Attachment 1 to
Staff Memorandum

Dispersion Analysis

Report to the South Dakota Public Utilities Commission

Revision: 1

12/3/2024

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1 Intent

The purpose of this document is to discuss regulatory requirements regarding vapor dispersion modeling and Summit Carbon Solutions' ("Summit") approach to vapor dispersion modeling as well as terrain-aided dispersion modeling, collectively "Dispersion Analysis." Additionally, this document will provide some context around potential impacts in the event of a pipeline rupture.

The Dispersion Analysis modeled a range of pipeline rupture scenarios and the results will inform Summit's system design and development of programs and plans to mitigate effects of a potential release. Historically, pipeline ruptures are the least likely type of failure from a CO_2 pipeline[1], and PHMSA has reported that "statistics on the transportation of CO_2 in its supercritical form has been safer relative to other hazardous liquids/gases; releases have been rare, and releases have rarely impacted people or the environment" (Daughtery, 2023). Notably, the Dispersion Analysis's focus on pipeline rupture scenarios is a conscious, conservative decision, as they are historically the least likely release type but have the largest potential impact.

1.1 Regulatory Requirements

Federal pipeline safety regulations are administered and enforced by the U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration (PHMSA). The regulations are contained within Title 49 of the Code of Federal Regulations, Part 195 (49 CFR 195) and specifically IM requirements described in §195.452. The Dispersion Analysis is used to improve pipeline safety, identify risk, develop emergency response plans, develop public awareness plans, inform security vulnerability assessments, and inform development of an integrity management (IM) program, which are required to comply with applicable regulations.

Summit will use the outputs of the Dispersion Analysis to inform its ongoing process of identifying pipeline segments that directly or indirectly could affect High Consequence Areas[2] (HCAs) pursuant to §195.452(a) and §195 Appendix C. The Dispersion Analysis demonstrates that approximately 1.8% of Summit's pipeline route in South Dakota is comprised of segments that may be characterized as High Consequence Direct Affect[3] while, conservatively, 6.2% of the segments may be characterized as Could Affect[4] Areas. Segments of the pipeline in close proximity to HCAs, including population areas and environmentally sensitive locations, will be subject to a variety of risk reduction measures called "preventative and mitigative measures" under §195.452(i), which are designed to reduce the likelihood and consequences of a release.

The data related to atmospheric dispersion and terrain-aided modeling have significant importance as inputs for Summit's continuous obligation to meet regulatory requirements for developing and periodically revising the risk assessment, which is applied to different components of the IM

[1] According to the U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration (PHMSA), two (2) CO_2 pipeline ruptures were reported between 2010 and 2024 and neither resulted in an injury, fatality, impact on wildlife, or water contamination. The lone injury reported in the past 20 years (PHMSA, 2024) involved a pipeline contractor and was avoidable.
[2] High consequence area means:
A commercially navigable waterway, which means a waterway where a substantial likelihood of commercial navigation exists;
A high population area, which means an urbanized area, as defined and delineated by the Census Bureau, that contains 50,000 or more people and has a population density of at least 1,000 people per square mile;
An other populated area, which means a place, as defined and delineated by the Census Bureau, that contains a concentrated population, such as an incorporated or unincorporated city, town, village, or other designed residential or commercial area;
An unusually sensitive area, as defined in 49 CFR 195.6
[3] Direct Affect – The pipeline is physically located within the bounds of an HCA.
[4] Could Affect – A "could affect" area is where the pipeline is located outside of the bounds of an HCA but could impact the HCA through a pipeline release by means of thermal, vapor dispersion, or other chemical processes.

regulations detailed in sections 195.452(g), 195.452(i), and 195.452(j). Finally, Summit will use the results of its modeling efforts to inform emergency response and public awareness activities consistent with Summit's approach and commitment to safety, and further in ways at least as robust as required by §195.402(e), §195.403 and §195.440.

2 Vapor Dispersion Modeling

2.1 Modeling Selection

The vapor dispersion modeling was carried out by an independent, third-party expert consultant, Audubon Field Solutions (Audubon). Audubon was tasked with identifying, evaluating, and determining the appropriate models for credibly evaluating the potential movement of CO_2 through the air – vapor dispersion – in the event of a variety of release scenarios. The following modeling programs were considered:

- Phoenics
- PHAST
- CFD
- CANARY

When selecting the most effective dispersion modeling software, an operator must, among other things, carefully assess the characteristics of the hypothetical release(s) to be modeled. For example, a supercritical (dense phase) CO_2 release is characterized as a high-velocity jet release, so the preferred modeling program must possess the capability to effectively simulate the high-velocity jet release itself, the intricate thermodynamics, mixture behavior, transient release rates, gas cloud density relative to air, initial velocity of the released gas, and heat transfer effects from the surrounding atmosphere and the substrate. These crucial aspects led to selecting CANARY as the preferred vapor dispersion modeling program for Summit's pipeline system.

While there are alternative modeling solutions available, CANARY stands out due to its adeptness in handling high-velocity jet releases, along with its proficiency in capturing the complexities of mixing and turbulence. CANARY is commonly used for many process safety applications in the pipeline and facility space. CANARY has a wide range of applications; the software package is flexible and intuitive such that it can be applied to almost any consequence analysis. This flexibility enables modeling for releases from various sources.

The CANARY model's momentum jet dispersion approach underwent validation through a comparison of its outcomes with experimental findings from field-scale tests. The data utilized for this validation, along with the model's operating conditions, were sourced from a study conducted by the American Petroleum Institute (API). Comparisons were made with the field dispersion tests performed by Quest Consultants, the software owner of CANARY (Hanna, 1991). The CANARY model's heavy gas dispersion approach also underwent validation through a comparison of its outcomes with experimental findings from field-scale tests (Hanna, 1991).

A study prepared for the federal Minerals Management Service (MMS) reviewed modeling software for routine and accidental releases of flammable and toxic gases. CANARY received the highest possible ranking in the science and credibility areas leading MMS to recommend the use of CANARY for evaluating dispersion (Chang et al., 1998).

2.2 Methodology

CANARY integrates multicomponent thermodynamics into time-varying fluid release simulations. These simulations encompass two-phase flow, flash vaporization, aerosol creation, and liquid rainout. The vaporization process from liquid pools considers factors like pool expansion, heat transfer influences, and containment. The outcomes produced by these models constitute the source terms for the hazard assessment models.

2.3 Inputs

The CANARY dispersion modeling, like any modeling, requires identification and selection of appropriate model inputs to produce credible results. Summit sources model inputs from geospatial information systems, system design documentation, pipeline industry expert feedback, and historical weather data to create a dispersion input database. The dispersion input database is subsequently fed into the CANARY dispersion modeling software and run on an individual case basis. Upon completion of the modeling process, both a PDF report and an ESRI Shapefile are generated. These records then become inputs for the other ongoing analyses and work at Summit, which include HCA analyses[5], IM plan development, and Risk Assessment[6].

To provide context around the potential impacts in the event of a pipeline rupture, Summit modeled two different vapor dispersion scenarios in CANARY. The inputs for these scenarios are outlined in **Table 1: Inputs**, while discussion on the specifics for each input follows. While both scenarios are very unlikely to occur, they would be classified as a pipeline rupture. The major difference between the two scenarios is the release type and the results demonstrate how the specific release characteristics can drastically impact vapor dispersion distances.

[5] HP24-001 Appendix 10 – High Consequence Area Mainline Valves (Confidential)
[6] Risk Assessment – Report to the South Dakota Public Utilities Commission, filed with Alexander Lange's pre-filed direct testimony.

2.3.1 Summary Table

Table 1: Inputs

Release Type	Full-bore Rupture	Mechanical Puncture
Composition (CO_2 %)	100	100
Wind Speed (mph)	11	11
Wind Speed Measurement Height (ft)	32.8	32.8
Wind Stability Class	E	E
Relative Humidity (%)	69	69
Air Temperature (°F)	47	47
Surrounding Surface Roughness (in)	.04	.04
CO_2 Pressure (psia)	Seg. Specific	Seg. Specific
CO_2 Temperature (°F)	Seg. Specific	Seg. Specific
Release Duration (min)	60	60
Rupture Release Point (ft)	0	0
Angle of Release (degrees)	19	67.5
Dispersion Coefficient Averaging Time (min)	1	1
Impoundment?	No	No
Max Flow Rate (lbs/sec)	Seg. Specific	Seg. Specific
Pipe Diameter (in)	Seg. Specific	Seg. Specific
Rupture Diameter (in)	Full-bore	Seg. specific
Valve Segment Length (mi)	Seg. Specific	Seg. Specific
Valve Closure Time (min)	10	10
Rupture Placement Along the Valve Segment	Seg. Specific	Seg. Specific

2.3.2 Release Type

Two release types were modeled: a full-bore rupture and a mechanical puncture. The full-bore rupture represents the worst-case release scenario, simulating a complete break in the pipeline. Understanding this type of release scenario is critical for training first responders and ensuring compliance with federal safety regulations, as it generates the largest potential plume and highlights the most severe consequences of a pipeline failure. In contrast, the mechanical puncture scenario reflects a more likely (although still rare) release scenario, with a localized failure that first responders are more likely to encounter in real-world situations. This scenario provides valuable insights into the dynamics of smaller-scale releases and supports targeted response planning and mitigation strategies.

2.3.3 Composition

The precise composition of the CO_2 will be in compliance with purity specifications, generally greater than 98% CO_2, with the other trace components comprising of mostly oxygen and nitrogen. The composition was modeled as 100% CO_2, which will provide slightly more conservative release results.

2.3.4 Wind Speed

Wind speed plays a crucial role in determining the potential spread of CO_2. Average wind speeds specific to South Dakota were utilized:

Table 2: Average State Wind Speeds

State	Wind Speed (mph)
South Dakota	11

2.3.5 Wind Speed Measurement Height

The wind speed height measurement was maintained at the default value for consistency across scenarios. This input influences the wind's interaction with the release. In high-concentration CO_2 releases, the plume tends to travel farther under low wind or calm conditions due to reduced dilution and mixing. Conversely, lowering the wind speed height increases turbulence and promotes mixing, leading to smaller and more dispersed plumes. Maintaining the default wind speed height ensures that the modeled scenarios capture realistic conditions while allowing for direct comparisons of plume behavior under different environmental assumptions.

2.3.6 Wind Stability Class

When CO_2 is released, it naturally disperses into the atmosphere. The extent of this dispersion largely depends on present conditions of atmospheric stability, which is in turn influenced by the amount of natural mixing (turbulence).

CANARY accounts for the effects of turbulence and mixing through the use of the Pasquill atmospheric stability classes (Pasquill, 1961). There are six stability classes, labeled A through F (Table 3, below). Class A represents the most unstable conditions, characterized by clear skies, moderate wind, strong solar radiation, and occurring during the daytime. Under Class A conditions, CO_2 released into the atmosphere would dissipate quickly due to high turbulence, resulting in a shorter downwind distance. Conversely, Class F represents the most stable conditions, typically occurring at night with limited cloud cover, limited solar radiation, and low wind. In these conditions, CO_2 would potentially travel further because the atmosphere is calm and stable, leading to less dissipation and longer potential transport distances with higher CO_2 concentration levels.

Table 3: Pasquill Class Definitions

Pasquill Class	Stability	Turbulence Potential
A	Extremely unstable conditions	HIGH
B	Moderately unstable conditions	
C	Slightly unstable conditions	
D	Neutral conditions	
E	Slightly stable conditions	
F	Moderately stable conditions	LOW

As the Table depicts, stability class has a noticeable influence on turbulence potential and therefore the extent of a vapor cloud in a supercritical CO_2 release. In more unstable conditions, the maximum extent of CO_2 exposure is diminished. Audubon ran comparable cases to further explore how to most effectively run the model with this potential effect. Audubon was able to correlate that the increase in turbulence and mixing decreases both the width and maximum extent distance of a CO_2 vapor cloud, based on comparable case analyses. Based on the selected wind speed and other ambient conditions discussed within this report, Stability class E was utilized.

2.3.7 Relative Humidity & Air Temperature

The modeling for both scenarios used historical weather data that was sourced from publicly available geospatial weather data sets. The data used for this portion of the study was gathered from the National Weather Service, National Oceanic and Atmospheric Administration, US Department of Agriculture (USDA) ground temperature probes, or other publicly available data sets. Annual averages for air temperature and humidity were reviewed and cases were modeled based on this data. These inputs are included in Table 1.

2.3.8 Surrounding Surface Roughness

The modeling for both scenarios utilized a preset long grass or crops input, with an associated surface roughness of 0.04 meters. Long grass or crops represents the most applicable terrain setting based on the pipeline route in South Dakota.

2.3.9 CO_2 Pressure and Temperature

In order to calculate the pressures and temperatures utilized in the scenarios, a number of assumptions were made in the hydraulic model:

- All plants on the base system were running at their design (max) rate;
- Ethanol plant discharge temperatures were set to 94°F; and
- Soil temperatures were determined by taking the average soil temperature at a depth of 40” over the last 6 years from the USDA website. Each segment was assigned a soil temperature in accordance with the closest weather station.

Current system hydraulics indicate that operating pressures will ranges from 1,300 - 2,160 psig based on the specific location along the pipeline system. Once the anticipated pressures and temperatures for each segment were calculated, each segment’s midpoint pressure and temperature were utilized. For segments that span across pump stations, the highest midpoint pressure of the multiple segments was utilized.

2.3.10 Release Duration

Although the valves isolating a damaged pipeline segment would be closed in a matter of minutes, if not seconds. The release duration was set to the standard value of one hour, as this timeframe typically allows for a complete drain-down scenario to occur in a CO_2 asset. This duration ensures that the modeling captures the full extent of the release, including the transition from the initial rapid discharge phase to the steady-state or depletion phase.

2.3.11 Rupture Release Point and Angle of Release

In both the full-bore rupture and mechanical puncture scenarios, the model assumed the pipeline was positioned at ground level, serving as the release point. This added a level of conservatism noting that PHMSA standards require a minimum depth of cover of 3 feet, and Summit's pipe will have a minimum depth of cover of 4 feet. During a large rupture, a crater would form due to the release force and the crater would act to propel the released product upwards into the air, aiding in the dispersion of CO_2. This would shorten the distance and concentration of the release, as some of the CO_2 would continue in an upward path above human breathing height. By modeling the release at ground level, a more conservative plume distance is observed, ensuring a higher safety margin in the assessment.

In order to be conservative, modeling of a pipeline at ground level and a release angle of 19 degrees were selected based on the findings of the sensitivity study conducted by the Health and Safety Executive (HSE, 2009). This study demonstrated that a release angle of 19 degrees resulted in the largest range of vapor dispersion and is the critical angle for assessing maximum potential impact. This decision ensures comprehensive safety measures by considering risk associated with conservative dispersion outcomes.

The Mechanical Puncture scenario, with a release angle of 67.5 degrees, is appropriate for modeling a topside puncture of the pipeline. The release angle was determined by the reach and angle of a descending excavator bucket that's removing soil in close proximity to the pipeline.

Table 4: Angle of Release

Attribute	Full-Bore Rupture	Mechanical Puncture
Angle of Release (degrees)	19	67.5

2.3.12 Dispersion Coefficient Averaging Time

The dispersion coefficient averaging time is a parameter that should align with the exposure duration relevant to the specified endpoints of the scenario. For the CO_2 release under consideration, the dispersion process is assumed to occur nearly instantaneously due to the rapid expansion and mixing dynamics of the gas upon release. Therefore, selecting a default averaging time of one minute is satisfactory for these scenarios. This timeframe captures the initial and most significant dispersion behavior, providing a realistic representation of exposure conditions during the critical early phase of the release. This approach ensures consistency in modeling and reflects the transient nature of CO_2 dispersion in open-air environments.

2.3.13 Impoundment

The impoundment input for both scenarios was modeled under the assumption of being unconfined. This means that each scenario was considered to occur in an open-air environment without any physical or structural confinement. This assumption is important as it can directly impact the flow dynamics, dispersion patterns, and potential interactions with environmental factors such as wind or precipitation. By excluding confinement constraints, the results provide a more generalized and versatile understanding of the behavior of the impoundment under natural, unrestricted conditions.

2.3.14 Max Flow Rate

Current system volumes were utilized for both scenarios and are segment specific.

2.3.15 Pipe Diameter

Current system pipeline diameters were utilized for both scenarios and are segment specific.

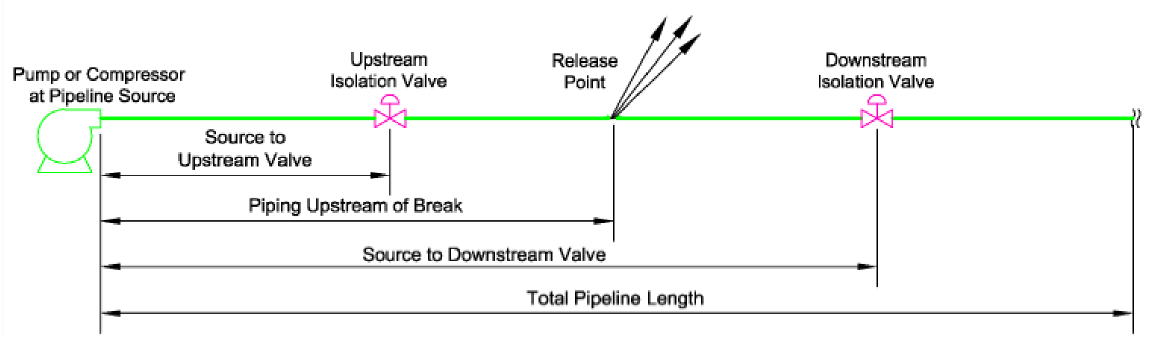
2.3.16 Rupture Diameter

The rupture diameter defines the size of the outlet through which CO_2 is released in each scenario, directly influencing the release rate and subsequent dispersion dynamics. For a full-bore rupture, the scenario assumes a complete break in the pipeline, with the rupture diameter equal to the pipeline's inner diameter. This represents the maximum possible release flow rate, simulating a worst-case failure type. In contrast, a mechanical puncture scenario involves smaller rupture diameters, representing partial strength loss in the pipeline due to localized damage.

2.3.17 Valve Segment Length, Valve Closure Time, and Rupture Placement Along the Valve Segment

Valves were located both upstream and downstream of the release point in all CANARY scenarios. For each valve, a shutdown time and the location relative to the source are specified. Shutdown times are measured from the beginning of the loss of containment to the time the valve fully closes and typically include the time it takes to: detect the leak, decide to close the valve (human or logic), travel to valve (human or signal), and close the valve. Figure 1 demonstrates the configuration of these valves in relation to the source. In general, this input set in CANARY allows for greater accuracy in capturing the correct volume available for release after valve closure. Response time was conservatively set to 10 minutes, even though actuated valves can be closed between 14 and 118 seconds depending on valve size. Historical valve closure times were less than 5 minutes approximately 50% of the time and less than 8 minutes 75% of the time (ORNL, 2012). For each scenario, the rupture placement was chosen to be equidistant between the two valves. This midpoint positioning provides a representative assessment of release behavior within the segment.

Figure 1 Pipeline Isolation Valve Inputs



2.3.18 Weather Data – Rain

Although CANARY cannot model dispersion in rain conditions, rain is not anticipated to have a major impact on CO_2 dispersion. Precipitation has the potential to strip CO_2 from the air through dissolution, although in very small quantities. The rain would only have seconds of interaction and dissolution into raindrops would likely be limited. Puddles that form may initially have a slightly lower pH, but would off gas to atmosphere, interact with soils or organic matter on the surface, and dilute with additional rain, returning the pH quickly to normal levels.

2.3.19 Weather Data – Atmospheric Inversions

Atmospheric inversions can occur at various altitudes depending on the specific atmospheric conditions and geographic location. Inversions can occur close to Earth's surface, typically within a few hundred feet, but can also occur at higher altitudes, extending several thousand feet into the atmosphere.

Near the surface, inversions are often associated with cool, calm, and clear nights, where the ground loses heat rapidly through radiation. This causes the air near the surface to cool more quickly than the air above it. Thus, forming a stable layer of air near the surface and trapping pollutants beneath it.

CANARY does not directly model atmospheric inversions, but other, similar conditions can be used as a proxy. In this instance, atmospheric conditions near the surface during an atmospheric inversion can be represented by Pasquill-Gifford stability class F combined with a low wind speed. Beyond these near surface conditions, atmospheric inversions are not anticipated to significantly impact CO_2 dispersion as they will occur at higher altitudes than what is typically considered in CANARY dispersion modeling due to the density of CO_2.

2.4 Outputs

2.4.1 CO_2 Concentration Endpoints

CANARY allows the user to specify three concentrations at which to model the dispersion distances. The three concentrations selected by Summit were 15,000ppm, 40,000ppm, and 80,000ppm. CO_2 is a non-flammable, colorless, and odorless gas that naturally occurs in the atmosphere in concentrations of 0.03% (300ppm) to 0.06% (600ppm). As set out below, the endpoint concentration is a model selection establishing the concentration level at which the dispersion distance is calculated. At low concentrations, CO_2 has no impact to humans or the environment, so modeling is focused on determining the concentration levels that may have impacts, which produces meaningful model results.

The 15,000ppm concentration represents the lowest concentration in which an individual may experience minor adverse effects but is generally not a health-based value.
The 40,000ppm concentration endpoint is based on the NIOSH designation of Immediately Dangerous to Life or Health (IDLH), which reflects acute inhalation toxicity findings (NIOSH, 1994). In other words, the 40,000ppm is the air concentration at or below which healthy workers may be exposed for 30 minutes without risk of permanent harm to health or ability to escape.

Although more recent studies suggest this value is conservative as the IDLH level, Summit chose to model one of the concentration endpoints at the IDLH level as it is an industry recognized concentration. This concentration also corresponds with a U.S. Department of Energy protective action criteria level 2 (PAC-2), which is the maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action (DOE/SCAPA, 2018).

According to a recent study—the van der Schrier study, healthy young men tolerated 75,000ppm for a full hour with no serious health effects and even 90,000ppm for a shorter duration. Summit selected 80,000ppm as a suitable upper limit for dispersion to represent a short-term emergency exposure level while also accounting for a populations' sensitive individuals.

When released in large quantities, such as in the case of a pipeline rupture, CO_2 can physically displace other components of ambient air and reduce the amount of available oxygen. Normal oxygen concentration is 20.9% of ambient air, with the balance consisting primarily of nitrogen, water vapor, trace gases, and other gases and particulates present due to local geography and ambient air quality. Oxygen concentrations needed for normal body function are at least 19.5% of inhaled air. As oxygen falls below 19.5%, physiological compensation results in higher breathing rates and higher cardiac output through increased heart rate. However, as oxygen levels drop further, decreased physical coordination and impaired mental acuity increase and the potential for more significant impacts increases. The approximate oxygen content in air as a function of CO_2 levels may be calculated by multiplying 0.209 by (1 minus the fraction of CO_2 atmosphere). The table below indicates atmospheric oxygen concentrations based on the corresponding CO_2 concentration:

CO_2 Concentration (ppm)	Oxygen Concentration (%)
15,000	20.59
40,000	20.06
80,000	19.23

2.4.2 Output Table

CANARY provides a number of outputs for each model including release rate over time. This data is important because the release rate of CO_2 in the event of a pipeline failure changes over time and directly corresponds to the dispersion distances. Since a pipeline failure is a dynamic event, the modeled distance a plume can travel at a specified concentration changes over time. CANARY also provides the worst-case distance, based on the model inputs, at the specified concentrations. In other words, the table below illustrates the projected downwind distance (the furthest) a certain concentration could reach for only a brief moment in time. Prior to this moment, it takes time for the plume to build in size and potentially move with the wind. As the pipeline failure continues, the release rate and associated pressure rapidly decrease, causing the plume to recede.

Case Name	Pipe Size (in)	Release Type	15,000 ppm Dispersion Distance (ft)	40,000 ppm Dispersion Distance (ft)	80,000 ppm Dispersion Distance (ft)
IAL - 510	6.625	Mechanical Puncture	90	40	22
IAL - 510	6.625	Full-Bore Rupture	206	111	70
NDM - 106	24.00	Mechanical Puncture	434	244	143
NDM - 106	24.00	Full-Bore Rupture	2,769	1,729	1,059
NDT - 211	12.75	Mechanical Puncture	235	126	71
NDT - 211	12.75	Full-Bore Rupture	1,308	694	247

SDL - 320	6.625	Mechanical Puncture	164	83	47
SDL - 320	6.625	Full-Bore Rupture	574	170	120
SDL - 335	6.625	Mechanical Puncture	120	54	29
SDL - 335	6.625	Full-Bore Rupture	287	160	101
SDL - 513	6.625	Mechanical Puncture	173	89	50
SDL - 513	6.625	Full-Bore Rupture	619	180	127
SDL - 514	6.625	Mechanical Puncture	175	91	51
SDL - 514	6.625	Full-Bore Rupture	646	183	129
SDL - 515	6.625	Mechanical Puncture	177	92	52
SDL - 515	6.625	Full-Bore Rupture	641	181	128
SDM - 104B	24.00	Mechanical Puncture	447	250	146
SDM - 104B	24.00	Full-Bore Rupture	2,673	1,679	1,027
SDM - 105A	24.00	Mechanical Puncture	408	227	131
SDM - 105A	24.00	Full-Bore Rupture	2,628	1,614	916
SDM - 105B	24.00	Mechanical Puncture	443	251	150
SDM - 105B	24.00	Full-Bore Rupture	2,757	1,732	1,123
SDT - 206	6.625	Mechanical Puncture	163	81	45
SDT - 206	6.625	Full-Bore Rupture	545	171	118.7
SDT - 207	6.625	Mechanical Puncture	169	87	49
SDT - 207	6.625	Full-Bore Rupture	590	172	121
SDT - 208	8.625	Mechanical Puncture	189	98	55
SDT- 208	8.625	Full-Bore Rupture	881	237	169.9
SDT- 209	6.625	Mechanical Puncture	163	81	46
SDT- 209	6.625	Full-Bore Rupture	565	176	122
SDT- 210	6.625	Mechanical Puncture	174	89	50
SDT- 210	6.625	Full-Bore Rupture	635	186	130
SDT- 212	6.625	Mechanical Puncture	167	83	46
SDT- 212	6.625	Full-Bore Rupture	559	174	121
SDT- 409	6.625	Mechanical Puncture	167	80.9	45
SDT- 409	6.625	Full-Bore Rupture	518	180	123
SDT- 410	8.625	Mechanical Puncture	196	103	58
SDT- 410	8.625	Full-Bore Rupture	890	235	169
SDT- 411	6.625	Mechanical Puncture	174	88	49
SDT- 411	6.625	Full-Bore Rupture	619	183	128

3 Terrain Aided Modeling

3.1 Modeling Selection

Vapor dispersion modeling is useful in performing HCA analysis for CO_2 pipelines, but it is also important to model the supercritical (dense phase) CO_2 release as a pooling spill component to consider the effects of terrain. Summit determined it was appropriate to supplement the CANARY model with an overland spread flow model to assist in determining additional dispersion distance and whether or not a heavy vapor plume could impact an HCA. Overland spread models provide a prudent and accessible alternative to a full Computational Fluid Dynamics (CFD) model. Although CFD modeling holds value, it isn't appropriate for an iterative study of surface-based spreading conducted along a pipeline route due to the following:

- CFD models are commonly utilized on processing “inside the fence” projects where the scenarios to be analyzed are limited. Accurately modeling releases along a pipeline corridor necessitates considering a significantly greater number of cases.
- CFD modeling demands an extensive dataset, typically not available at incremental points along a pipeline corridor.
- CFD modeling requires a large amount of computational power, resulting in timelines and resource consumption that is not commensurate with any resulting benefits from a risk and safety perspective.

Summit requested that Audubon help to identify and utilize the appropriate overland spread flow model(s). Audubon considered overland spread models referenced below and made considerations for each model’s applicability as alternatives to CFD.

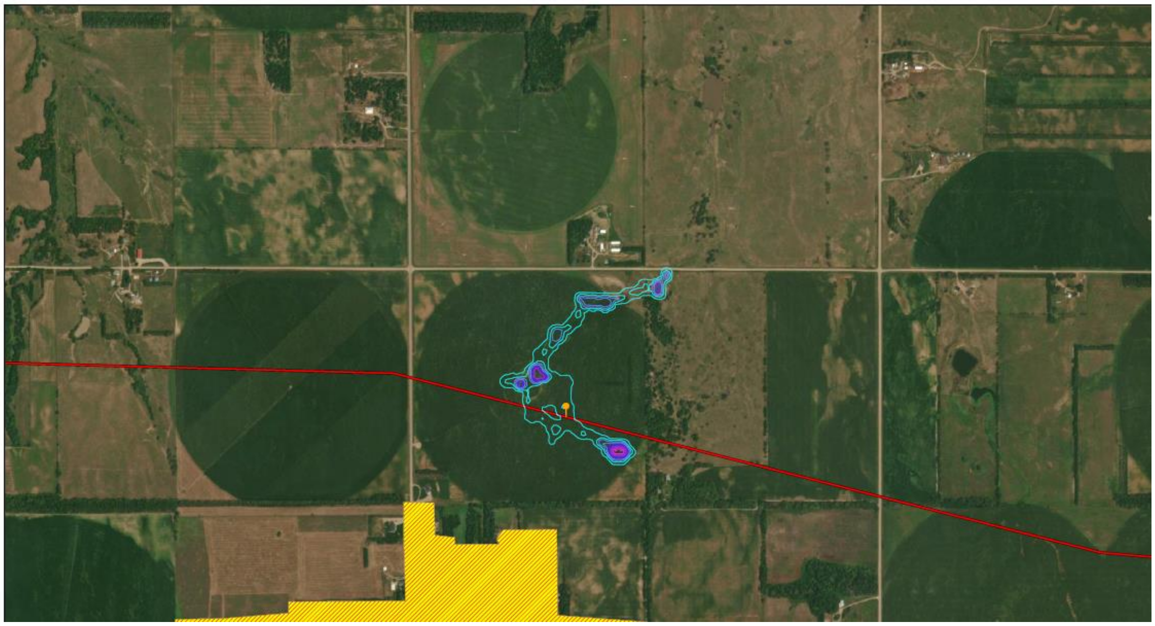
- Entrust Liquids Spill Analysis Tool
- Integrity Solutions Spill Impact Analysis Tool
- FLO-2D Overland Spread Model

Entrust’s and Integrity Solutions’s tools, both of which are commercial liquid spill modeling tools, were found to be not suitable for modeling CO_2 vapor. The resultant overland spread polygons would have utilized the physics of a crude oil release based on oil spill mechanics. This would have limited the spread of the model substantially. With FLO-2D, Audubon was able to model out the entirety of the downhill terrain polygons without the restrictions stemming from product mechanics. For this reason, FLO-2D was identified as having the most conservative overland flow mechanics. Additionally, FLO-2D has the capability to accept inputs available from existing studies, enhancing overall results. The pipeline mapping data, volume results from CANARY cases, and digital elevation model (DEM) data were all imported into FLO-2D easily in a QGIS (open-source GIS) environment.

3.2 Methodology

Audubon utilized the pipeline centerlines and digital elevation model to identify critical valleys along the pipeline right of way, as the presence of valleys has the potential to impact the dispersion modeling. This work was informed by considerable experience and expertise, PHMSA guidance and learnings from prior releases. This elevation analysis was performed in FLO-2D as a surface study in three dimensions. It is important to note that in vapor dispersion modeling performed by Audubon, no heavy vapor components were present in the releases. Audubon had to adjust the conditions (e.g., temperature and pressure) dramatically to get a heavy vapor component to appear. Even using conservative assumptions, heavy vapor comprised a very small part of the total release volume. Audubon then increased the percentage of heavy vapor in the total release so that Summit could generate a heavy vapor release that was visible in a mapping deliverable. These release percentages added to the significant level of conservatism built into the terrain-aided flow model.

Figure 2: Overland Transport Example



Summit has used this specialized terrain-aided modeling to supplement the CANARY analysis, which has facilitated a thorough assessment of the potential impacts of a release, including on HCAs.

3.3 Inputs

Outputs from Canary were incorporated into FLO-2D's parameters to ensure the flow model accurately modeled each applicable scenario. Audubon created a buffer of two (2) miles for all CO_2 assets that extended far beyond the previously modeled vapor dispersions. The buffers had to be very conservative to interact with the target-populated regions (High Population Areas (HPAs) and Other Population Areas (OPAs)). ArcMap was utilized to identify and map possible gravity flow pathways between the pipeline corridor and high consequence areas. This analysis provided linear features showing where the CO_2 could travel in a release based on site specific topography. Gravity flow pathways that could impact HCAs were then analyzed further in FLO-2D to map out the valleys that could carry the heavy vapor CO_2 to an HCA, see Figure 3.2.1. These valley sites were considered "critical valleys". Critical valleys were defined as any valley that could transport heavy vapor CO_2 to a populated area (HPAs and OPAs). At each critical valley site, the volume of the heavy vapor CO_2 component was then modeled with the modeling platform FLO-2D to create polygons of the release in reference to the digital elevation model. These overland spread polygons were then overlaid on the populated area mapping to determine if any intersected the OPA or HPA boundaries.

3.4 Outputs

The utilization of both vapor dispersion modeling and terrain-aided modeling facilitated the generation of more comprehensive outcomes. Both methodologies used collectively identify risk, improve pipeline safety, and inform development of Summit's integrity management program. Terrain-aided modeling was not found to impact any locations not already taken into consideration when using vapor dispersion modeling, for this reason vapor dispersion modeling was used as the source when reviewing the potentially impacts to HCAs.

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