rainout. Vaporization from liquid pools takes into account pool spreading, heat transfer effects, and impoundment.
CDC	Centers for Disease Control and Prevention
CFD	Computational fluid dynamics
CO_2	Carbon dioxide
Levels of Concern (LOCs)	A threshold value of a hazard (toxicity, flammability, thermal radiation, or overpressure); usually, the value above which a threat to people or property exists
NOAA	National Oceanic and Atmospheric Administration
Product	Synonymous with “products in the pipeline'”
Valve Segment	A segment of pipeline that is between two valves
VCE	Vapor cloud explosion

4. Methodology

In this section, we describe the methodology, software, and analyses we use for all aerial and thermal dispersion analyses.

NOTE: In this analysis, we did not consider terrain and vegetation when calculating impact area. Terrain and vegetation are considered in a separate computational fluid dynamics (CFD) analysis noted in the Reference section.

4.1 Software and General Analyses

We perform aerial dispersion analyses using CANARY software, which was designed by engineers at Quest Consultants, Inc. The software uses a multi-component thermodynamics model to determine the potential outcomes following a hazardous liquid release. Our Integrity Engineers who perform these analyses are trained and qualified by Quest to use CANARY.

CANARY software is an industry standard for aerial and thermal dispersion analysis. See Appendix C for an overview of aerial dispersion software available on the market.

These are the types of analyses we perform with CANARY software to check for potentially hazardous conditions:

- Toxic area impact of vapor cloud;

- Flammable area impact of vapor cloud;
- Vapor cloud explosion area impact; and
- Jet fire and pool fire area of impact.

5. Project-Specific Methodology and Data

For this project, we completed an aerial and thermal analysis of the proposed Otter Tail to Wilkin CO_2 pipeline and validated the aerial dispersion analysis conducted by the applicant.

5.1 Aerial and Thermal Analysis

We used the data in Tables 2 and 7 (see Appendix A) to perform the toxic area impact analyses for this project. Table 7 lists the specific variables we used for our analysis.

Because CO_2 is not flammable, we did ***not*** conduct the following analyses:

- Flammable area impact of vapor cloud;
- Vapor cloud explosion area impact; and
- Jet fire and pool fire area of impact.

We performed a toxic exposure aerial dispersion analysis of the proposed project pipeline rights-of-way, keeping the worst-case scenario in mind.

The Levels of Concern (LOCs) we chose for the project are 40,000 ppm (the NIOSH-defined limit of “immediately dangerous to life or health” (IDLH)) and 30,000 ppm (the NIOSH short-term exposure limit (STEL)). STEL is the maximum time-weighted average concentration a person could be exposed to over a 15-minute period without injury.

Evidence presented by the CDC suggests that longer exposures to higher concentrations can produce signs of intoxication but not death or permanent impact to health. Regardless, to be conservative, we have selected the CDC-recommended IDLH level of 40,000 ppm.

We selected these LOCs because they are useful exposure milestones typically presented by the CDC to inform the public of relevant exposure limits.

Table 2. Project-Specific Analysis Information

Product	Analyses Performed	Toxic LOC (ppm)
CO_2	Toxic vapor cloud	30,000
		40,000

NOTE: We conducted modeling in CANARY based on the assumption that the product was pure CO_2, not a mixture of CO_2 and other components, because:

- The introduction of even fractions of a percent of other product components can interfere with CANARY’s ability to accurately model the result due to software model constraints; and

- Modeling pure CO_2 produces more conservative results.

5.2 Applicant's Aerial Dispersion Analysis

We vetted the applicant's aerial dispersion analysis of the proposed Otter Tail to Wilkin CO_2 pipeline. The applicant used the data in Tables 3 and 8 (Appendix A) to perform the toxic area impact analyses. Table 3 lists the analyses they conducted and the CO_2-specific LOCs they used. Table 8 in Appendix A lists the project-specific data they used.

Table 3. Applicant Project-Specific Analysis Information

Product	Analyses Performed	Toxic LOC (ppm)
CO_2	Toxic vapor cloud	15,000
		40,000
		80,000

NOTE: The applicant modeled their analysis in CANARY using a mixture of CO_2 and other components such as nitrogen (0.0047 molar fraction) and oxygen (0.002 molar fraction). This can interfere with CANARY's ability to accurately model the result due to software model constraints, per Quest Consultants.

6. Results

Since the environment where the pipeline would be located can vary greatly in terms of temperature and humidity (see Table 9 in Appendix B), we ran models for both the hottest part of the year and the coldest part of the year, along with the associated humidity levels, to determine worst-case toxic impact distance. Table 10 (Appendix B) shows the data we used for reasonable worst-case scenarios.

Based on our modeling of release impact distances using the highest and lowest reasonable temperatures and associated humidities (Table 10), we chose a reasonable worst-case temperature of -22.1 °F and a humidity level of 74.3%.

Table 4 shows the toxic impact distances for CO_2 at different concentrations.

There is a reasonable chance that the pipeline will need to be shut in during pipeline operations, which would leave CO_2 trapped in the pipeline for an undetermined amount of time. If the CO_2 stays above 1,200 psi, it stays in a supercritical state. If the CO_2 is allowed to depressurize below 1,200 psi, the operator runs the risk of CO_2 phasing to a mixture of gas and liquid—an operational condition to avoid.

Table 4. Toxic Impact Distances for CO2 at Different Concentrations

Pipeline	Pipeline Diameter (in)	Segment Length (mi)	Pressure (psi)	Max of Toxic Impact Distance at 40,000 ppm[1] (ft)	Max of Toxic Impact Distance at 30,000 ppm[2] (ft)	Max of Toxic Impact Distance at 15,000 ppm[3] (ft)
Otter Tail to Wilkins CO_2	4[4]	13.9	2,197.89	617.5	701.6	910.1

[1] 40,000 ppm is the immediately dangerous to life or health (IDLH) limit.

[2] 30,000 ppm is the National institute for Occupational Safety and Health (NIOSH) short-term exposure limit (STEL). The NIOSH STEL is the maximum time-weighted average concentration a person could be exposed to over a 15-minute period without injury.

[3] 15,000 ppm is half of the NIOSH STEL. We used it to compare with the applicant LOCs.

[4] A 4-inch nominal diameter pipeline has an outside diameter of 4.5 inches.

6.1 Evaluation of Applicant's Aerial Dispersion Analysis

Using applicant-provided data (see Table 8), Allied ran the CANARY model and verified the applicant-provided impact distances (see Table 5).

Table 5. Applicant Provided LOCs and Associated Impact Distances

Product	Analyses Performed	Toxic LOC (ppm)	Max of Toxic Impact Distance (ft)
CO_2	Toxic vapor cloud	15,000	896.0
		40,000	509.6

Also, the applicant used a software package called FLO-2D to model the aerial dispersion over terrain. However, from information supplied by the applicant, it appears that the FLO-2D analysis did not affect the impact distances produced using CANARY.

7. Discussion and Recommendations

Our analysis resulted in greater potential impact distances than the applicant-calculated impact distances. To understand what could contribute to this discrepancy, see the differences in project-specific values in Table 6.

Table 6. Differences in Project-Specific Values Contributing to Discrepancies in Potential Impact Distances

Attribute	Applicant Value Used	Allied Value Used	Comment
Wind Speed (mph)	5	4	Slower wind speeds tend to extend impact distances. See Table 7 for more information.
Product Temperature Before Rupture (°F)	30	-20	It is our opinion that this should be the colder temperature based on the last five years of weather data at Fergus Falls, Minnesota. See Appendix B for more information.
Relative Humidity	71%	88.7%	It is our opinion that this should be the higher value based on the last five years of weather data at Fergus Falls, Minnesota. See Appendix B for more information.
Air Temperature (°F)	3.2	-22.1	It is our opinion that this should be the colder temperature based on the last five years of weather data at Fergus Falls, Minnesota. See Appendix B for more information.
Angle of CO_2 Release from Horizontal	5 degrees	19 degrees	Quest Consultants recommend 19 degrees because it generates the worst-case scenario with their models. Angles less than 19 degrees tend to be unrealistically conservative and generate a greater area of impact than is practical.
Dispersion Coefficient Averaging Time (min)	1	Same as the Rupture Release time (60 minutes)	In general, when this value is less than the release time, it generates an artificially greater potential impact distance. In general, matching the rupture release time is standard.
Valve Segment Length (ft)	105,600.69	73,392.0	The different valve segment lengths do not materially affect the impact distance.
Rupture Placement Along the Valve Segment	About 1/8 downstream of the center of the valve segment	Equidistant from both ends of the valve segment	The different rupture locations do not materially affect the impact distance.

In general, the applicant's methodology and results are valid, but they could have been more conservative in their modeling parameters and LOCs. The main concern is the impact distance at the 40,000-ppm concentration level. Allied calculated 617.5 ft and the applicant calculated 509.6 ft. Even though the applicant uses the more conservative impact distance at the 15,000-ppm concentration LOC to make certain determinations, the 30,000-ppm and 40,000-ppm level LOCs are more meaningful because they have a larger effect on the health and wellbeing of those impacted by a potential pipeline rupture.

There are slight terrain changes along the rights-of-way, in addition to windbreaks designed to interrupt the wind that carries CO_2. It seems appropriate to take into consideration those factors when determining the reasonable worst-case impact from a potential rupture. The applicant uses FLO-2D to attempt that analysis. However, FLO-2D only considers terrain, not windbreaks or other flora. Also, according to engineers at FLO-2D, their software is meant to model liquid releases (single-phase flow) or liquid releases with sediment, which they refer to as "2-phase flow."

Furthermore, engineers at FLO-2D maintain that said software cannot account for gaseous mixing—a key component in aerial dispersion—and is not intended to be used for aerial dispersion analyses. As Allied did not attempt to account for windbreaks and terrain and the use of FLO-2D is not appropriate for terrain modeling of gaseous releases, we recommend using a computational fluid dynamics (CFD) software to determine if windbreaks and terrain materially affect a potential release.

Performing a CFD analysis would not only provide better insight into the effect of terrain and local windbreaks, it would also show how long LOCs would be exceeded at various impact distances away from the pipeline. The time aspect of impact is very important because many NIOSH limits are based on exposure time at different limits. Exposure times associated with different concentration levels and impact distances are some of the most important aspects of aerial dispersion analysis. Again, we recommend using CFD software to determine the exposure time associated with various NIOSH exposure limits.

8. References

We performed this analysis in conjunction with the following reports:

- Single Line CFD Analysis – Proposed Otter Tail to Wilkin CO_2 Pipeline Project – Report v0.pdf
- Reports and documents supplied by the applicant.

Appendix A – Project-Specific Data

Table 7 describes the project-specific data we used to conduct the analysis.

Table 7. Project-Specific Data

Attribute	Used For	Value Used	Source	Justification
Wind Speed (mph)	Momentum jet dispersion model VCE momentum jet dispersion model	4	Allied Solutions	4.47 mph is endorsed by Quest Consultants to produce reasonable worst-case conditions when using their software. We used a slightly lower value for additional conservatism.
Product Temperature Before Rupture (°F)	All models	-20	Allied Solutions	Due to a measured soil temperature at burial depth being subzero[5] and the existence of aboveground valve sets, this temperature should be nearly the same as the air temperature.
Wind Speed Measurement Height (ft)	Momentum jet dispersion model VCE momentum jet dispersion model	32.81 (10 m)	Allied Solutions	Endorsed by Quest Consultants to produce reasonable worst-case conditions when using their software
Wind Stability Class	Momentum jet dispersion model VCE momentum jet dispersion model	Class F	Allied Solutions	A laminar wind condition that produces the largest impact long distances away from the pipeline
Relative Humidity	All models	88.7%	Allied Solutions	Selected from analysis in Appendix B
Air Temperature (°F)	All models	-22.1	Allied Solutions	Selected from analysis in Appendix B

[5] NOAA. Soil Temperature Maps by Depth: History data in CSV. Data retrieved 12/15/2023. https://www.weather.gov/ncrfc/LMI_SoilTemperatureDepthMaps.

Attribute	Used For	Value Used	Source	Justification
Surrounding Surface Roughness (in)	All models	6 (0.007 m)	Allied Solutions	Selected to provide the reasonably largest impacted area by assuming the smoothest onshore surfaces the CANARY software can offer
CO_2 Pressure (psi)	All models	2,197.89	Applicant Provided	Applicant-provided data adjusted for altitude
Release Duration (min)	All models	60	Allied Solutions	Sufficient time to fully depressurize a valve segment (If we find it insufficient, we increase it until results verify that it is sufficient)
Rupture Release Point (ft)	All models	0	Allied Solutions	Indicates the worst case of pipe at ground level and unburied
Angle of CO_2 Release from Horizontal	All models	19 degrees	Allied Solutions	The angle of release Quest Consultants recommend because it generates the worst-case scenario with their models
Dispersion Coefficient Averaging Time (min)	Momentum jet dispersion model VCE momentum jet dispersion model	Same as the Rupture Release time	Allied Solutions	Must be the same as the Rupture Release Time or results cannot be trusted
Impoundment?	All models	No	Allied Solutions	No impoundment generates the worst case
Max Flow Rate (lbs/sec)	All models	13.34	Applicant Provided	Applicant-provided data
Pipe Diameter (in)	All models	4.5	Applicant Provided	Applicant-provided data plus 0.5 inches for conservatism
Rupture Diameter (in)	All models	Same as pipe diameter to simulate a full guillotine rupture	Applicant Provided	Applicant-provided data

Attribute	Used For	Value Used	Source	Justification
Valve Segment Length (ft)	All models	73,392	Applicant Provided	Result from running CANARY on all pipeline segments provided by Applicant. The segment that generated the largest impact area starts at the valve at milepost 4.8 and ends at the valve at milepost 18.7.
Rupture Placement Along the Valve Segment	All models	Equidistant from both ends of the valve segment	Allied Solutions	Provides accurate answers considering how the various models work
Isolation Valve Closure Time (min)	All models	10	Applicant Provided	Applicant-provided data

Table 8. Applicant Project-Specific Data

Attribute	Value Used
Wind Speed (mph)	5
Product Temperature Before Rupture (°F)	30
Wind Speed Measurement Height (ft)	32.81 (10 m)
Wind Stability Class	Class F
Relative Humidity	71%
Air Temperature (°F)	3.2
Surrounding Surface Roughness (in)	6 (0.007 m)
CO_2 Pressure (psi)	2,197.89

Attribute	Value Used
Release Duration (min)	60
Rupture Release Point (ft)	0
Angle of CO_2 Release from Horizontal	5 degrees
Dispersion Coefficient Averaging Time (min)	1
Impoundment?	No
Max Flow Rate (lbs/sec)	13.34
Pipe Diameter (in)	4.03
Rupture Diameter (in)	Same as pipe diameter to simulate a full guillotine rupture
Valve Segment Length (ft)	105,600.69
Rupture Placement Along the Valve Segment	About 1/8 downstream of the center of the valve segment
Isolation Valve Closure Time (min)	10

Appendix B – Finding Reasonable Worst-Case Values for Humidity and Air/Ground Conditions

To use humidity and air/ground temperature inputs that generate a reasonable worst-case scenario, we reviewed temperature and humidity data for Fergus Falls, Minnesota for the last five years: 12-17-2018 through 12-17-2023[6] (see Table 9).

Table 9. Descriptive Weather Statistics for Fergus Falls 12-17-2018 through 12-17-2023

Attribute	Minimum Value	Maximum Value	Median Value
Air Temperature (°F)	-34.6	98.6	43.9
Relative Humidity (%)	27.4	99.8	75.3

To find the reasonable worst-case temperature and humidity, we test reasonable high and low temperatures with their associated humidities to see which ones produce the reasonable worst-case impact scenario.

Finding Low Temperature and Humidity Values

To determine the reasonable worst-case scenario low temperature and humidity values for our model, we reviewed the temperature and humidity data for Fergus Falls, Minnesota for the last five years: 12-17-2018 through 12-17-2023.

There were 196 days on which the temperature at Fergus Falls dropped below zero during the last five years. The vast majority of the coldest temperatures were above -25.2 °F. Figure 1 shows the number of days the minimum temperature was in each range of below-zero temperatures. For example, the minimum temperature was in the range of -11.1 °F to -6.4 °F for a total of 37 days between 12-17-2018 and 12-17-2023.

[6] Visual Crossing. Total Weather Data: History & forecast data in CSV or JSON. Data retrieved 12/18/2023. https://www.visualcrossing.com/weather-data

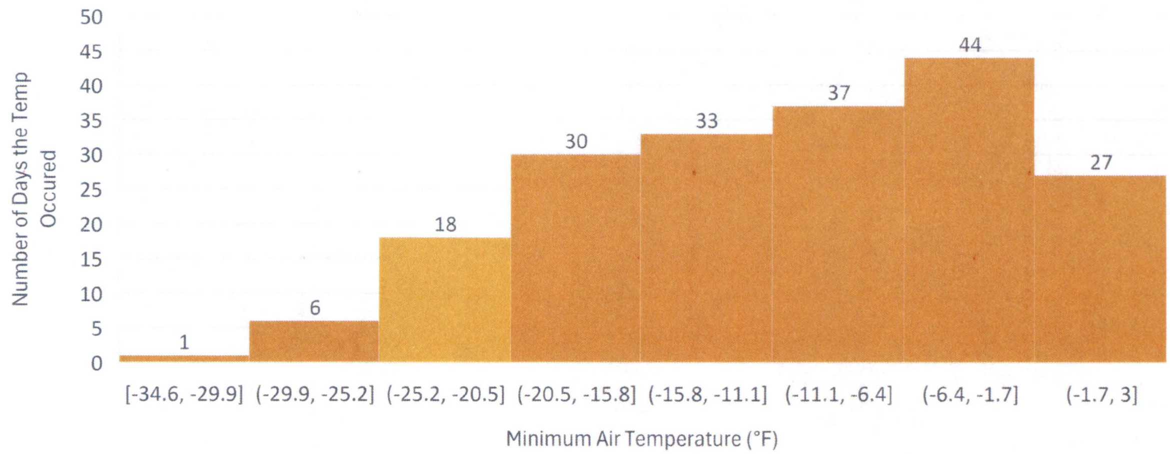

Figure 1. Number of Days Minimum Temperature Was Below Zero in Fergus Falls 12-17-2018 through 12-17-2023

We chose -25.2 and -20.5 °F as the reasonable worst-case temperature range to use for this project. We did not choose the extreme worst-case temperatures, which occur extremely seldom (0.4% of the time). For the 18 cases where the temperature was within the chosen reasonable worst-case scenario range, we averaged the high and low of the range to come up with a single value: -22.9 °F.

In the weather dataset we used, there isn't a recorded measurement of -22.9 °F. The closest temperature recorded was in February 2021—a minimum temperature of -22.1 °F, which was associated with a relative humidity of 74.3%. We used those values as the low temperature and humidity values for this project.

Note About Temperature at Pipe Depth

It is our understanding that the applicant will install its proposed pipeline at a depth of 54 inches (measured from top of pipe). Normally, this would provide considerable insulation from the ambient temperature aboveground. However, we looked at soil temperature data from NOAA[7] and discovered that over the last two years, the coldest soil reading of the year at 40 inches deep differed from the coldest ambient temperatures by only a few degrees Fahrenheit. Since colder temperatures in Minnesota can penetrate so deeply into the ground, the installation depth of the pipeline does far less to insulate it from colder temperatures than in other parts of the country. Therefore, to be conservative, we chose the coldest air temperatures as the basis for a worst-case scenario rather than modifying those temperatures to approximate below-ground temperatures.

Finding High Temperature and Humidity Values

To determine the reasonable worst-case scenario high temperature and humidity values for our model, we reviewed the temperature and humidity data for Fergus Falls, Minnesota for the last five years: 12-17-2018 through 12-17-2023.

[7] NOAA. Soil Temperature Maps by Depth: History data in CSV. Data retrieved 12/15/2023. https://www.weather.gov/ncrfc/LMI_SoilTemperatureDepthMaps.

When evaluating the 606 days on which the maximum temperature at Fergus Falls was above 70 degrees[8] during the last five years, we saw that the vast majority of the hottest temperatures were below 87.4 °F. Figure 2 shows the number of days the maximum temperature was in each range of above 70-degree temperatures. For example, the maximum temperature was in the range of 80.2 °F to 82.6 °F for a total of 143 days between 12-17-2018 and 12-17-2023.

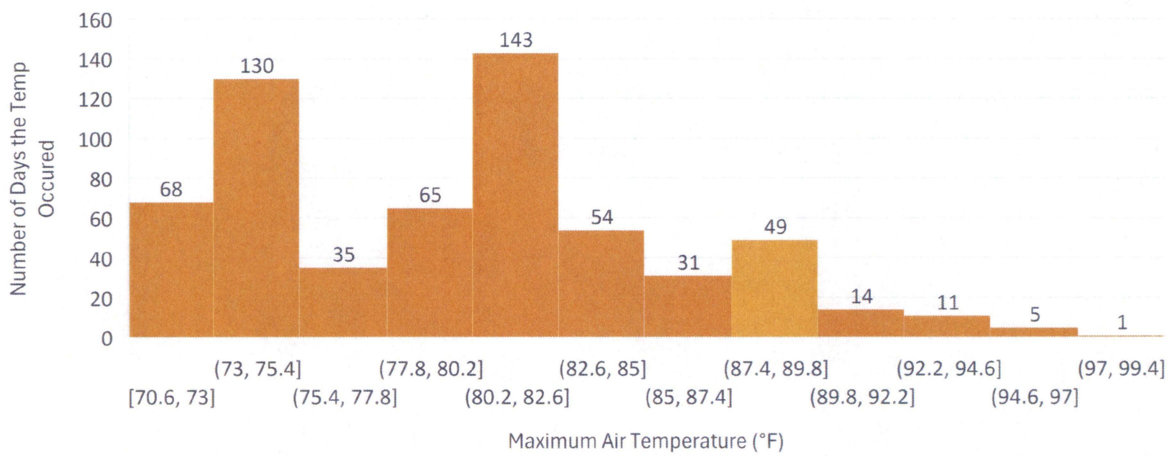

Figure 2. Number of Days Maximum Temperature Was Above 70 degrees in Fergus Falls 12-17-2018 through 12-17-2023

We chose 87.4 to 89.8 °F as the reasonable worst-case temperature. We did not choose the extreme worst-case temperatures, which occur extremely seldom (1.7% of the time). For the 49 cases where the temperature was within the chosen reasonable worst-case scenario range, we averaged the high and low of the range to come up with a single value: 88.6 °F.

In the weather dataset we used, there isn't a recorded measurement of 88.6 °F. The closest temperature was recorded in June 2019—a maximum temperature of 88.7 °F, which was associated with a relative humidity of 55.5%. We used those values as the high temperature and humidity values for this project.

Finding Final Reasonable Temperature and Humidity Values

Table 10 shows the high and low Fergus Falls temperatures and associated humidity values we used for our analysis.

[8] Days with temperatures above 70 degrees are temperatures within roughly 30 degrees of the maximum temperatures in the dataset used for this project. This range was chosen to mirror the range chosen in the previous section which looked at temperatures roughly within 30 degrees of the coldest temperature recorded.

Table 10. High and Low Temperatures with Humidity Levels Used in Our Analysis

Attribute	Minimum Value	Maximum Value
Air Temperature (°F)	-22.1	88.7
Relative Humidity (%)	74.3	55.5

These are not the extreme worst-case temperatures and humidities, because we are not trying to represent a "sky is falling" scenario. Instead, we are trying to base our analysis on a "reasonable" worst-case scenario.

To that end, we used the other model variables in Appendix A, along with the variables in Table 10, to run CANARY and determine which set of temperature and relative humidity variables create a larger area of impact from a potential release. With all other variables being equal, the lowest temperature and its associated humidity level created a larger area of impact.

Appendix C – Overview of Available Aerial Dispersion Software

Aerial dispersion modeling plays a crucial role in assessing the environmental impact of and potential risks associated with the release of hazardous substances into the atmosphere. Additionally, aerial dispersion modeling is typically completed for proposed CO_2 pipeline projects as part of engineering, design, and other compliance requirements of the Pipeline and Hazardous Materials Safety Administration (PHMSA).

Various software tools have been developed to simulate and predict the dispersion patterns of pollutants. Such simulations help users conduct emergency response planning, assess risk, and comply with applicable regulations. As the demand for accurate and reliable dispersion modeling increases, it's important to continuously compare aerial dispersion modeling software packages, their functionality and limitations, and user reviews and feedback.

In this report, we provide a brief overview of the three most common, non-CFD[9] software packages—CANARY, ALOHA, and CHARM—all of which can be used to conduct aerial dispersion analyses of liquid CO_2 pipeline releases as the CO_2 rapidly decompresses to a heavier-than-air gas. Please note that CFD and non-CFD software are not designed to quantify risk or conduct risk analysis. Rather, they are tools for establishing potential impacts and limits of said impacts, which is only one element of risk analysis.

CANARY, a software tool developed by Quest, is a multi-component thermodynamics model that determines potential outcomes following a liquid CO_2 release. CANARY provides the means for a qualified user to model the development of a variety of toxic, flammable, explosive, and radiant energy releases. CANARY is used for siting buildings and planning for pipeline and rail transport of highly volatile hazardous liquids such as liquid CO_2. Use of CANARY is commonplace in the pipeline industry.

ALOHA, which stands for Areal Locations of Hazardous Atmospheres, is a software tool developed by the National Oceanic and Atmospheric Administration (NOAA) to model the dispersion of hazardous chemicals in the atmosphere. ALOHA is used for emergency response planning, risk assessment, and decision support in the event of accidental chemical releases.

CHARM, which stands for Complex Hazardous Air Release Model, is a modeling program developed and maintained by Dr. Mark Eltgroth. It calculates and predicts the dispersion and concentration of airborne vapor and particle plumes from released chemicals. CHARM also predicts the footprints of thermal radiation, overpressures, and particle deposition. CHARM is used for evaluating the impact of hazard liquid releases, designing emergency response plans, and implementing training programs.

There are many technical pros and cons related to each software package. However, in this overview, we present high-level distinctions.

Pros:

- All three software packages accurately model CO_2 aerial dispersions of volatile hazardous liquid releases – for which they were designed.

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[9] Computational fluid dynamics (CFD) is the branch of applied science that concerns the analysis of flow, turbulence, and pressure distribution of liquids and gases, and their interaction with structures. It also helps predict fluid flow, mass transfer, chemical reactions, and related phenomena.

- CANARY has a long and vetted history in the pipeline industry—so much so that some major pipeline operators have it written into their standards that they will use only CANARY when modeling aerial dispersions.
- ALOHA is free and has an extensive library of chemicals and levels of concern.
- CHARM has a "pseudo-CFD" capability to incorporate terrain in dispersion models.

Cons:

- All three software packages require special training to use them correctly (that is, an untrained individual could pick up any of the three software packages, input data, and receive what looks like a reasonable answer but it would be wrong).
- CANARY does not incorporate terrain into its dispersion modeling capabilities.
- ALOHA can only model a limited number of basic situations and requires significant amounts of personnel time to run large numbers of simulations. ALOHA also doesn't take terrain into account.
- CHARM has difficulty coupling the heavier-than-air modeling with the lighter-than-air modeling in some cases, which can affect the accuracy of the initial release for some products.

Combining these factors with our professional experience, Allied chooses to primarily use CANARY for aerial dispersion modeling. CANARY is widely used and accepted in the pipeline industry, and other software packages can be used in conjunction with CANARY to include the effects of terrain and other objects if necessary. In addition, since the applicant used CANARY to perform their aerial dispersion analysis, Allied chose to use CANARY when validating the applicant's results. Using the same software also allowed us to more easily compare the results of the applicant's analysis to our own independent analysis.