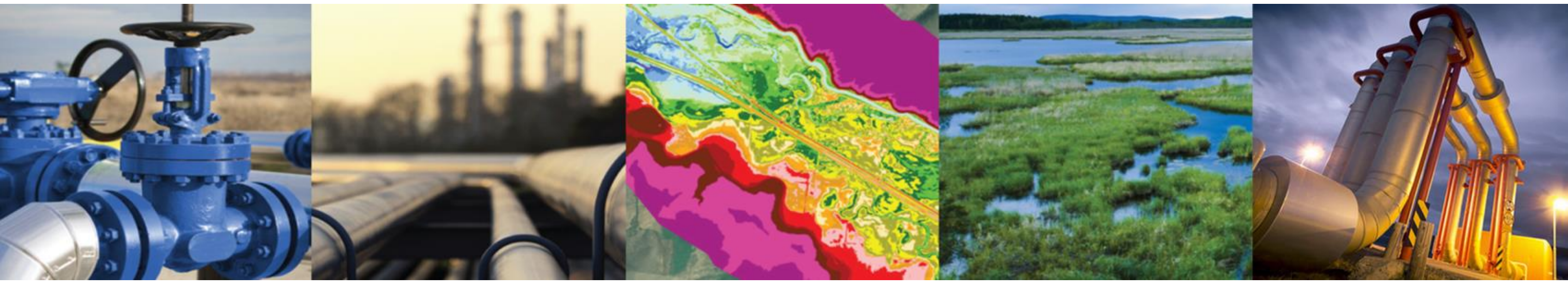


Mariner East 2 Pipeline and Existing Adelphia Pipeline Risk Assessments

Submitted on: November 13, 2018
Submitted to: Timothy A. Boyce, Director of DES, BoyceT@co.delaware.opa.us
Submitted by: Courtney R. Phillips, Courtney.Phillips@g2-is.com
Tracking codes: 113097

Version	Date	Author	Checked by	Approved by	Summary
1.1	11/02/2018	R. Mancik	C. Phillips	J. F. Kill	Issue for Client Review
2.1	11/13/2018	R. Mancik	C. Phillips	J. F. Kill	Final Issue

About G2-IS

G2 Integrated Solutions (G2-IS) delivers expertise to pipeline operators, utility companies, and other energy stakeholders in seven specialized service disciplines:

- Asset Integrity
- Engineering
- Regulatory and Strategic Consulting
- Geospatial
- Field Assurance
- Programmatic Management Solutions
- Software & Technology

We provide asset life cycle solutions that help manage risk, assure compliance, and optimize performance. G2-IS is committed to maintaining a safe and incident-free working environment for our people and our customers, and to sound environmental stewardship. We work within controlled management systems that achieve continual improvement and assure reliable delivery of high quality products, services and outcomes.

Table of Contents

List of Figures

List of Tables

1.0 EXECUTIVE SUMMARY

Residents of Delaware County, Pennsylvania desire to better understand the risks associated with the operation of the Mariner East 2 pipeline and the converted Adelphia pipeline. In response to public discussions, this risk assessment was undertaken to estimate the level of individual risk to those people located within the County of Delaware from either the Mariner East 2 pipeline or the converted Adelphia pipeline and then compare to other common sources of risk experienced by the general population.

The Mariner East 2 pipeline and Adelphia pipeline quantitative risk assessments were executed in a systematic process in which potential accident events were identified, the associated consequence and likelihood of such events were determined, and the risk measures estimated. The risk measure calculated for each of the pipelines is individual fatality risk, which is the measure of the likelihood of an individual suffering a fatal injury, as the result of an accident event, in a period of a year.

The concluding intent of these risk assessments was to present a comparison of the Mariner East 2 pipeline and Adelphia pipeline estimated individual fatality risk levels against other individual fatality risk levels from common sources. This comparative evaluation establishes an improved perspective when interpreting the meaning of the pipeline individual fatality risks.

It was concluded that the individual fatality risk levels estimated for both the Mariner East 2 pipeline and the Adelphia pipeline fall within a range of other common risk sources such as traffic accident, house fire, or fall from stairs.

2.0 INTRODUCTION

Residents of Delaware County, Pennsylvania desire to better understand the risks associated with the operation of the Mariner East 2 pipeline and the converted Adelphia pipeline. In response to public discussions, the Delaware County Council would like to estimate the level of individual risk to those people located within the County of Delaware from either the Mariner East 2 pipeline or the converted Adelphia pipeline, and compare these risk results to other common sources of risk experienced by the general population.

The County of Delaware has contracted G2 Integrated Solutions to undertake the following two tasks:

- An independent risk assessment of the event of an accidental release located within Delaware County from the Mariner East 2 pipeline
- An independent risk assessment of the event of an accidental release located within Delaware County from the converted existing Adelphia pipeline

This document provides the results of these risk assessments.

2.1 Objectives

The specific objectives of the Mariner East 2 pipeline and Adelphia pipeline risk assessments were to:

- Calculate the individual fatality risk as a function of distance from the pipeline route and generate a risk transect
- Compare the level of individual fatality risk to other common risk sources

2.2 Scope of Work

The following sections detail the scope of work for the Mariner East 2 pipeline and Adelphia pipeline risk assessments.

The risk measure calculated for each of the pipelines is individual fatality risk ("individual risk"), which is the measure of the likelihood of an individual suffering a fatal injury, as the result of a hazardous accident event, in a period of a year. Such a risk measure is preferred because it can be compared to readily available statistics.

2.2.1 Mariner East 2 Pipeline Risk Assessment

The scope of the Mariner East 2 pipeline risk assessment is for the quantification of individual fatality risk to the Delaware County public residing and working nearby the future 20-inch natural gas liquid (NGL) transmission pipeline. The physical scope of work is an accidental release from the body of the Mariner East 2 pipeline segment located within the Delaware County boundaries.

The following items are excluded from the Mariner East 2 pipeline risk assessment scope of work:

- Associated pipeline equipment such as meters, pumps, valves, compressors, etc.
- Escalation events resulting from an initiating event from the Mariner East 2 pipeline
- Other pipelines connected to, or nearby, the Mariner East 2 pipeline
- Societal fatality risk calculation

2.2.2 Adelphia Pipeline Risk Assessment

The scope of the Adelphia pipeline risk assessment is for the quantification of individual fatality risk to the Delaware County public residing and working nearby the existing 18-inch natural gas transmission pipeline. The physical scope of work is an accidental release from the body of the existing Adelphia pipeline segment located within the Delaware County boundaries.

The following items are excluded from the existing Adelphia pipeline risk assessment scope of work:

- Associated pipeline equipment such as meters, pumps, valves, compressors, etc.
- Escalation events resulting from an initiating event from the existing Adelphia pipeline
- Other pipelines connected to, or nearby, the existing 18-inch Adelphia pipeline
- Societal fatality risk calculation

3.0 DEFINITIONS

Release Event	An accidental loss of containment from the pipeline via a pinhole, leak, or rupture.
Accident Event	A hypothetical event, such as a jet fire, flash fire, or explosion, that results from a pipeline release.
Accident Event Frequency	A measure of how often a hypothetical accident event could occur. For pipelines, the accident event frequency is measured on an annual per mile basis (i.e., per mile-year).
Accident Event Consequence	The potential harmful effect of an accident event, such as jet fire thermal radiation, flash fire, or explosion overpressure.
Atmospheric Condition	The condition of the atmosphere in terms of both Pasquill stability class (e.g., stable "F" or neutral "D") and wind speed.
Individual Fatality Risk	Individual fatality risk is the annual chance an individual will suffer a fatal level of harm due to hazards to which they are exposed.
Societal Fatality Risk	Societal fatality risk is the annual chance that a specified number of people will suffer a fatal level of harm due to hazards to which they are exposed.
Full Bore Release	A full bore release is the equivalent to a complete severing of the pipeline diameter resulting in discharge from pipe on both sides of the rupture point. The equivalent can occur by a large longitudinal rip or tear – complete severing is not required. Note that PHMSA uses the term "rupture" for full bore and any size longitudinal rip or tear, and then details the size of the longitudinal rip or tear.
Jet Fire	A directional flame resulting from the combustion of a fuel continuously released.
Flash Fire	A fire resulting in a rapidly spreading flame front; characterized by short duration and without damaging explosion overpressure.

Vapor Cloud	A region or volume containing a vaporized fuel in flammable concentrations; below a certain concentration, the cloud is not flammable.
Vapor Cloud Explosion	A vapor cloud that expands so rapidly, such as from a spreading flame front, as to result in a damaging overpressure or shockwave.

4.0 METHOD

A quantitative risk assessment is a systematic process in which hazards from an activity or operation are identified, and the consequence and likelihood of potential accidental events are estimated.

The following approach was executed for the Mariner East 2 pipeline and the Adelphia pipeline quantitative risk assessments:

1. Establish study context
2. Define the releases and accident events to be assessed
3. Determine accident event frequency
4. Determine magnitude of the harmful consequence and impact
5. Calculate individual risk results
6. Compare individual risk results to other common risk sources

5.0 STUDY CONTEXT

The descriptions and operating conditions of both the Mariner East 2 and Adelphia pipelines as assessed in this report are taken from publicly available sources. Where specific information needed for this assessment is not detailed in the publicly available sources, conservative interpretation of the available information and/or judgement is used to provide the necessary basis for the risk assessment. Such specific information may be used only indirectly in the analysis; for example: the depth of cover.

Table 1 is a summary of the Mariner East 2 pipeline information used as the basis of the risk assessment.

Table 2 is a summary of the Adelphia pipeline information used as the basis of the risk assessment.

Table 1: Mariner East 2 Pipeline Risk Assessment Basis

Item	As Assessed	Comment
Pipeline diameter	20 inches	Reference [2]
Total pipeline length	306 miles	Reference [2]
Commodity transported	Natural gas liquids	Reference [3]
Commodity composition	Propane	Assumption: Mariner East 2 pipeline to carry propane or butane, batched and not mixed [2]. The pipeline is anticipated to carry primarily propane [4]. Thus, propane is the representative single component for the Mariner East 2 risk assessment.
Operating pressure	1,480 psig	Reference [2]
Operating temperature	12.5°C (54.5°F)	Assumed to be same as the average outdoor air temperature. Average outdoor air temperature from Reference [22].
Flowrate	275,000 barrels/day (258 kg/s)	Reference [4]
Emergency flow restriction devices	2 located in Delaware County	Both automated and manual valves will be located along the pipeline route. Two emergency flow restriction devices (EFRD) will be located in Delaware County [2]. For the purposes of consequence modeling, this risk assessment will assume that the 2 EFRDs located in Delaware County will isolate a volume equivalent to 8 miles of a 20-inch pipeline within 15 minutes.
Isolated length	8 miles	Reference [2] Approximate distance between the EFRD valves located in Delaware County.

Item	As Assessed	Comment
Isolation time	15 minutes	Reference [1] Sensing devices along the pipeline send data every 15 seconds to 15 minutes.
Depth of cover	4 feet	Reference [8]
Pipeline route surroundings in Delaware County	Varies from urban to suburban. Mixed residential and commercial land use.	Google Maps, Google Earth
Atmospheric condition	D-4.5 m/s	D-4.5 m/s is the neutral atmospheric condition in this risk assessment. Atmospheric stability class “D” is the dominating atmospheric condition based on published fractions. [9]. 4.5 m/s average wind speed from Reference [22].
	F-1.5 m/s	F-1.5 m/s is the stable atmospheric condition in this risk assessment. It represents the allocation of both atmospheric classes “F” (i.e., stable) and “E” (i.e., slightly stable) and the lowest wind speed category used in Purple Book for “F” and “E” stability conditions [9]. Stable wind conditions tend to have much greater dispersion distances than average wind conditions.

Table 2: Adelphia Pipeline Risk Assessment Basis

Item	As Assessed	Comment
Pipeline diameter	18 inches	Reference [6]
Pipeline length (overall)	84 miles	Reference [6]
Commodity transported	Natural gas	Reference [6], [7]
Commodity composition	Methane	Simplification: Natural gas is primarily methane. Methane is used as the representative single component for this risk assessment.
Operating pressure	1,083 psig	Reference [6]
Operating temperature	12.5°C (54.5°F)	Reference [22]
Flowrate	250 MMSCFD (58.8 kg/s)	Reference [6]
Isolated length	N/A	While natural gas pipelines typically are equipped with emergency isolation capability, such capability does not factor into the consequence modeling approach used for this risk assessment. See Section 8.1 for details.
Isolation time	N/A	See Section 8.1 for details.
Depth of cover	4 feet	Assumption: 4 feet of cover is considered typical.
Pipeline route surroundings in Delaware County	Varies from urban to suburban. Mixed residential and commercial land use.	Google Maps, Google Earth

Item	As Assessed	Comment
Atmospheric condition	D-4.5 m/s	D-4.5 m/s is the neutral atmospheric condition in this risk assessment. Atmospheric stability class "D" is the dominating atmospheric condition based on published fractions [9]. 4.5 m/s average wind speed from Reference [22].

6.0 DEFINE RELEASE AND ACCIDENT EVENTS

This study considers the loss of containment, or unwanted releases, from the pipeline body and assesses the potential events and associated impact on individuals exposed within the potential consequence zones. This section defines the loss of containment characteristics, accident event frequencies, and potential associated consequences.

The defined characteristics of a loss of containment, or release event, include:

- Release hole-size
- Release location
- Release orientation

The following accident event frequencies, associated consequences, and impacts were considered:

- Jet fires resulting in harmful thermal radiation levels
- Flash fire resulting in harmful thermal radiation levels
- Vapor cloud explosion resulting in harmful overpressures

6.1 Release Hole-Size

Loss of containment hole-sizes can range from full bore ruptures to pinhole punctures. For this risk assessment, the following two hole-sizes were considered:

- Full bore rupture
- 50 mm equivalent hole (i.e., approximately two inches)

As specified in the "Guidelines for Quantitative Risk Assessment" (widely referred to as the "Purple Book") [9], simplifying the potential range of pipeline release hole-sizes to two (2) representative hole-sizes is sufficient for calculating risk and is consistent with pipeline release scenarios.

A full bore rupture event is when the pipeline body is completely severed (sometimes called "guillotine" break) or has a longitudinal split or crack with a large area. In such an event, the resulting discharge comes from both the portion of the pipeline upstream of the rupture point and the portion downstream of the rupture point. Such releases are characterized by a massive, but a rapidly decreasing discharge rate.

A 50 mm equivalent hole represents an event with a much smaller discharge rate. Such releases are characterized by discharge rates that do not decrease appreciably over the time periods relevant to quantitative risk assessments. Although such events might range from tiny pinhole leaks to leaks considerably larger than 50 mm, 50 mm is selected to represent the range of possible leaks.

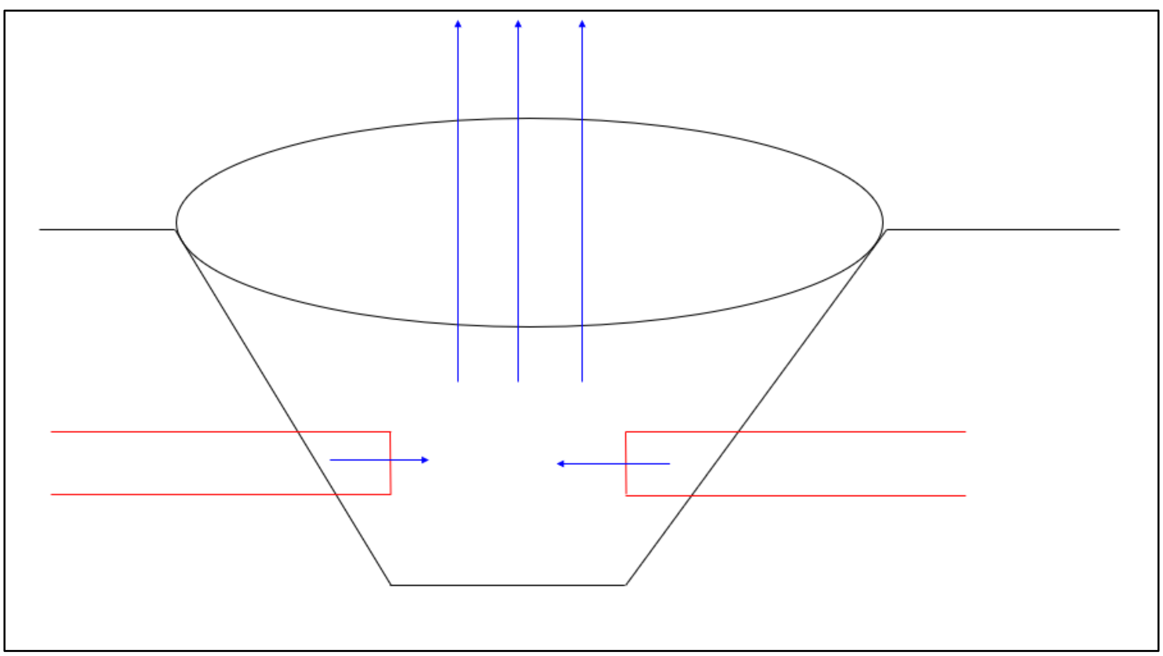
6.2 Release Location and Release Orientation

For the objectives of these risk assessments, only below-ground, shallow depth, pipeline body release locations are considered.

Given a shallow depth of cover, a gas or two-phase flashing liquid release from a buried pipeline can result in the formation of a crater at the release location. The crater has the effect of directing the resulting discharge into an upwards direction with a reduced velocity, as compared to a free jet. Such effects can greatly alter the impact of the resulting consequence at ground level.

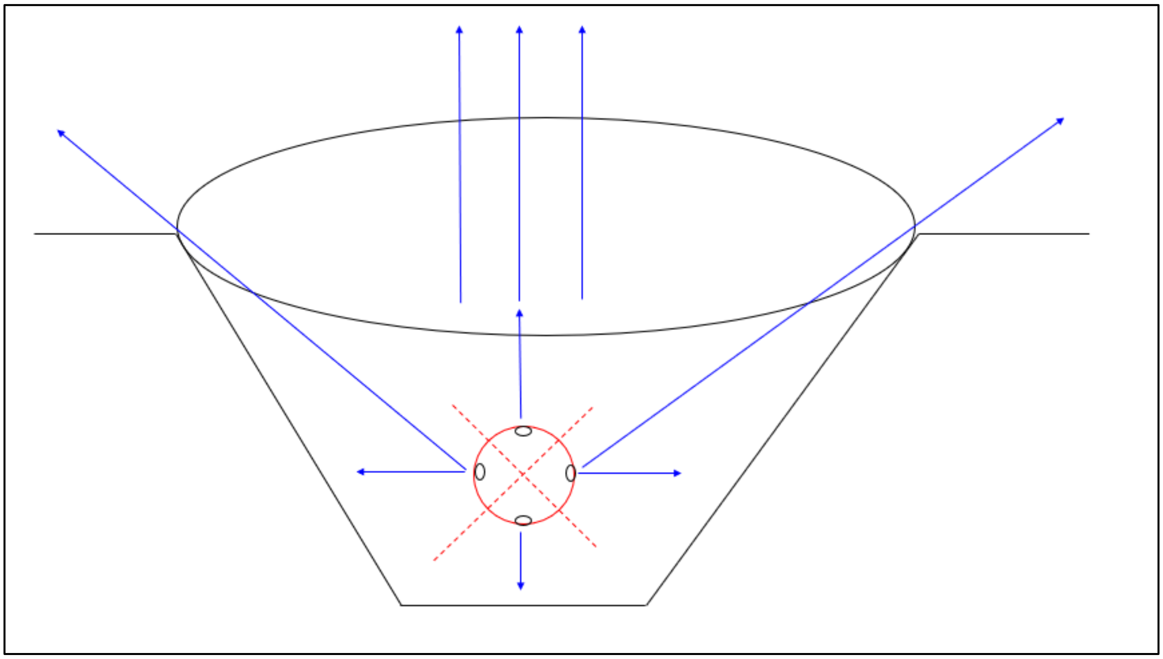
Figure 1 is a simplified diagram that illustrates the release orientation of a full bore release, with a shallow depth of cover. The discharge comes from both upstream and downstream portions of the ruptured pipeline. The two flows impinge on each other, form a crater, and exit the crater in a vertical orientation.

Figure 1: Full Bore Release Orientation



For the 50 mm hole-size, the release location can be anywhere around the pipeline body. For releases located near the top or bottom of the pipe, the release orientation will be nearly vertical as caused by the walls of the resulting crater. For releases located near the side of the pipeline body, the release orientation will be some angle closer to horizontal when exiting the crater. Figure 2 is a simplified diagram that illustrates the release orientation of a 50 mm hole-size release.

Figure 2: 50 mm Release Orientation



6.3 Accident Event Frequencies

After defining the release characteristics, the frequency of the associated potential accident events (i.e., jet fire, explosion, etc.) were determined. PHMSA historical data was used to estimate the frequency of an initiating release event for the Mariner East 2 pipeline and the Adelphia pipeline.

Event tree diagrams were then used to model and examine the potential accident event frequencies based on pathways from the initiating release event. The initiating release event starts at the left side of the tree and is followed by the occurrence, or not, of subsequent events and continues until the consequential outcome, or accident event, is reached. The frequency of each evaluated accident event is determined by multiplying the initiating release event frequency and the probabilities assigned to each of the subsequent events along the relevant pathway.

The event trees specific to the Mariner East 2 pipeline risk assessment and the Adelphia pipeline risk assessment are discussed in Section 7.0 and Section 8.0, respectively.

6.4 Accident Event Consequences

For the purposes of quantitative risk assessment, accident event consequence refers to the potential physical effects from pipeline loss of containment events. For this risk assessment, the accident event consequences relevant to the risk assessment of the Mariner East 2 and Adelphia pipelines are:

- Discharge rate
- Ignition
- Jet fire thermal radiation
- Flash fire thermal radiation
- Vapor cloud explosion overpressure

Each of these has specific meanings and relevant characteristics as applied within a quantitative risk assessment, which are described in the following sections.

The consequence modeling was performed using the DNV GL Phast software package.

6.4.1 Discharge Rate

In determining individual risk levels, the discharge rate, rather than the total quantity released, establishes the magnitude of the harmful consequence assessed. The discharge rate is based on the release hole-size and the pipeline operating parameters.

For the 50 mm release hole-size used in this risk assessment, the discharge rate is less than the normal pipeline flowrate, and is, therefore, nearly constant for over an hour, even with emergency isolation.

For a full bore rupture release, the initial discharge rate will be much greater than the normal pipeline flowrate but will decrease rapidly over time. The location of the rupture along the pipeline, the location of upstream and downstream isolation valves, and the isolation time for stopping the incoming flow may influence the discharge rate as a function of time.

The DNV GL Phast consequence modeling software was used to calculate the discharge rate over time for each of the two hole-sizes considered, based on the pipeline diameter, operating pressure, pipeline length, and isolation valve locations.

6.4.2 Ignition

A release of flammable material from a pipeline could result in the following ignition scenarios:

- Not ignite
- Ignite immediately
- Ignite after some time delay

Ignition of released flammable contents of a pipeline can potentially result in a jet fire, flash fire, or explosion.

Ignition sources for such accident events may be remote from the pipeline, in the form of open flames, electrical equipment, motorized vehicles, and other heat or spark sources. Additionally, the release event itself or electrostatic ignition sources near the release location can also be a source of ignition.

6.4.3 Jet Fire Thermal Radiation

A jet fire results from either the immediate or delayed ignition of a release of pressurized flammable gas. The resulting jet fire produces thermal radiation that can harm people directly by causing burns to people exposed over time or indirectly by starting secondary fires.

The thermal radiation level reaching a given point is largely determined by the:

- Size of the resulting flame (i.e., the larger the flame, the greater the distance to a given thermal radiation level)
- Composition of the fuel

It should be noted that the composition of the materials involved in the subject pipelines has an effect that is secondary compared to the flame size.

A jet fire from an ignited buried pipeline release will be oriented upwards as a result of the crater formed, with a near vertical flame tilting downwind. This flame tilt has the net effect of “shifting” the thermal radiation consequence zone downwind. Because the flame shift downwind is minimal, assessing the event at varying wind speeds was not warranted and, therefore, an average wind speed is used in this risk assessment for jet fire thermal radiation.

The modeling software also accounts for the effects the crater has on the momentum of the resulting jet, which can influence the thermal radiation footprint.

6.4.4 Flash Fire Thermal Radiation

If there is sufficient ignition delay to allow the release of pressurized flammable gas to disperse and form a flammable cloud, a flash fire results once the flammable cloud is ignited. Unlike a jet fire, a flash fire has a short duration but may be followed by a jet fire.

Although capable of starting secondary fires, in a quantitative risk assessment the harmful impact of a flash fire is simplified by limiting harm only to people directly exposed outdoors. The consequence zone of a flash fire is taken as equivalent to the area of the flammable cloud.

6.4.5 Vapor Cloud Explosion Overpressure

A vapor cloud explosion results in a shockwave, measured as an overpressure, that can cause harm directly to persons exposed outdoors, or indirectly to persons indoors by causing damage or collapse of buildings or structures. If the overpressure is sufficient to cause harm it is referred to as a damaging overpressure. At some low overpressure, there is insufficient energy to cause significant harm.

It should be noted that in common language usage, outside of risk assessment, the term "explosion" is often used rather loosely to describe any large ignited release of highly flammable gas or liquid. Such terminology use may make no distinction between jet fire, flash fire, or damaging vapor cloud explosion. Written material using the term outside of a quantitative risk assessment context should be interpreted accordingly.

6.5 Accident Event Impact

The accident event impact effects of the harmful accident event consequences described in Section 6.4 are needed to estimate an individual risk. For each of the consequence types, a vulnerability to an exposed person is applied. The vulnerability can be described as the fatality fraction of those persons exposed.

The vulnerability values used in this risk assessment are taken from the Purple Book [9] and are summarized in the following sections.

6.5.1 Jet Fire Thermal Radiation

For jet fire thermal radiation, the vulnerability varies with the thermal radiation level. For this risk assessment, the thermal radiation levels are divided into four ranges and an average vulnerability is applied to each range. The value of the vulnerability for each range is calculated from the radiation level and exposure time relationship published in the Purple Book [9], using a maximum of a 20-second exposure time. The 20-second maximum exposure time is also stipulated in the Purple Book [9].

Table 3 summarizes the vulnerability values applied in this risk assessment to people directly exposed (i.e., outdoors) to jet fire thermal radiation consequence.

Table 3: Jet Fire Thermal Radiation Vulnerability, Persons Outdoors

Consequence Level	Fatality Vulnerability	Basis
Greater than 35 kW/m^2	1.0	20 second exposure to unprotected skin
18 kW/m^2 to 35 kW/m^2	0.69	20 second exposure to unprotected skin
12.5 kW/m^2 to 18 kW/m^2	0.23	20 second exposure to unprotected skin
9.46 kW/m^2 to 12.5 kW/m^2	0.04	20 second exposure to unprotected skin
Less than 9.46 kW/m^2	0	20 second exposure to unprotected skin

People inside buildings are mostly shielded from direct exposure to thermal radiation. However, being present in a building does not eliminate vulnerability to thermal radiation, such as if the thermal radiation results in the building catching fire. The Purple Book stipulates an indoor vulnerability of 1.0 for jet fire thermal radiation levels greater than 35 kW/m^2 and zero for levels less than 35 kW/m^2, as summarized in Table 4 [9].

Table 4: Jet Fire Thermal Radiation Vulnerability, Persons Indoors

Consequence Level	Fatality Vulnerability	Basis
Greater than 35 kW/m^2	1.0	Assumes buildings are set on fire
Less than 35 kW/m^2	0	Below building ignition threshold

6.5.2 Flash Fire Thermal Radiation

For flash fire thermal radiation, the harmful impact is assumed not to vary by radiation level nor exposure time, because flash fires have very short durations (See Table 5). The Purple Book stipulates an outdoor vulnerability of 1.0 for persons in the flash fire flame envelope and zero for persons outside the flame envelope [9]. The Purple Book further stipulates that the flash fire flame envelope is equal to the flammable cloud footprint (the lower flammable level concentration contour) at the time of ignition [9].

Persons inside buildings are assumed to not be vulnerable to flash fire. The rationale for this simplification is not discussed in the Purple Book [9]; however, can be presumed to be related to the very short durations of flash fires. Persons inside buildings are likely able to escape after the flash fire, even if the building catches fire.

Table 5: Flash Fire Thermal Radiation Vulnerability

Consequence Level	Fatality Vulnerability	Basis
Inside LFL Cloud, Outdoors	1.0	Inside flash fire flame envelope
Inside LFL Cloud, Indoors	0	Inside flash fire flame envelope
Outside LFL Cloud, Outdoors or Indoors	0	Outside flash fire flame envelope

6.5.3 Vapor Cloud Explosion Overpressure

The Purple Book provides both indoor and outdoor vulnerabilities for vapor cloud explosion overpressure (See Table 6 and Table 7) [9]. The Purple Book [9] does not cite a specific basis or rationale for these vulnerabilities, however the Purple Book often cites the related Green Book [10]. The Green Book describes in detail the impact on humans of exposure to toxic substances, heat radiation, and overpressure [10].

Table 6: Vapor Cloud Explosion Vulnerability, Persons Outdoors

Consequence Level	Fatality Vulnerability	Basis
Overpressure greater than 4.35 psig (0.3 bar)	1.0	Not provided[1]
Overpressure less than 4.35 psig (0.3 bar)	0	Not provided[1]
[1] The Purple Book does not provide a basis for the vulnerability values provided. See Section 6.5.3.		

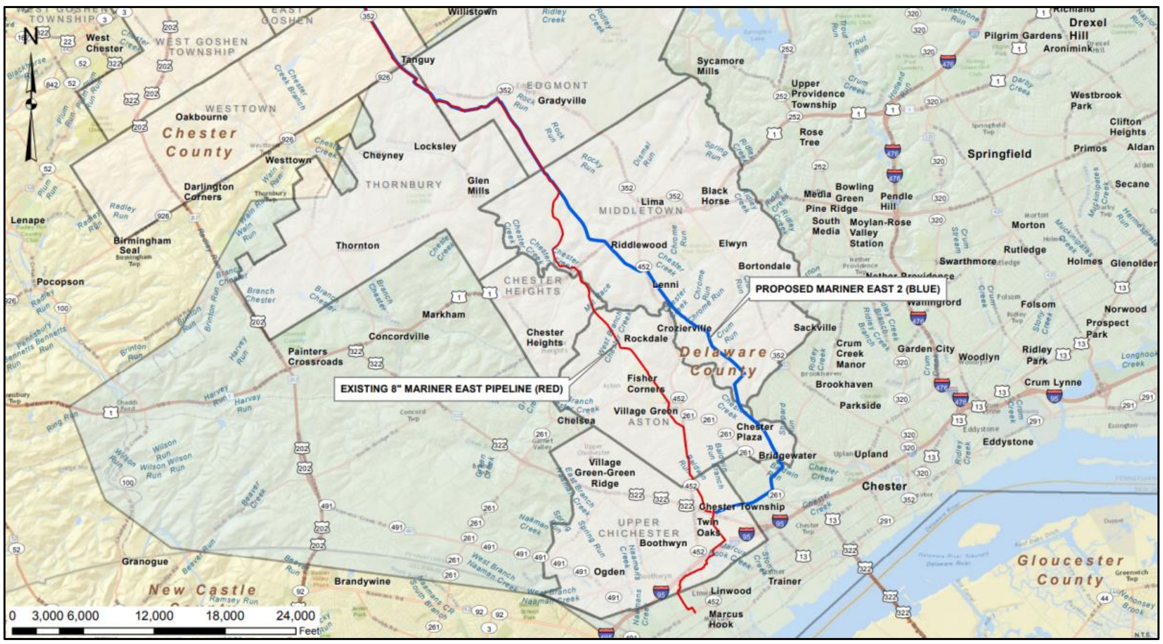
Table 7: Vapor Cloud Explosion Vulnerability, Persons Indoors

Consequence Level	Fatality Vulnerability	Basis
Overpressure greater than 4.35 psig (0.3 bar)	1.0	Not provided[1]
Overpressure greater than 1.45 psig (0.1 bar) but less than 4.35 psig (0.3 bar)	0.025	Not provided[1]
Overpressure less than 1.45 psig (0.1 bar)	0	Not provided[1]
[1] The Purple Book does not provide a basis for the vulnerability values provided. See Section 6.5.3.		

7.0 MARINER EAST 2 PIPELINE RISK ASSESSMENT

The Mariner East 2 pipeline is an expansion of the existing Mariner East pipeline system and will transport NGLs from Ohio and the Pittsburgh area to the Marcus Hook facility for both domestic distribution and export. Mariner East 2 will be a 20-inch diameter pipeline with an initial transporting capacity of approximately 275,000 barrels per day of NGLs. The high-pressure pipeline will tunnel beneath 17 counties with a length of approximately 11.4 miles through Delaware County, Pennsylvania. Figure 3 shows the proposed route for the Mariner East 2 pipeline.

Figure 3: Proposed Route of Mariner East 2 Pipeline through Delaware County [11]



The following sections describe the risk assessment details specific to the Mariner East 2 pipeline.

7.1 Accident Event Consequence

The Mariner East 2 pipeline is modelled as pure propane to determine the accident event consequences. Upon release, liquid propane vaporizes to a dense gas, and, if not ignited immediately, the vaporized propane disperses downwind as a low-to-the-ground flammable cloud. After the pipeline is isolated and the content has leaked out, the flammable cloud will decrease in size until it is no longer at flammable concentrations.

For the purposes of this risk assessment, the dynamic nature of the Mariner East 2 pipeline accident event and associated consequences was reflected by considering two wind speed-stability conditions and dividing the event into three ignition periods.

The size of flammable cloud that is passively dispersing can vary considerably depending on the wind speed and atmospheric stability, which also varies.

The dispersing flammable cloud could ignite at any point in time and the time of ignition, with respect to the changing size of the flammable cloud means that the resulting consequence can vary greatly. If ignited early, the size of the flammable cloud will be small and jet fire thermal radiation will be the dominant harmful effect. A delayed ignition will result in a smaller jet fire due to the reducing discharge rate.

If ignition is delayed, the size of the flammable cloud means that a flash fire or vapor cloud explosion will occur, with the size of the flash fire or explosion increasing with increasing ignition delay, up to the maximum extent of dispersion. Additionally, at some delayed time, the effect of the flash fire or explosion will be greater than the effect of the delayed jet fire and will dominate the harmful effect.

For the full bore release event the following consequence outputs are contained in Appendix A:

- Release (i.e., discharge rate versus time)
- Jet fire thermal radiation footprint
- Side view of the early and late flammable cloud dispersion
- Early and late dispersion footprint of the flammable cloud (used for early and late flash fire consequence)
- Early and late vapor cloud explosion overpressure footprint

For the 50 mm release event the following consequence outputs are contained in Appendix A:

- Release (i.e., discharge rate versus time)
- Jet fire thermal radiation footprint
- Side view of the early and late flammable cloud dispersion

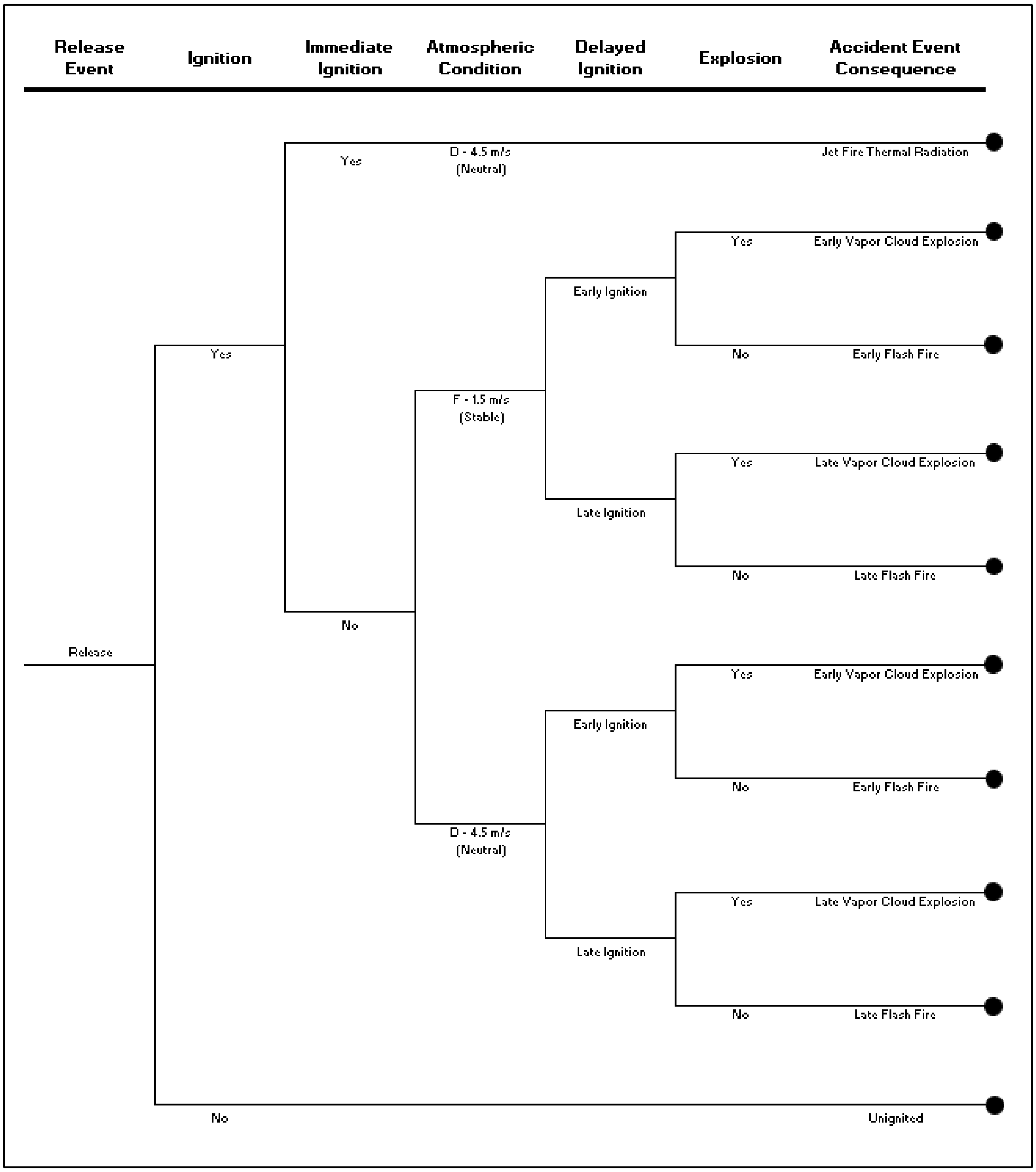
It should be noted that the side view flammable cloud dispersion figures for a 50 mm release event illustrate an upward dispersion, away from ignition sources and people, such that flash fire and vapor cloud explosion events do not contribute to the individual fatality risk level, if they were to occur.

For the purposes of this risk assessment, the following ruleset was defined:

- Assume immediate ignition and use the initial discharge rate (the average rate of the first 20 seconds of discharge) for jet fire thermal radiation consequence.
- Assume an intermediate ignition delay to represent an early flash fire or an early explosion of the expanding flammable cloud. The ignition delay is such that the flammable cloud would not have reached the maximum extent possible before ignition occurs (chosen to be approximately halfway to the maximum extent). Also, the discharge rate will have fallen to a point where the jet fire thermal effects will be smaller than the flash fire or explosion effects.
- Assume a longer ignition delay to represent a late flash fire or late explosion. The ignition delay is long enough that the expanding flammable cloud would have reached the steady-state, maximum extent. Again, the discharge rate will have fallen to a point where the jet fire thermal effects will be smaller than the flash fire or explosion effects.
- For jet fire thermal radiation consequence, only the overall average wind speed and neutral atmospheric stability is used (D – 4.5 m/s).
- For early and late flash fire or explosion, two wind speed and atmospheric stability combinations are used:
    - Overall average wind speed and neutral atmospheric stability
    - A worst-case condition reflecting a stable atmosphere (F – 1.5 m/s)

Figure 4 presents the event tree used to examine a chronological series of subsequent events and finally the frequency of consequential outcomes, or potential accident events resulting from a Mariner East 2 pipeline release. Additionally, the above rulesets are illustrated in the event tree shown in Figure 4. The branch probabilities used for each event tree branch in the risk summation is described in Section 7.2.

Figure 4: Mariner East 2 Pipeline Risk Assessment Event Tree



7.2 Accident Event Frequencies

The following subsections detail the release frequencies and conditional probabilities used in the Mariner East 2 pipeline risk assessment. Note that all values are taken directly from, or utilize common, published risk assessment references, including the Purple Book. The purpose of the Purple Book is to provide common starting points to facilitate obtaining verifiable, reproducible, and comparable quantitative risk assessment results [9].

7.2.1 Release Frequencies

A Mariner East 2 pipeline full bore release frequency was derived from the following available data sets:

1. PHMSA incident report statistics from hazardous liquid transmission pipelines for the period from 2002 through mid-2018 [11][14]
2. PHMSA hazardous liquid transmission pipeline mileage statistics [15]

The PHMSA incident and mileage data were refined, or filtered, to include the following relevant information:

- Highly volatile liquid (HVL) full bore release incidents
- Pipelines of diameter 12-inch and greater, to represent the 20-inch diameter Mariner East 2 pipeline
- Below-ground HVL transmission pipeline mileage

It should be noted that even though PHMSA details NGL pipeline incidents, PHMSA does not detail the mileage of NGL pipelines. Therefore, obtaining release frequencies specific to NGL pipelines is not possible using only the PHMSA data.

The filtering resulted in the following relevant historical data:

- Six HVL full bore release incidents
- 253,371 mile-years of HVL pipeline (12-inch or greater diameter)

Based on this data, an HVL pipeline full bore release frequency of 2.4E-05 incidents per mile-years (1.5E-05 incidents per km-years), was calculated.

The full bore release frequency value derived from PHMSA data compares well to that for a generic pipeline located in a dedicated route given in the Purple Book [9] (note that the pipeline diameter is not specified in the Purple Book values). The Purple Book value of 7E-06 incidents per km-year for full bore rupture is only a factor of 2 lower than the value derived from the PHMSA data.

Additionally, the Purple Book states that the release frequencies for pipelines located in a dedicated route are lower than other pipelines because of extra preventative measures [9]. The PHMSA data includes all pipelines and, according to the Purple Book, should be expected to be higher than full bore release frequency for pipelines located only in a dedicated route.

In determining a Mariner East 2 pipeline 50 mm release frequency, the estimated Mariner East 2 pipeline full bore release frequency was multiplied by a factor of 2.5 to result in a 50 mm release frequency of 5.9E-05 incidents per mile-years (3.7E-05 incidents per km-years). The 2.5 multiplying factor is taken from International Association of Oil and Gas Producers (OGP) recommended distribution of non-full bore hole sizes and full bore hole sizes for onshore oil pipelines [18].

Details of the PHMSA HVL incident and mileage data filtering and frequency calculations are provided in Appendix C.

7.2.2 Ignition Probability

OGP published ignition probability look-up correlations, which relate ignition probabilities to discharge rates for typical scenarios, were used in determining an overall (total) ignition probability given a release [19].

Specifically, Ignition Probability Correlation Number 3 was used as it is applicable for releases of flammable gases, vapor, or liquids significantly above their normal boiling point from onshore cross-country pipelines running through industrial or urban areas (many ignition sources as opposed to a rural area which would have sparse ignitions sources). This correlation is considered appropriate because the Mariner East 2 pipeline is transporting NGL, a liquid significantly above its normal boiling point, and the pipeline route through Delaware County can be described as urban. The values published for Ignition Probability Correlation Number 3 are provided in Table 8.

Table 8: OGP Published Ignition Probability Correlation #3 [19]

Discharge Rate (kg/s)	Ignition Probability
0.1	0.0010
0.2	0.0017
0.5	0.0033
1.0	0.0056
2.0	0.0095
5.0	0.0188
10	0.0316
20	0.0532
50	0.1057
100	0.1778

Discharge Rate (kg/s)	Ignition Probability
200	0.2991
500	0.5946
1000	1.0000
Ignition Probability Correlation #3: Flammable gases, vapor, or liquids significantly above their normal boiling point from onshore cross-country pipelines running through industrial or urban areas.	

Applying this correlation to the 20-inch Mariner East 2 pipeline discharge rates, for the two (2) hole-sizes, results in the following ignition probabilities:

- 50 mm release @ 3.4 kg/s, ignition probability = 0.01384 (interpolated)
- Full bore release @ 1586 kg/s (average of first 20 seconds), ignition probability = 1.0

Note that these are total ignition probabilities and do not indicate the timing of ignition.

7.2.3 Immediate Ignition

For the conditional probability of immediate ignition (given ignition) the Purple Book specifies a value of 0.3 for rupture of a liquefied flammable gas, buried cross-country pipeline [9].

The Purple Book does not detail the time delay criteria used to define “immediate” ignition. However, in the Mariner East 2 pipeline risk assessment, “immediate” is used as a differentiating factor between the jet fire and flash fire/explosion accident event consequences. Given that it takes some time for a dense flammable cloud to disperse passively downwind, the relevant time frame for “immediate” ignition in this risk assessment is roughly about one minute or less.

Note that in the case of an NGL release, a risk assessment using an immediate ignition probability that is lower than the delayed ignition probability produces more conservative results because the lower immediate ignition probability puts more emphasis on the effects of a delayed flash fire or explosion.

7.2.4 Atmospheric Condition

As a reference, the meteorological condition distribution of several locations in the Netherlands, as published in the Purple Book, was reviewed. The published fractions of stable and slightly stable atmospheric conditions added together result in a probability value slightly lower than 0.2.

Based on this information a conditional probability of a stable ("worst case") atmospheric condition was set at 0.25 in this risk assessment. The use of a higher value is to be conservative and accommodate uncertainty of the differences between the Netherlands locations and eastern Pennsylvania.

7.2.5 Ignition Delay

As discussed in Section 7.1, the Mariner East 2 pipeline risk assessment divides the delayed ignition effects into two periods:

- An intermediate (or early) delay, where the flammable cloud ignites before the maximum, steady-state size is reached resulting in an early flash fire or early vapor cloud explosion.
- A long (or late) delay (for late flash fire, or late explosion), where the flammable cloud reaches a maximum, steady-state size resulting in a worst case late flash fire or late vapor cloud explosion.

For the purposes of this risk assessment, the conditional probability that the ignition delay is late is set at 0.1 resulting in an early ignition conditional probability of 0.9. This is a conservative simplification that is justified by the argument that in a populated, urban area such as Delaware County, a dispersing flammable NGL cloud is more likely to ignite sooner rather than later due to the likely presence of numerous ignition sources.

Furthermore, to support the validity of this argument, the probability of early delayed ignition was checked using the model presented in Appendix 4.A of the Purple Book [9]. The inputs to this model are the area of the flammable cloud, the time interval the cloud is exposed over the ignition sources, and the effectiveness of the ignition sources.

Using the early flash fire flammable cloud area with a corresponding exposure time, and an ignition effectiveness based on the overall population density of Delaware County, the Purple Book delayed ignition model predicts a probability of ignition of 1.0 for the smaller, early flammable cloud. This supports that it is unlikely for a cloud to reach the maximum size before igniting in such an urban area.

To be conservative, the late ignition conditional probability is not set to zero, as suggested by the Purple Book delayed ignition model argument. A value of 0.1 is used in this risk assessment, which reflects that 10% of the delayed ignition events are assumed to have a late ignition, versus an early ignition, and result in the flammable clouds reaching the maximum, steady-state size before igniting.

7.2.6 Vapor Cloud Explosion

This Mariner East 2 pipeline risk assessment assumes that a vapor cloud explosion is a viable accident event given the combination of a propane flammable fuel source, a ground hugging flammable cloud, and some likely congestion near the pipeline. Thus, a suitable event tree branch probability split between a flash fire outcome and a vapor cloud explosion outcome is required.

This risk assessment uses a simple 0.6 flash fire/0.4 vapor cloud explosion split, as suggested by the Purple Book [9], for both the early ignition scenario and the late ignition scenario.

7.3 Individual Risk Results

The Mariner East 2 pipeline accident event consequences (Section 7.1), accident event frequencies (Section 7.2), and defined accident event impacts (Section 6.5) are combined to produce outdoor and indoor individual risk results. The individual risk results are then plotted on a grid to produce transects showing individual risk levels as a function of distance from the pipeline route. Separate risk transects for outdoor and indoor locations are provided, since different impact rulesets are used for the two location types (Section 6.5).

Note that the individual risk transects reflect an individual's continuous presence (i.e., 24-hours per day, 7-days per week) at a select location. This assumption is consistent with common quantitative risk assessment methodology; the continuous presence at a select location reflects a most exposed individual and, therefore, represents a maximum individual risk level.

The outdoor and indoor individual risk transects are shown in Figure 5 and Figure 6. Note that distance from the pipeline are expressed in meters.

Figure 5: 20-inch Mariner East 2 Pipeline, Outdoor Individual Risk Transect

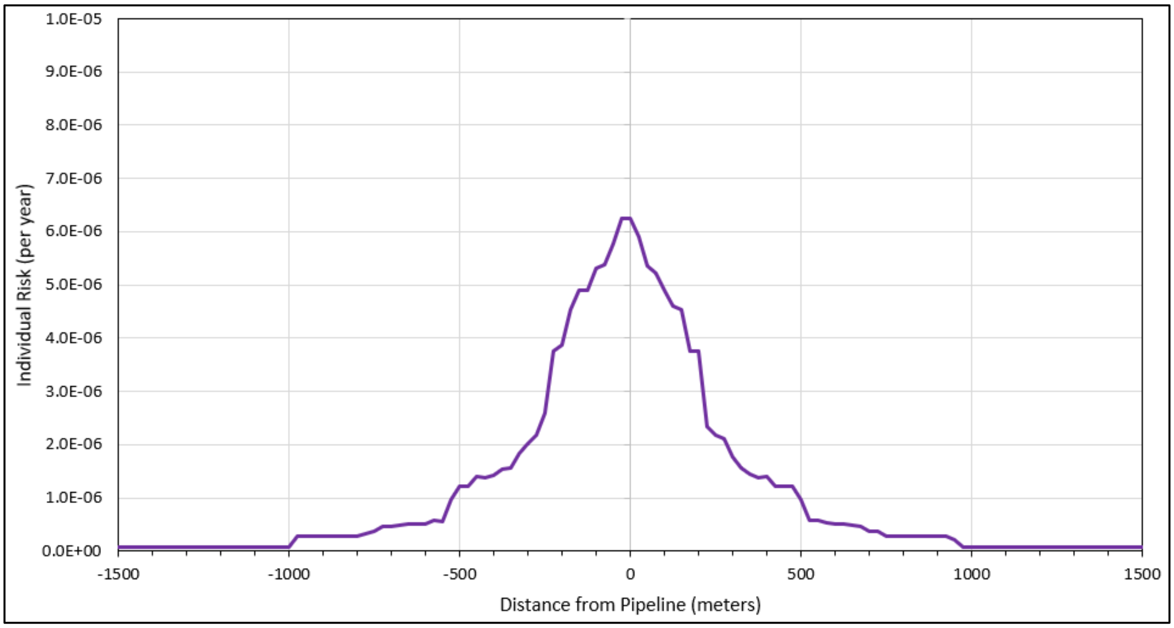
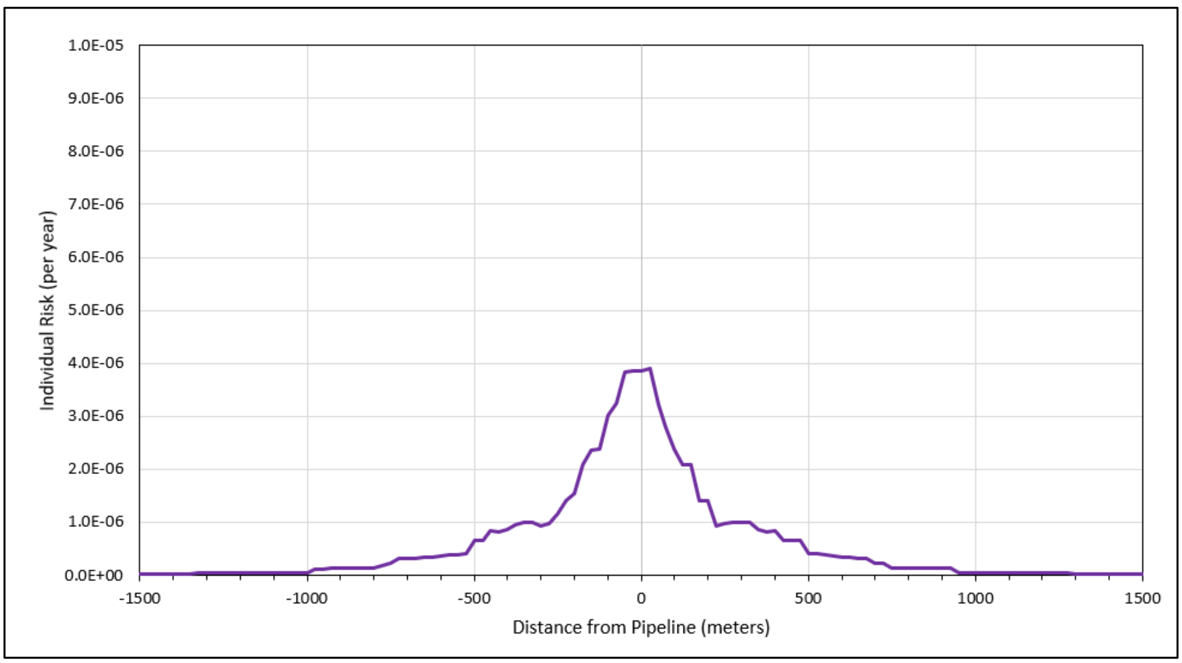


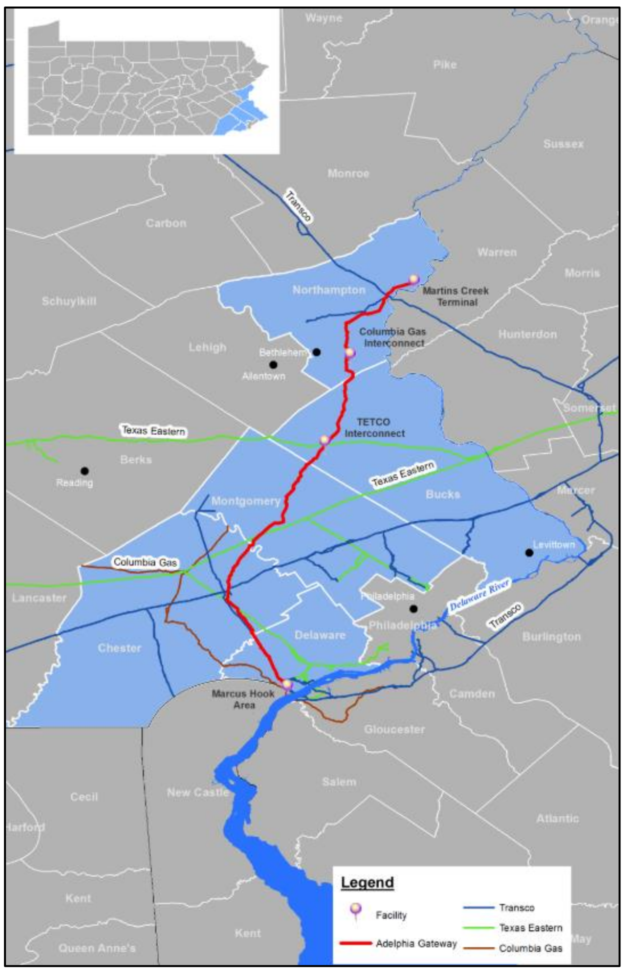
Figure 6: 20-inch Mariner East 2 Pipeline, Indoor Individual Risk Transect



8.0 ADELPHIA PIPELINE RISK ASSESSMENT

The existing Adelphia pipeline is an 84-mile pipeline that runs through five Pennsylvania counties, including Delaware County, and was originally constructed to transport oil from Marcus Hook to Martins Creek, Pennsylvania. In 1996, the northern 34 miles of the Adelphia pipeline was converted to transport natural gas. The remaining 50 miles of existing Adelphia pipeline is planned to be converted to transport natural gas, of which approximately 12 miles traverses Delaware County. Figure 7 shows the route of the existing Adelphia pipeline.

Figure 7: Route of Existing Adelphia Pipeline [12]

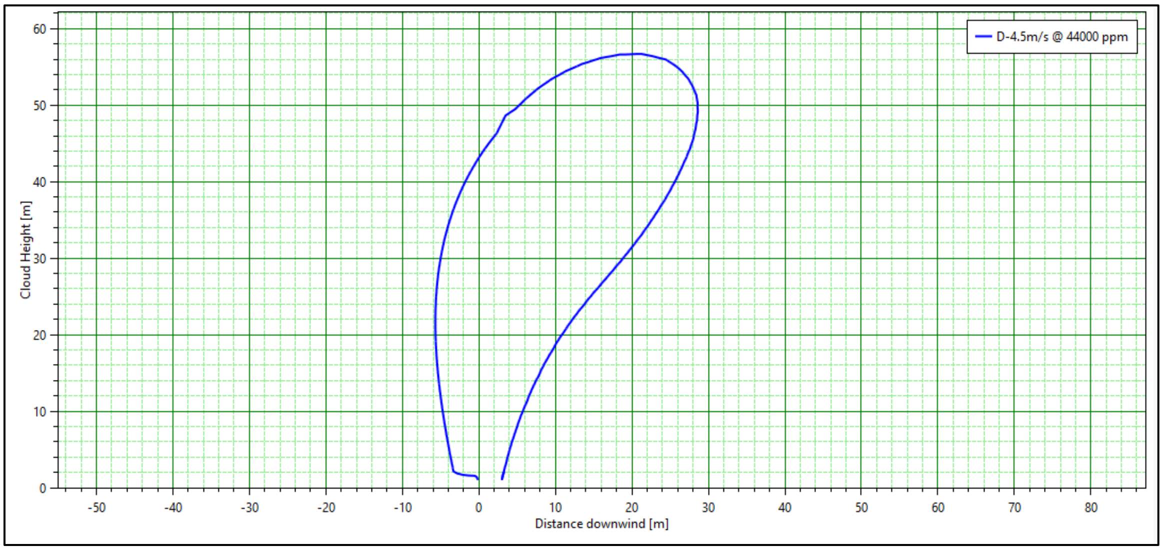


The following sections describes the risk assessment details specific to the Adelphia pipeline.

8.1 Accident Event Consequences

The Adelphia natural gas pipeline is modeled as pure methane to determine the accident event consequences. Upon release, the gas rapidly mixes with air to concentrations below the lower flammable limit. This rapid dilution combined with the vertical orientation of the resulting flammable cloud, caused by a combination of the effects of the crater and the buoyancy of the released gas, results in a small flammable gas cloud footprint near the ground level. This is illustrated in Figure 8 with a side view plot of the flammable vapor cloud from a full bore release.

Figure 8: Side View of Flammable Cloud from Full Bore Adelphia Gas Pipeline Release



The two key implications of the nearly vertical flammable vapor cloud from a natural gas release from a buried pipeline are:

1. A flash fire impact would be negligible since near the ground level only the immediate vicinity of the release (just a few square meters) is within the flash fire envelope.

2. A vapor cloud explosion is very unlikely because, with natural gas, the confinement or congestion needed within the cloud (See Section 6.5) is unlikely to be present immediately above the transmission pipeline.

For these reasons, the Adelphia pipeline risk assessment only considers jet fire thermal radiation consequences and excludes the minimal contributions of flash fire thermal radiation and vapor cloud explosion overpressure consequences to the pipeline risk estimations.

For the full bore release event the following consequence outputs are contained in Appendix B:

- Release (i.e., discharge rate versus time)
- Jet fire thermal radiation footprint
- Side view of the flammable cloud dispersion

For the 50 mm release event the following consequence outputs are contained in Appendix B:

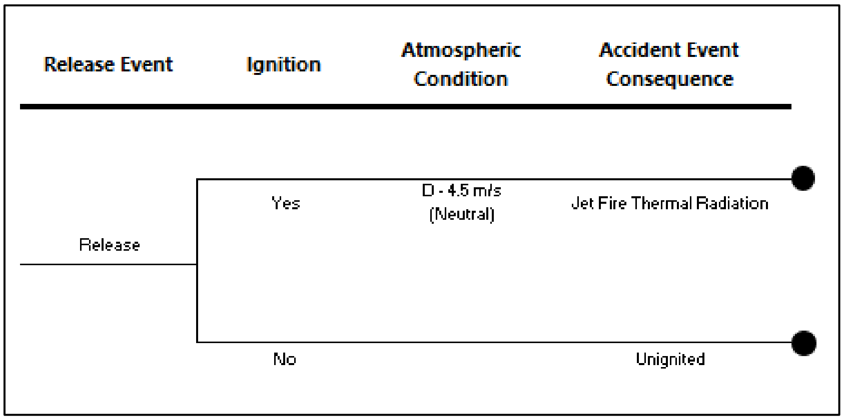
- Jet fire thermal radiation footprint
- Side view of the flammable cloud dispersion

The approach for this risk assessment is to assume that if the release ignites, it is ignited immediately, and the initial discharge rate is used for thermal radiation consequence. This ruleset is a conservative simplification. In reality, the ignition could be delayed. If delayed, then the discharge rate will have reduced and the jet fire thermal radiation consequence will be smaller. The greater the ignition delay, the greater the discharge is reduced and the smaller the consequence.

The Purple Book references for “immediate” ignition probability do not provide criteria of what time frame constitutes “immediate” ignition. However, it could be interpreted to be as quickly as only a few seconds, if not instantaneous. This could leave “non-immediate” ignition thermal radiation consequence similar in magnitude to “immediate” ignition thermal radiation consequence. This justifies simply using the initial discharge rate for jet fire thermal consequence without applying an immediate ignition conditional probability.

The consequence rulesets described above are illustrated in the event tree shown in Figure 9. The release event frequency and probabilities used for each event tree branch in the risk summation is described in Section 8.2.

Figure 9: Adelphia Pipeline Risk Assessment Event Tree



8.2 Accident Event Frequencies

The following subsections detail the release frequencies and conditional probabilities used in the Adelphia pipeline risk assessment. Note that all values are taken directly from, or utilize common, published risk assessment references, including the Purple Book. The purpose of the Purple Book is to provide common starting points to facilitate obtaining verifiable, reproducible, and comparable quantitative risk assessment results [9].

8.2.1 Release Frequencies

An Adelphia pipeline full bore release frequency was derived from the following available data sets:

1. PHMSA incident report statistics from natural gas transmission pipelines for the period from 2007 through mid-2018 [16].
2. PHMSA natural gas transmission pipeline mileage statistics [17].

The PHMSA incident and mileage data were refined, or filtered, to include the following relevant information:

- Natural gas full bore release incidents
- Pipelines of diameters greater than 10-inches but less than 28-inches to represent the 18-inch diameter Adelphia pipeline
- Below-ground natural gas transmission pipeline mileage

The filtering resulted in the following relevant historical data:

- 128 full bore release incidents
- 2,214,615 mile-years of natural gas pipeline (10-inch to 28-inch diameter range)

Based on this data, a natural gas pipeline full bore release frequency is 5.8E-05 incidents per mile-years (3.6E-05 incidents per km-years) was calculated.

The full bore release frequency value derived from PHMSA data compares reasonably well to that given in the Purple Book [9] for a generic pipeline located in a dedicated route (note that the pipeline diameter is not specified in the Purple Book values). The Purple Book value of 7E-06 incidents per km-year for full bore rupture is 5 times lower than the value derived from the PHMSA data. The Purple Book value reflects pipelines located "in a dedicated route", whereas the PHMSA data is for all pipelines.

The Purple Book states that the release frequencies for pipelines located in a dedicated route are lower than other pipelines because of extra preventative measures [9]. Additionally, the PHMSA data includes all pipelines and so could be expected to be higher than pipelines located only in a dedicated route.

In determining an Adelphia pipeline 50 mm release frequency, the estimated Adelphia pipeline full bore release frequency was multiplied by a factor of 6 to result in a 50 mm release frequency of 3.5E-04 incidents per mile-years (2.2E-04 incidents per km-years). The multiplying factor of 6 is taken from OGP recommended distribution of non-full bore hole sizes and full bore hole sizes for onshore gas pipelines [18].

Details of the PHMSA natural gas incident and mileage data filtering and frequency calculation are provided in Appendix D.

8.2.2 Ignition Probability

OGP published ignition probability look-up correlations, which relate ignition probabilities to discharge rates for typical scenarios, were used in determining an overall (total) ignition probability given a release [19].

Specifically, Ignition Probability Correlation Number 3 was used as it is applicable for releases of flammable gases, vapor, or liquids significantly above their normal boiling point from onshore cross-country pipelines running through industrial or urban areas. This correlation is considered appropriate because the Adelphia pipeline is transporting natural gas and the pipeline route through Delaware County can be described as urban (many ignition sources as opposed to a rural area which would have sparse ignitions sources). The values published for Correlation Number 3 are shown in Table 9.

Table 9: OGP Published Ignition Probability Correlation #3 [19]

Discharge Rate (kg/s)	Ignition Probability
0.1	0.0010
0.2	0.0017
0.5	0.0033
1.0	0.0056
2.0	0.0095
5.0	0.0188
10	0.0316
20	0.0532
50	0.1057
100	0.1778
200	0.2991
500	0.5946
1000	1.0000
Ignition Probability Correlation #3: Flammable gases, vapor, or liquids significantly above their normal boiling point from onshore cross-country pipelines running through industrial or urban areas.	

Applying this correlation to the 18-inch Adelphia pipeline discharge rates, for the two (2) hole-sizes, results in the following ignition probabilities:

- 50 mm release @ 8.8 kg/s (nominally 10 kg/s), ignition probability = 0.0316
- Full bore release @ 434 kg/s (average of first 20 seconds, nominally 500 kg/s), ignition probability = 0.5946

8.3 Individual Risk Results

The Adelphia pipeline accident event frequencies (Section 8.2), accident event consequences Section 8.1), and defined accident event impacts (Section 6.5) are combined to produce outdoor and indoor individual risk results. The individual risk results are then plotted on a grid to produce transects showing individual risk levels as a function of distance from the pipeline route. Separate risk transects for outdoor and indoor locations are provided, since different impact rulesets are used for the two location types (Section 6.5).

Note that the individual risk transects reflect an individual's continuous presence (i.e., 24-hours per day, 7-days per week) at a select location. This assumption is consistent with common quantitative risk assessment methodology; the continuous presence at a select location reflects a most exposed individual and, therefore, represents a maximum individual risk level.

The outdoor and indoor individual risk transects are shown in Figure 10 and Figure 11. Note that distance from the pipeline is expressed in meters.

Figure 10: 18-inch Adelphia Pipeline, Outdoor Individual Risk Transect

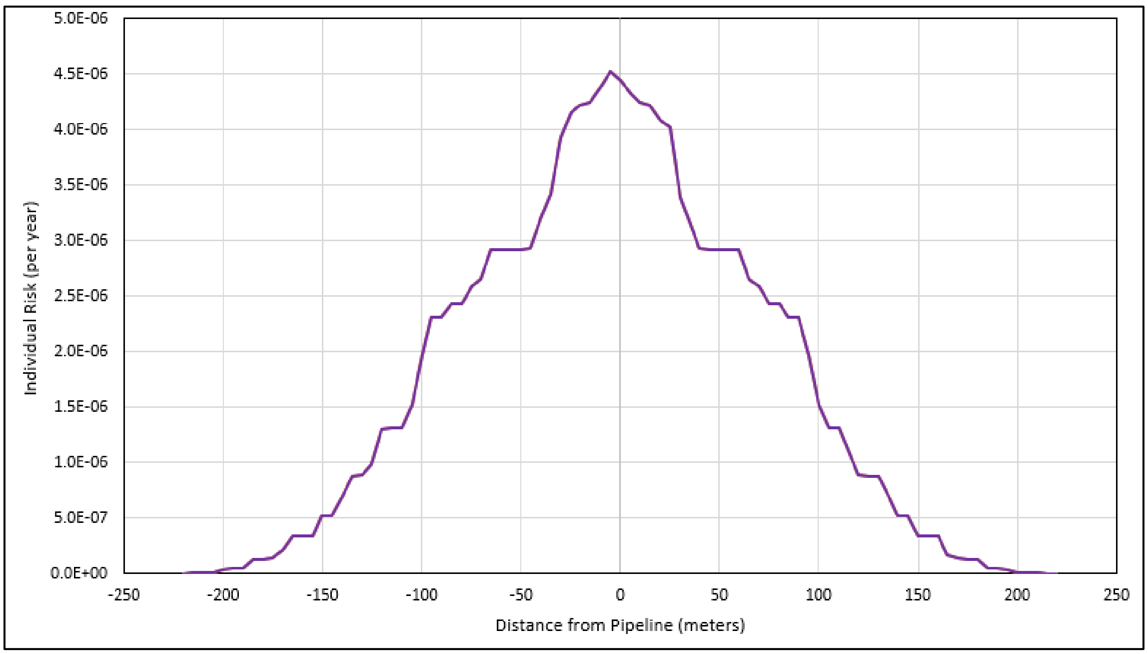
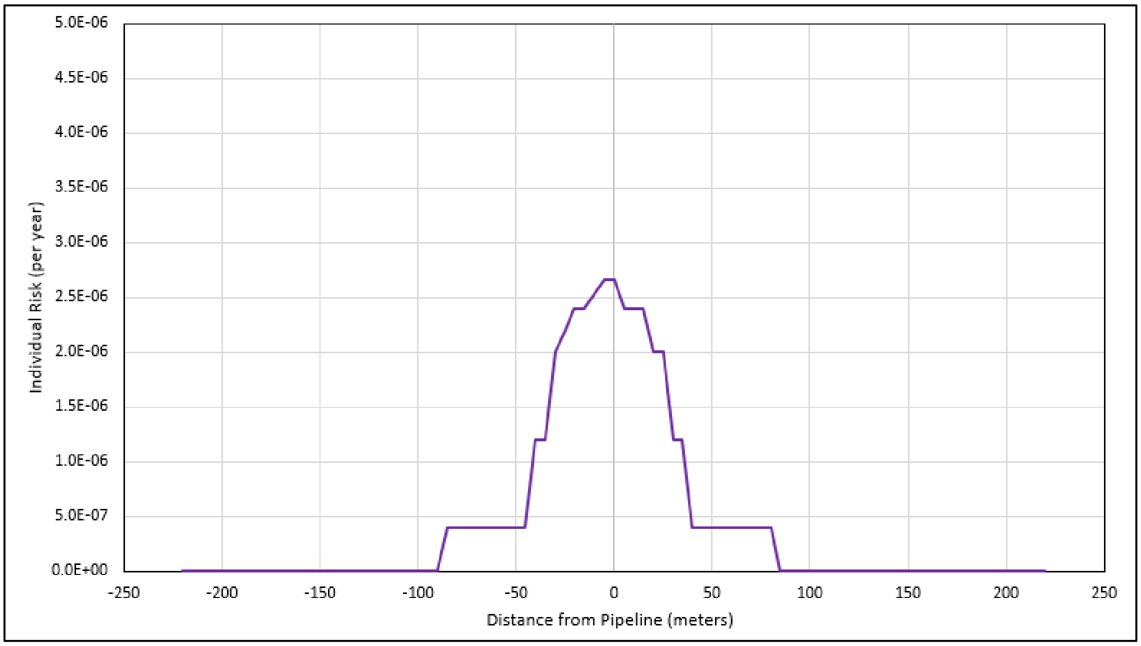


Figure 11: 18-inch Adelphia Pipeline, Indoor Individual Risk



9.0 COMMON INDIVIDUAL RISK SOURCES

Table 10 provides a list of common risk sources and corresponding published individual risk levels derived from United States fatality statistics [20]. The one-year odds are the number of deaths in one year that occurred in the United States divided by the total population of the United States. The individual risk level equates to the inverse of the one-year odds.

Note that the values in Table 10 are shown in the order of decreasing risk level (i.e., highest risk to lowest) and range from approximately 1.2E-04 per year (motor vehicle accident fatalities) to 1.1E-07 per year (lightning fatalities).

Table 10: Odds of Death in The United States by Selected Cause, 2016

Cause [20]	Number of Deaths (2016) [20]	One Year Odds[1] [20]	Individual Risk (per year)[2]
Motor vehicle accident	40,327	8,013	1.2E-04
Assault by firearm	14,415	22,416	4.5E-05
Exposure to smoke, fire, flames	2,730	118,362	8.4E-06
Falls from stairs or steps	2,344	137,853	7.3E-06
Swimming pool	780	414,266	2.4E-06
Firearm accident	300	1,077,092	9.3E-07
Hurricane, tornado, blizzard, storm	66	4,895,871	2.0E-07
Lightning	36	8,975,764	1.1E-07

[1] Values are based on total U.S. population and not on a number of activity participants.

[2] Calculated based on one year odds and rounded to the nearest decimal.

Source Insurance Information Institute
https://www.iii.org/fact-statistic/facts-statistics-mortality-risk

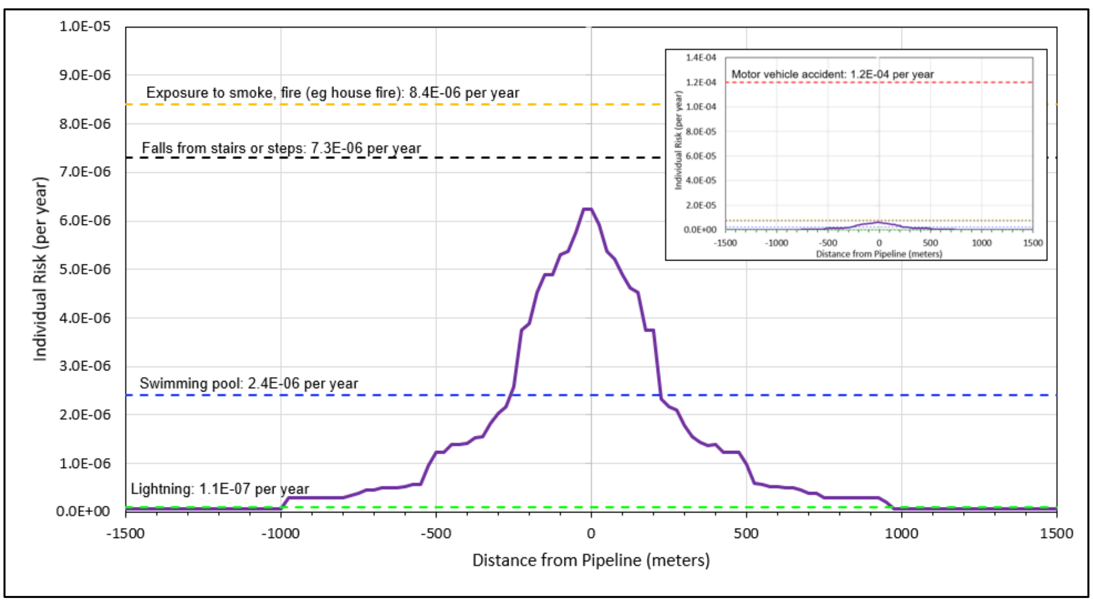
10.0 CONCLUSIONS

The final objective of these assessments was to present a comparison of the Mariner East 2 pipeline and Adelphia pipeline estimated individual risk levels against other individual risk levels from common sources. This is done in order to establish an improved perspective when interpreting the meaning of the individual fatality risks.

Figure 12 presents such comparisons using the resulting outdoor individual risk transect for the Mariner East 2 pipeline together with several common risk sources presented in Section 9.0.

Note that the plot contains an inset figure using a compressed risk axis to accommodate the 1.2E-04 per year motor vehicle accident individual risk value, which would otherwise be off the scale of the main plot (i.e., greater than 1.0E-05 per year).

Figure 12: Mariner East 2 Outdoor Individual Risk versus Common Risk Sources



The following are examples of how to interpret the above Mariner East 2 pipeline comparative plot:

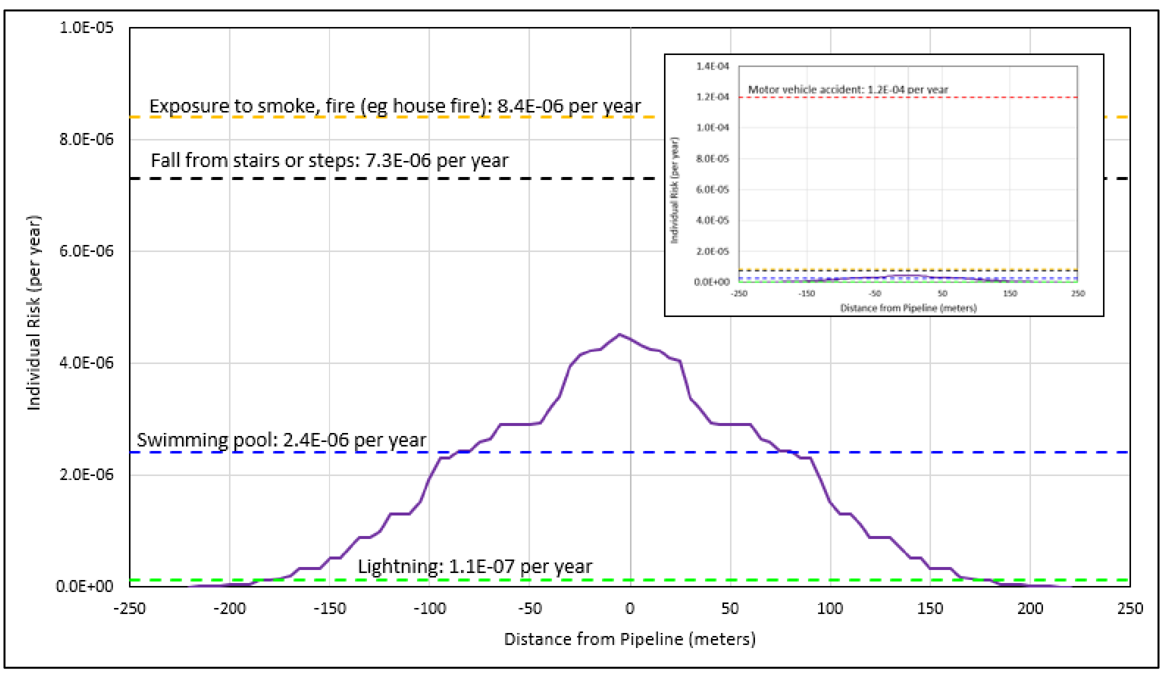
- The average person's annual exposure to a fatal traffic accident (1.2E-04 per year) is approximately 20 times greater than that of the annual individual risk level (6.2E-06 per year, or odds of 1 in 161,290) of a person present 24 hours per day, 7 days per week at a zero distance from the Mariner East 2 pipeline route (i.e., on the centerline).

- The average person's exposure to fatal house fires (8.4E-06 per year) is approximately 35% greater than that of the individual risk level (6.2E-06 per year, or odds of 1 in 161,290) of a person present 24 hours per day, 7 days per week at a zero distance from the Mariner East 2 pipeline route (i.e., on the centerline).
- The average person's exposure to a fatal fall from stairs (7.3E-06 per year) is approximately 20% greater than that of the individual risk level (6.2E-06 per year, or odds of 1 in 161,290) of a person present 24 hours per day, 7 days per week at a zero distance from the Mariner East 2 pipeline route (i.e., on the centerline).

Figure 13 presents such comparisons using the resulting outdoor individual risk transect for the Adelphia pipeline together with several common risk sources presented in Section 9.0.

Note that the plot contains an inset figure using a compressed risk axis to accommodate the 1.2E-04 per year motor vehicle accident individual risk value, which would otherwise be off the scale of the main plot (i.e., greater than 1.0E-05 per year).

Figure 13: Adelphia Outdoor Individual Risk versus to Common Risk Sources



The following are examples of how to interpret the above Adelphia pipeline comparative plot:

- The average person's exposure to a fatal traffic accident (1.2E-04 per year) is approximately 27 times greater than that of the individual risk level (4.5E-06 per year, or odds of 1 in 222,222) of a person present 24 hours per day, 7 days per week at a zero distance from the Adelphia pipeline route (i.e., on the centerline).
- The average person's exposure to fatal house fires (8.4E-06 per year) is approximately 2 times greater than that of the individual risk level (4.5E-06 per year, or odds of 1 in 222,222) of a person present 24 hours per day, 7 days per week at a zero distance from the Adelphia pipeline route (i.e., on the centerline).
- The average person's exposure to a fatal fall from stairs (7.3E-06 per year) is approximately 60% greater than that of the individual risk level (4.5E-06 per year, or odds of 1 in 222,222) of a person present 24 hours per day, 7 days per week at a zero distance from the Adelphia pipeline route (i.e., on the centerline).

In conclusion, based on the figures above, it can be stated that the individual risk levels estimated for both the Mariner East 2 pipeline and the Adelphia pipeline fall within a range of other common risk sources.

11.0 REFERENCES

[1] Sunoco Pipeline: An Energy Transfer Partnership. *Pipeline Operations and Safety Overview*. https://marinerpipelinefacts.com/resources-links/ (downloaded August 2018).

[2] Tetra Tech, Inc. Prepared for Sunoco Pipeline L.P. *Pennsylvania Pipeline Project, Project Description*. December 2016.

[3] Sunoco Pipeline: An Energy Transfer Partnership. *Mariner East Projects: FAQs*. https://marinerpipelinefacts.com/resources-links/ (downloaded August 2018).

[4] Township of Edgmont Pennsylvania. Sunoco Mariner East II Project – General Information. Sunoco FAQ. *Mariner East 2 Project – Sunoco Pipeline L.P.* https://edgmont.org/vertical/sites/%7B05006893-23B5-46CE-8F41-1CE251B86F61%7D/uploads/MARINER_FAQS_2017.pdf (downloaded September 2018).

[5] Sunoco Logistics. *Sunoco Logistics Mariner Systems & Marcus Hook Industrial Complex*. June 2016 (presentation).

[6] Adelphia Gateway, LLC. *Adelphia Gateway Project, Resource Report 1, General Project Description*. January 2018.

[7] Adelphia Gateway, LLC. *Adelphia Gateway Fact Sheet*. https://adelphiagateway.com (downloaded August 2018).

[8] Sunoco Pipeline: An Energy Transfer Partnership. *Mariner East 2: Pipeline Project Safety Practices and Design*. https://marinerpipelinefacts.com/resources-links/ (downloaded August 2018).

[9] Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek. *Guidelines for Quantitative Risk Assessment*, The Purple Book. 2005.

[10] The Committee for the Prevention of Disasters. *Methods for the Determination of Possible Damage*, The Green Book, CPR16E. 1989.

[11] Chester County Planning Commission, Pipeline Information Center. Sunoco Pipeline Mariner East. http://www.chescoplanning.org/pic/ProjectsMariner.cfm (downloaded October 2018).

[12] Adelphia Gateway, Project Information. https://adelphiagateway.com/project-information/ (downloaded October 2018).

[13] Pipeline and Hazardous Materials Safety Administration, PHMSA. Data and Statistics. Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data.

Hazardous Liquid Accident Data – January 2002 to December 2009. https://www.phmsa.dot.gov/data-and-statistics/pipeline/distribution-transmission-gathering-lng-and-liquid-accident-and-incident-data (downloaded August 2018).

[14] Pipeline and Hazardous Materials Safety Administration, PHMSA. Data and Statistics. Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data. Hazardous Liquid Accident Data – January 2010 to Present. https://www.phmsa.dot.gov/data-and-statistics/pipeline/distribution-transmission-gathering-lng-and-liquid-accident-and-incident-data (downloaded August 2018).

[15] Pipeline and Hazardous Materials Safety Administration, PHMSA. Data and Statistics. Gas Distribution, Gas Gathering, Gas Transmission, Liquified Natural Gas (LNG), and Underground Natural Gas Storage (UNGS) Annual Report Data. Hazardous Liquid Annual Data – 2004 to 2009 and 2010 to Present. https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids (downloaded August 2018).

[16] Pipeline and Hazardous Materials Safety Administration, PHMSA. Data and Statistics. Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data. Gas Transmission & Gathering Incident Data – 2002 to December 2009 and January 2010 to Present. https://www.phmsa.dot.gov/data-and-statistics/pipeline/distribution-transmission-gathering-lng-and-liquid-accident-and-incident-data (downloaded August 2018).

[17] Pipeline and Hazardous Materials Safety Administration, PHMSA. Data and Statistics. Gas Distribution, Gas Gathering, Gas Transmission, Liquified Natural Gas (LNG), and Underground Natural Gas Storage (UNGS) Annual Report Data. Gas Transmission & Gathering Annual Data – 2001 to 2009 and 2010 to Present. https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids (downloaded August 2018).

[18] OGP Risk Assessment Data Directory, Riser & Pipeline Release Frequencies, Report No. 434-4, International Association of Oil & Gas Producers. March 2010.

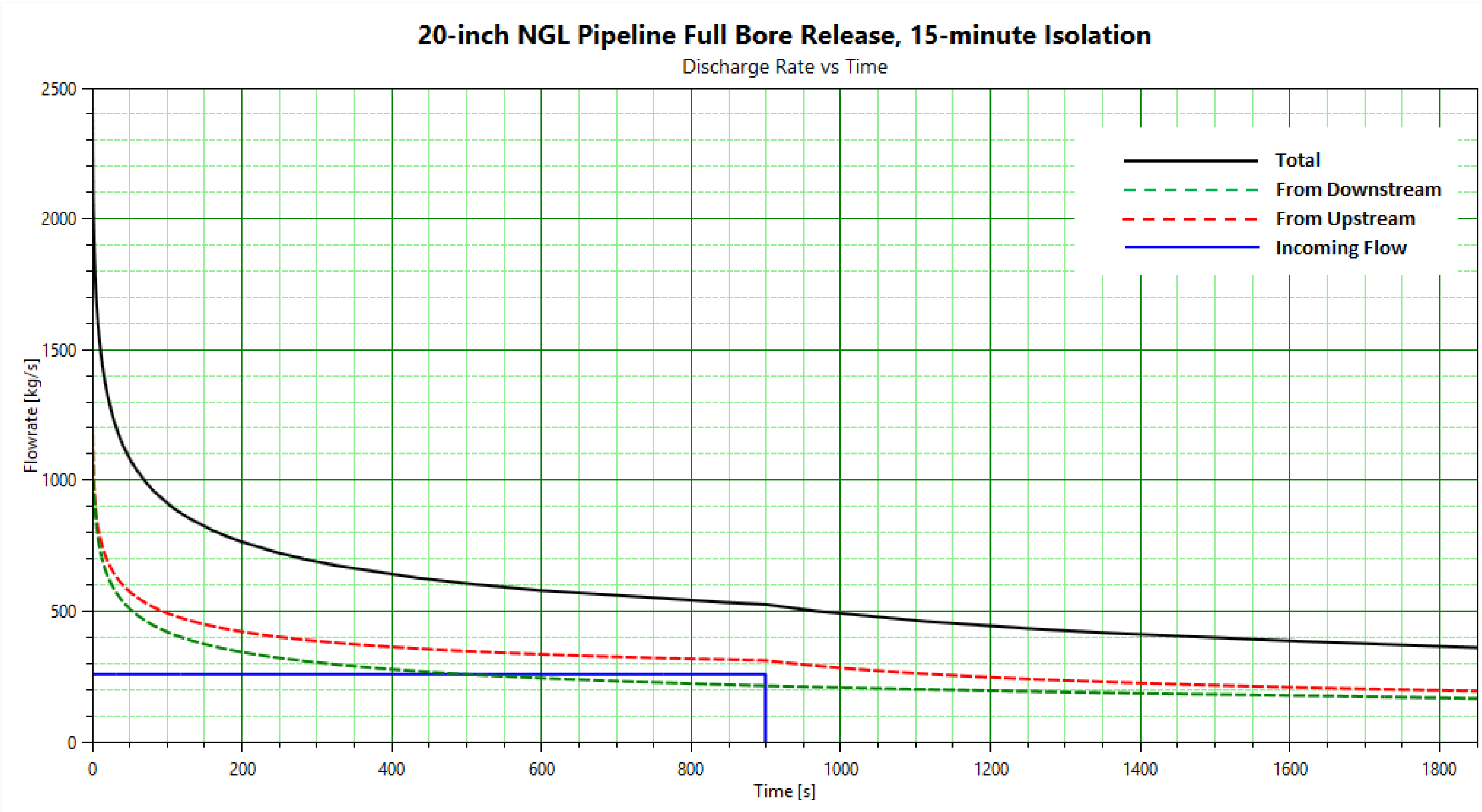
[19] OGP Risk Assessment Data Directory, Ignition Probabilities, Report 434-6, International Association of Oil & Gas Producers. March 2010.

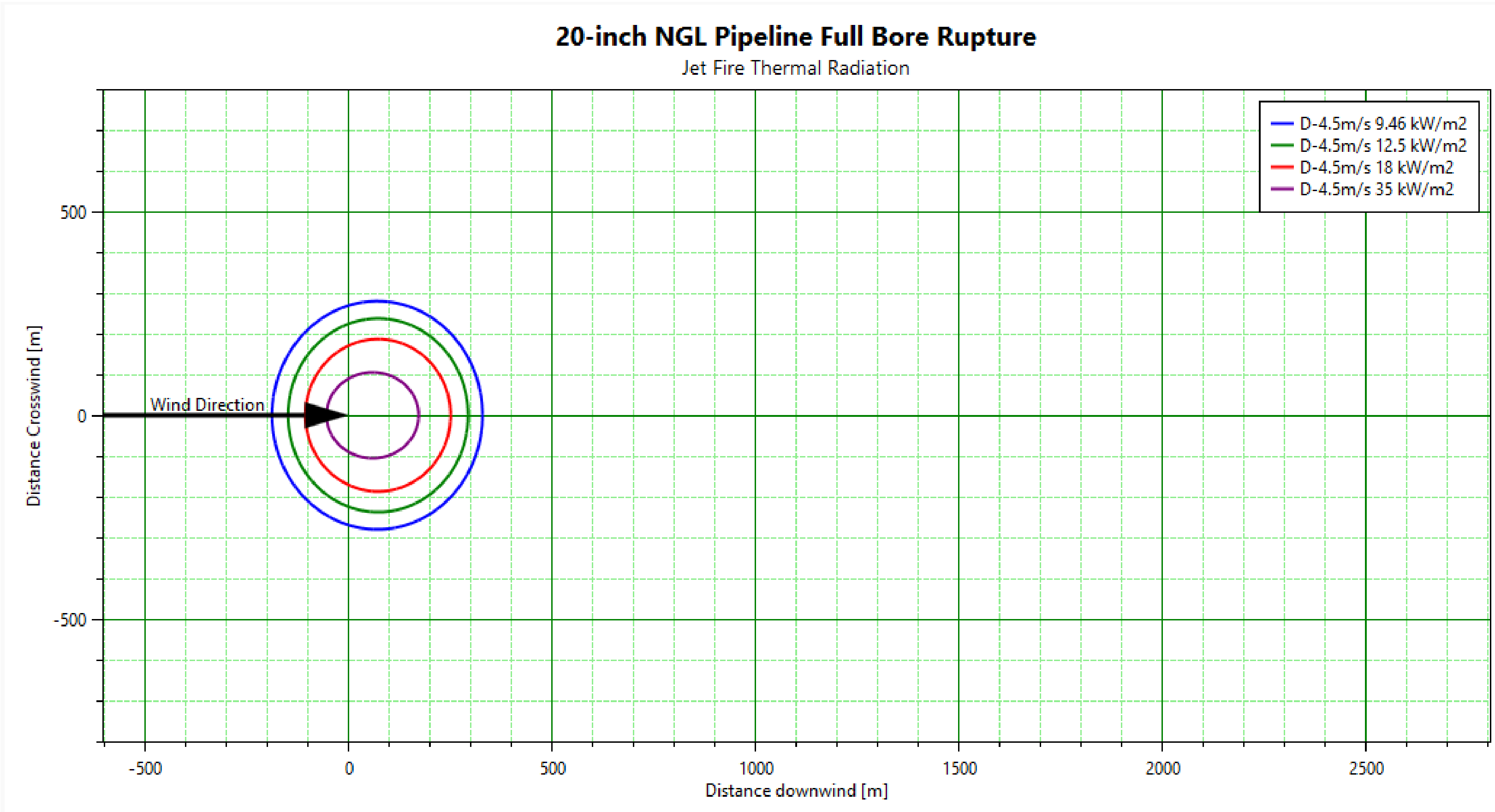
[20] Insurance Information Institute. Facts + Statistics: Mortality Risk. https://www.iii.org/fact-statistic/facts-statistics-mortality-risk (downloaded October 2018).

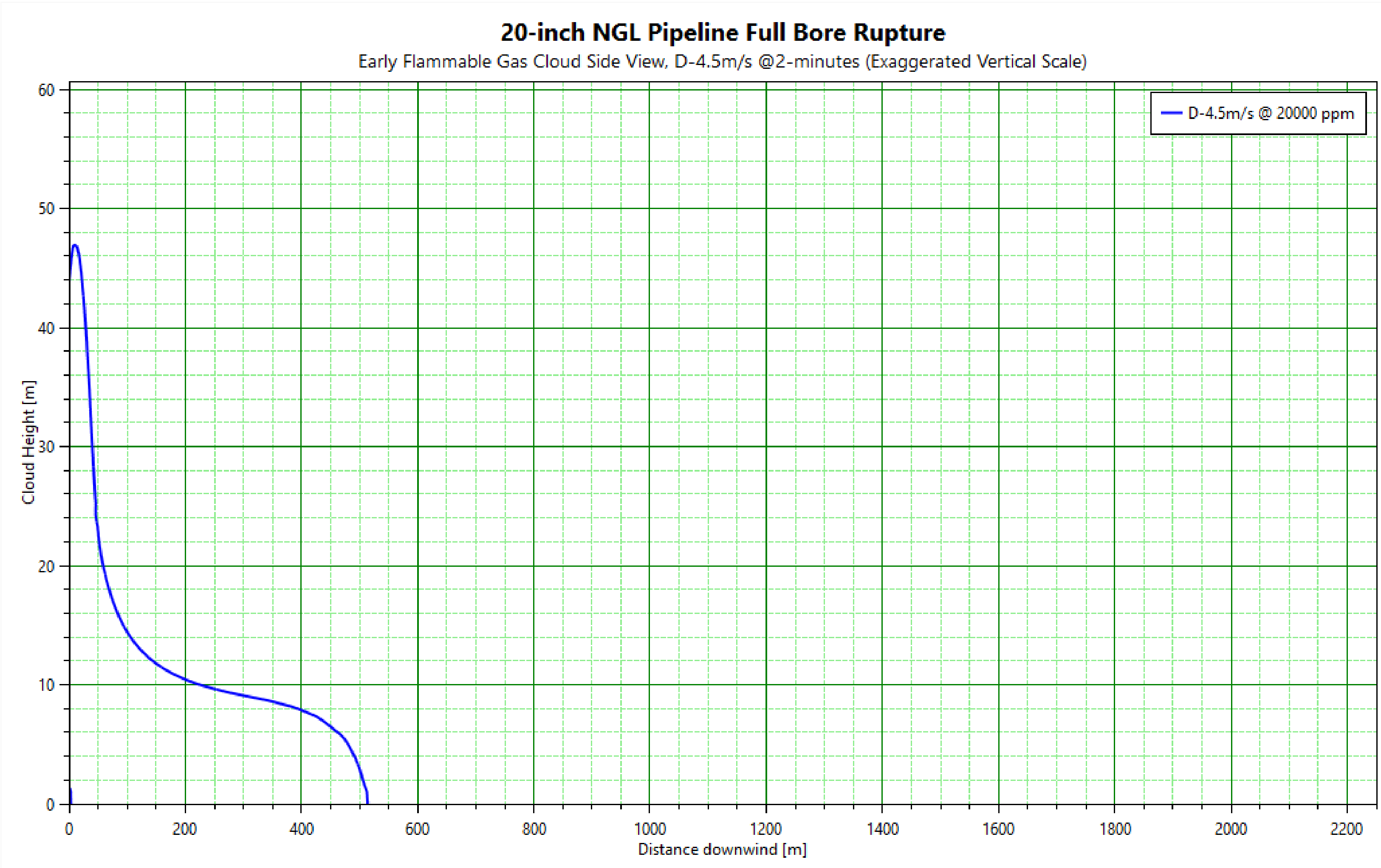
[21] Paper Study on Risk Tolerance, U.S. DOT PHMSA, Final Report No. 16-092, Kiefner and Associates, 2016.

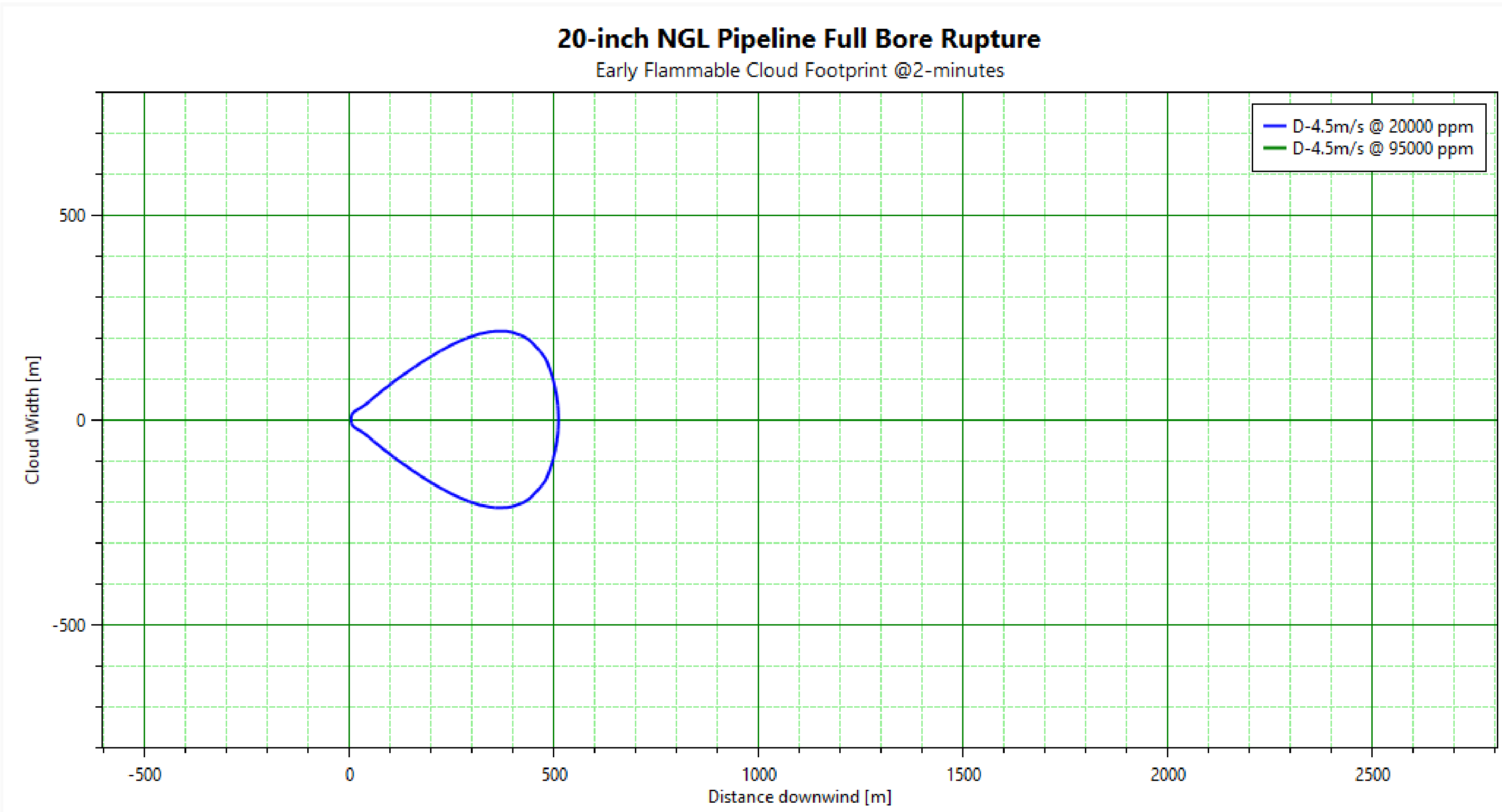
[22] Philadelphia NE Philadelphia Airport, PA US. https://www.ncdc.noaa.gov/cdo-web/datatools/normals (downloaded September 2018).

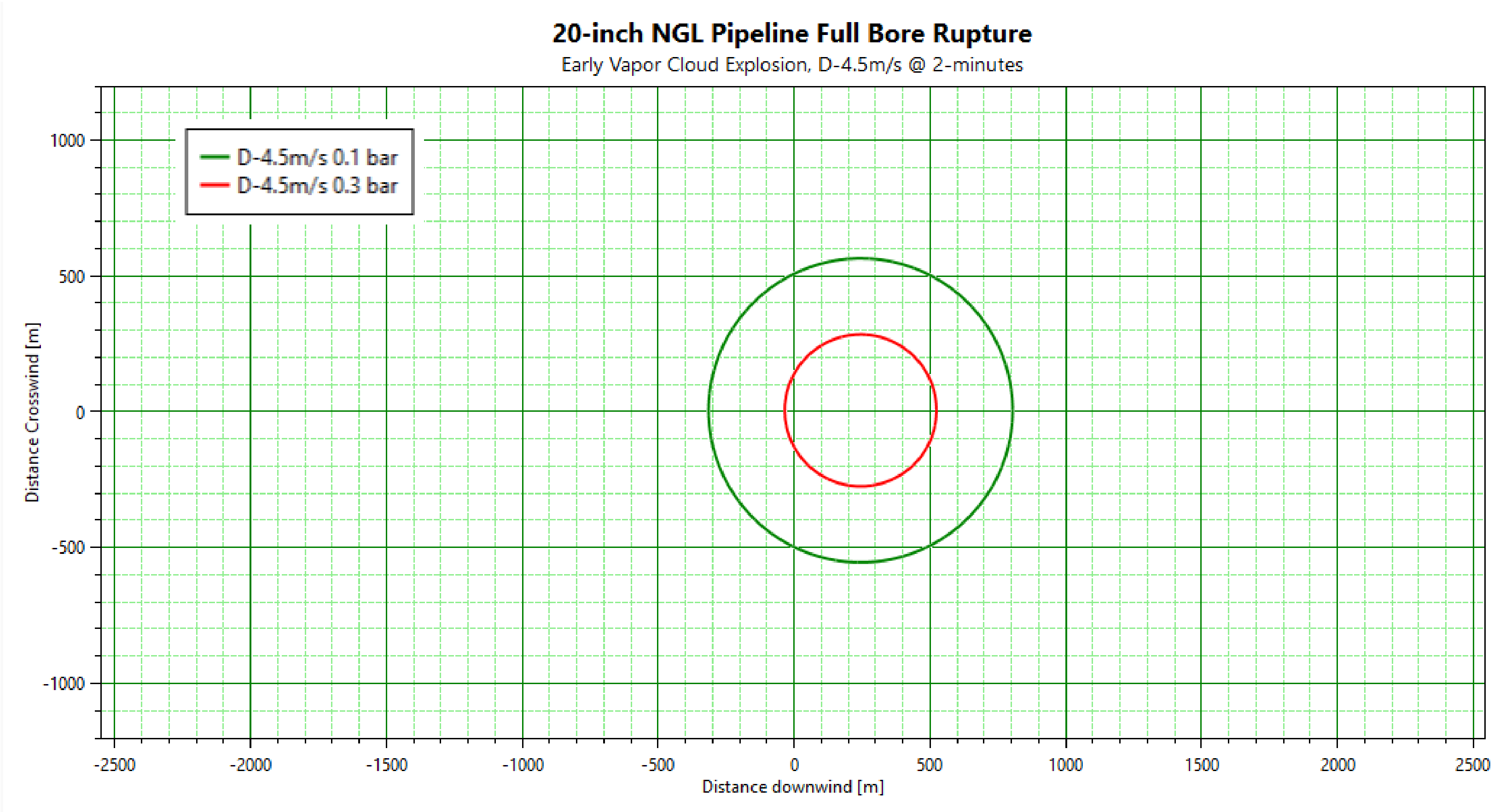
APPENDIX A: MARINER EAST 2 PIPELINE CONSEQUENCE PLOTS

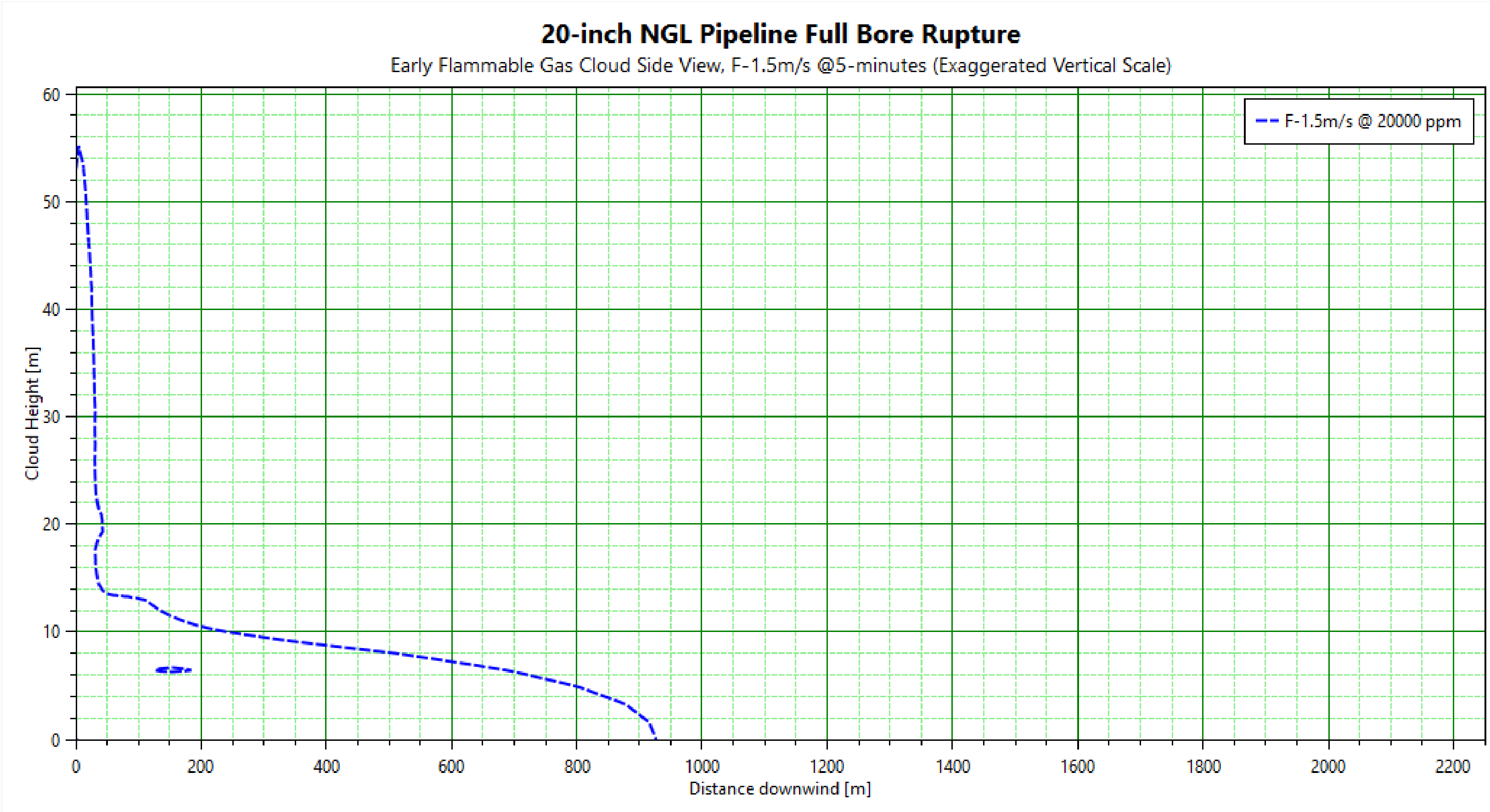

20-inch NGL Pipeline Full Bore Release, 15-minute Isolation
Discharge Rate vs Time
Flowrate [kg/s]
Time [s]
0
500
1000
1500
2000
2500
200
400
600
800
1000
1200
1400
1600
1800
Total
From Downstream
From Upstream
Incoming Flow

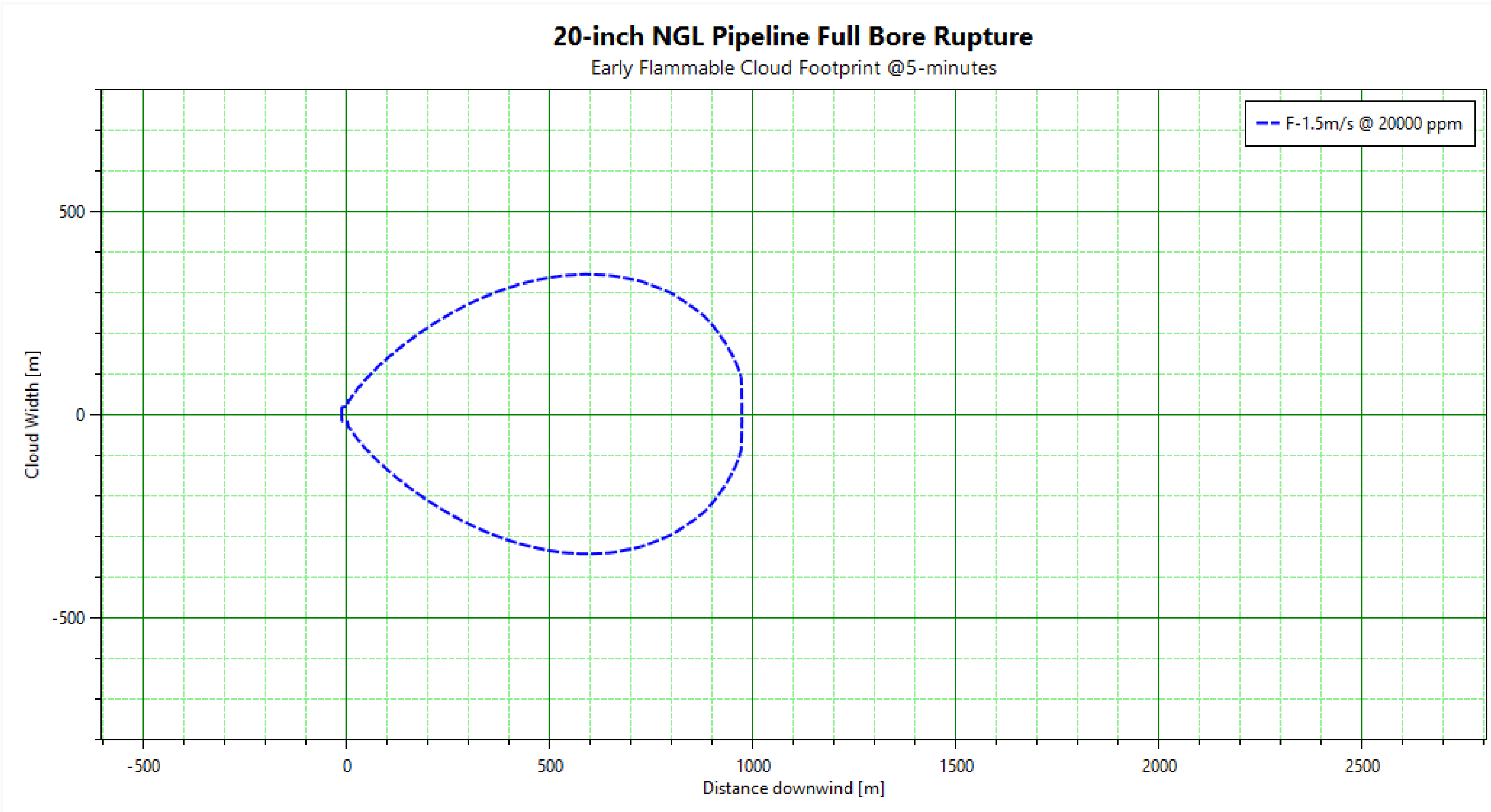

20-inch NGL Pipeline Full Bore Rupture
Jet Fire Thermal Radiation
D-4.5m/s 9.46 kW/m2
D-4.5m/s 12.5 kW/m2
D-4.5m/s 18 kW/m2
D-4.5m/s 35 kW/m2
Wind Direction
Distance Crosswind [m]
500
0
-500
-500
0
500
1000
1500
2000
2500
Distance downwind [m]

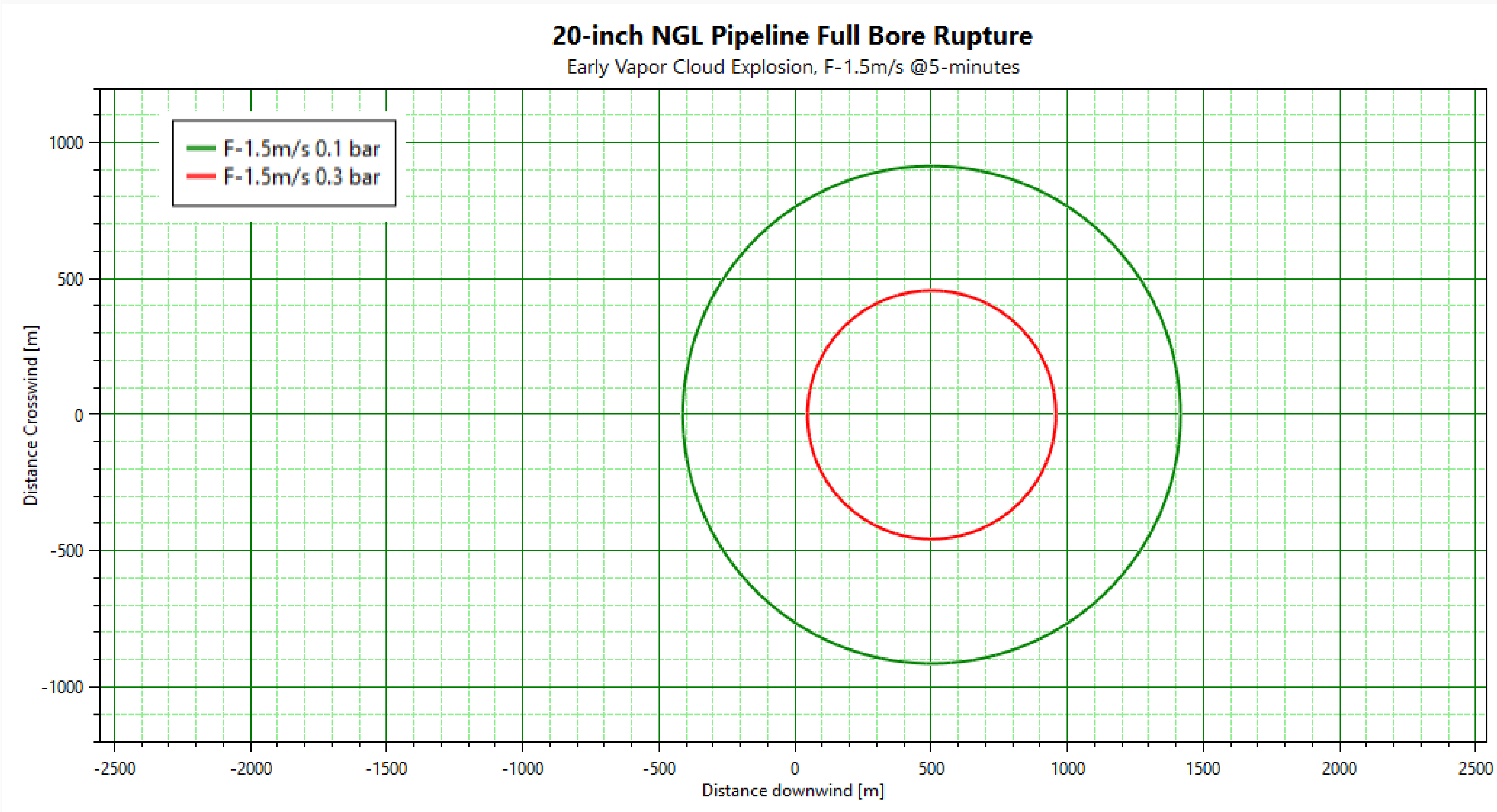

20-inch NGL Pipeline Full Bore Rupture
Early Flammable Gas Cloud Side View, D-4.5m/s @2-minutes (Exaggerated Vertical Scale)
D-4.5m/s @ 20000 ppm
Cloud Height [m]
Distance downwind [m]
0
10
20
30
40
50
60
200
400
600
800
1000
1200
1400
1600
1800
2000
2200

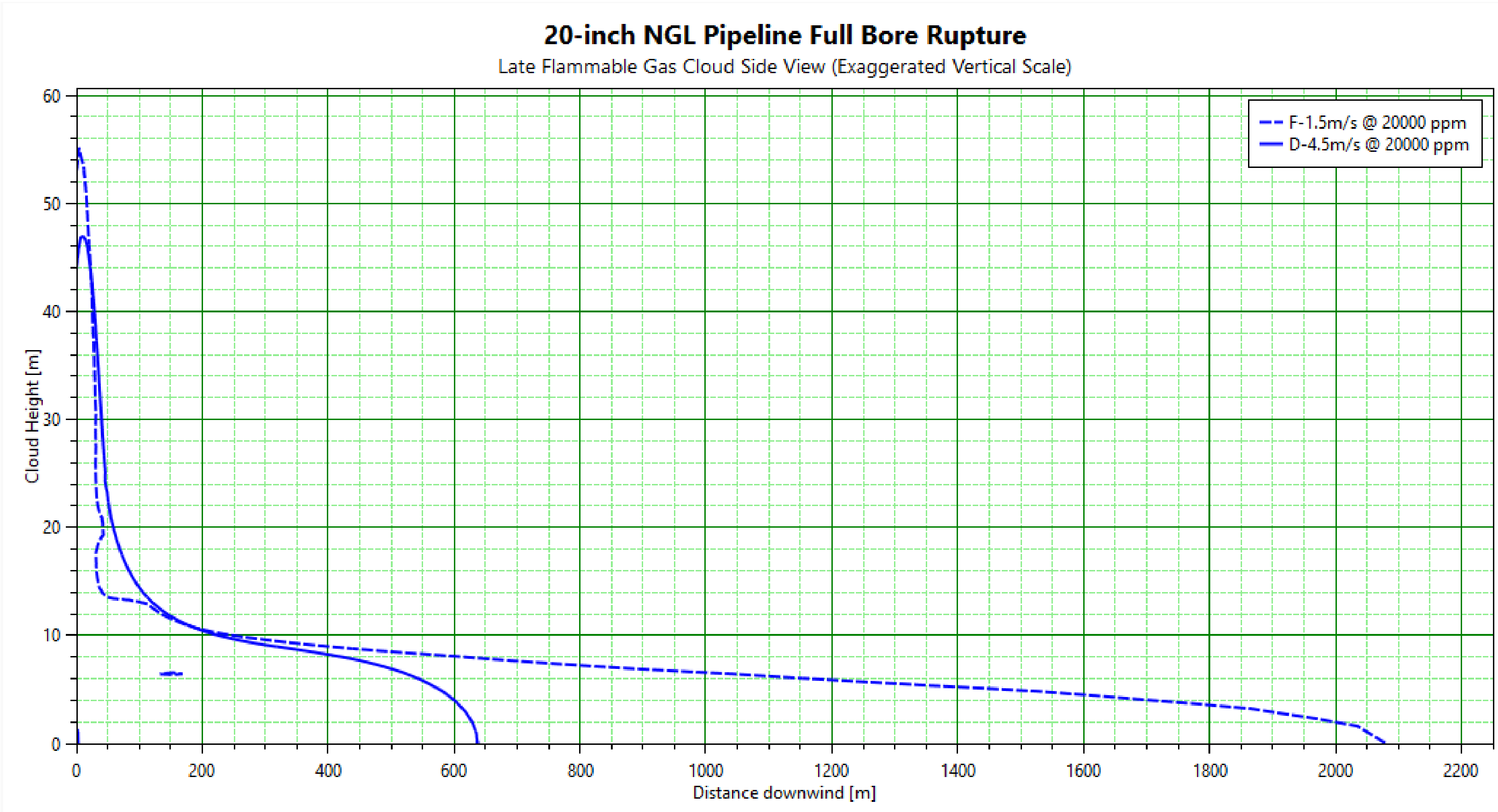

20-inch NGL Pipeline Full Bore Rupture
Early Flammable Cloud Footprint @2-minutes
D-4.5m/s @ 20000 ppm
D-4.5m/s @ 95000 ppm
500
0
-500
Cloud Width [m]
-500
0
500
1000
1500
2000
2500
Distance downwind [m]

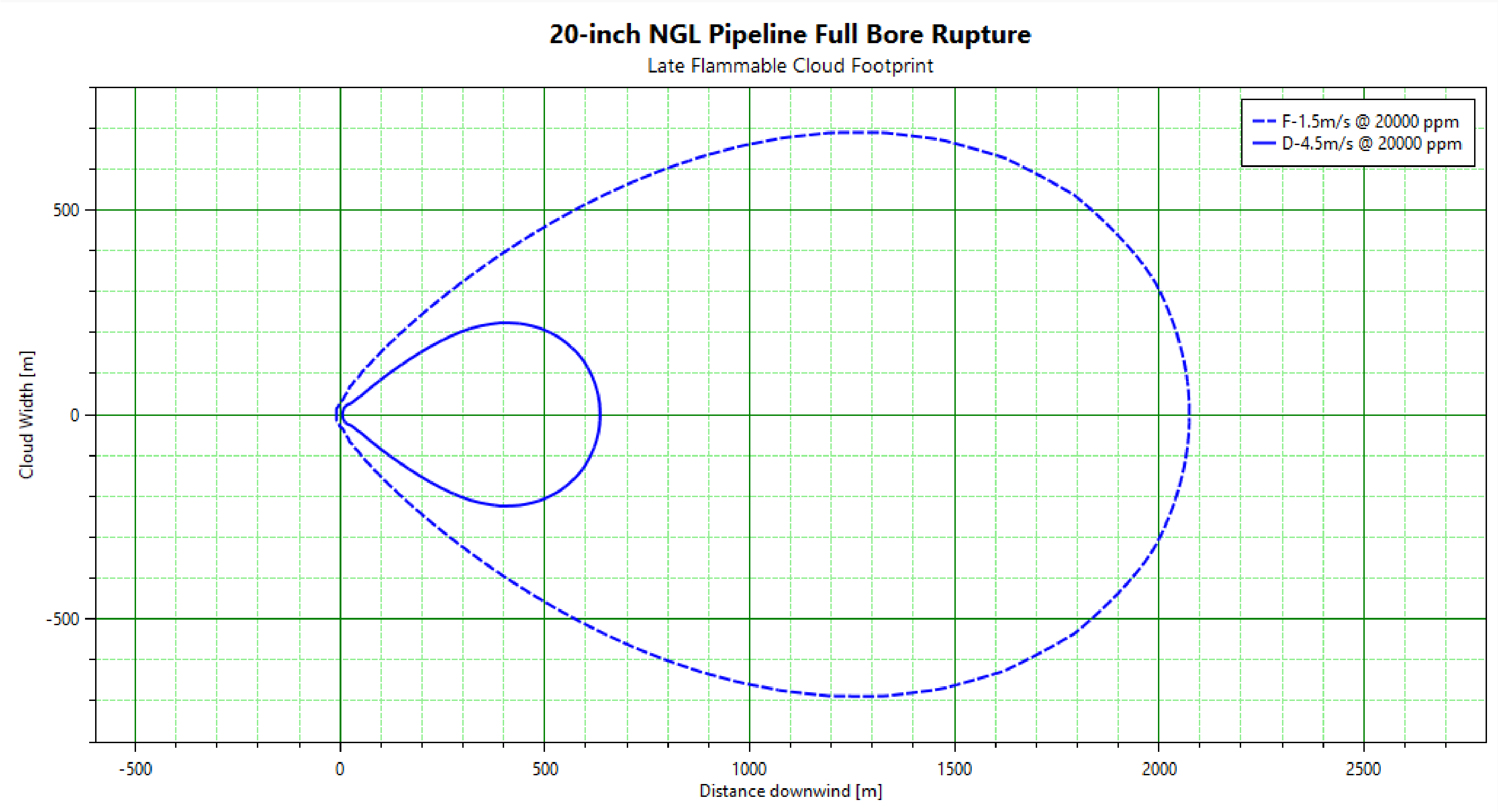

20-inch NGL Pipeline Full Bore Rupture
Early Vapor Cloud Explosion, D-4.5m/s @ 2-minutes
D-4.5m/s 0.1 bar
D-4.5m/s 0.3 bar
1000
500
0
-500
-1000
Distance Crosswind [m]
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
Distance downwind [m]

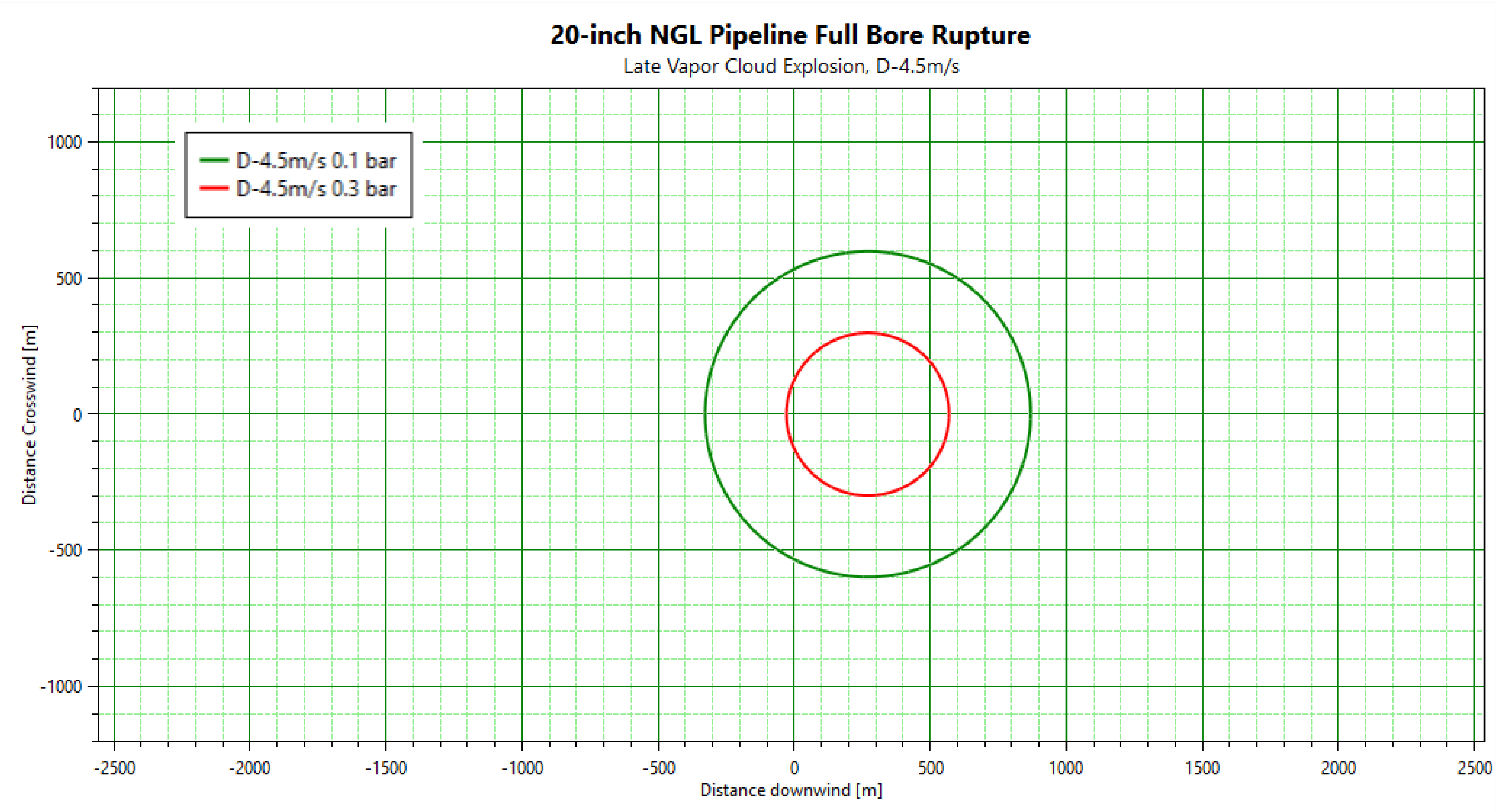

20-inch NGL Pipeline Full Bore Rupture
Early Flammable Gas Cloud Side View, F-1.5m/s @5-minutes (Exaggerated Vertical Scale)
F-1.5m/s @ 20000 ppm
Cloud Height [m]
Distance downwind [m]
0
10
20
30
40
50
60
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200

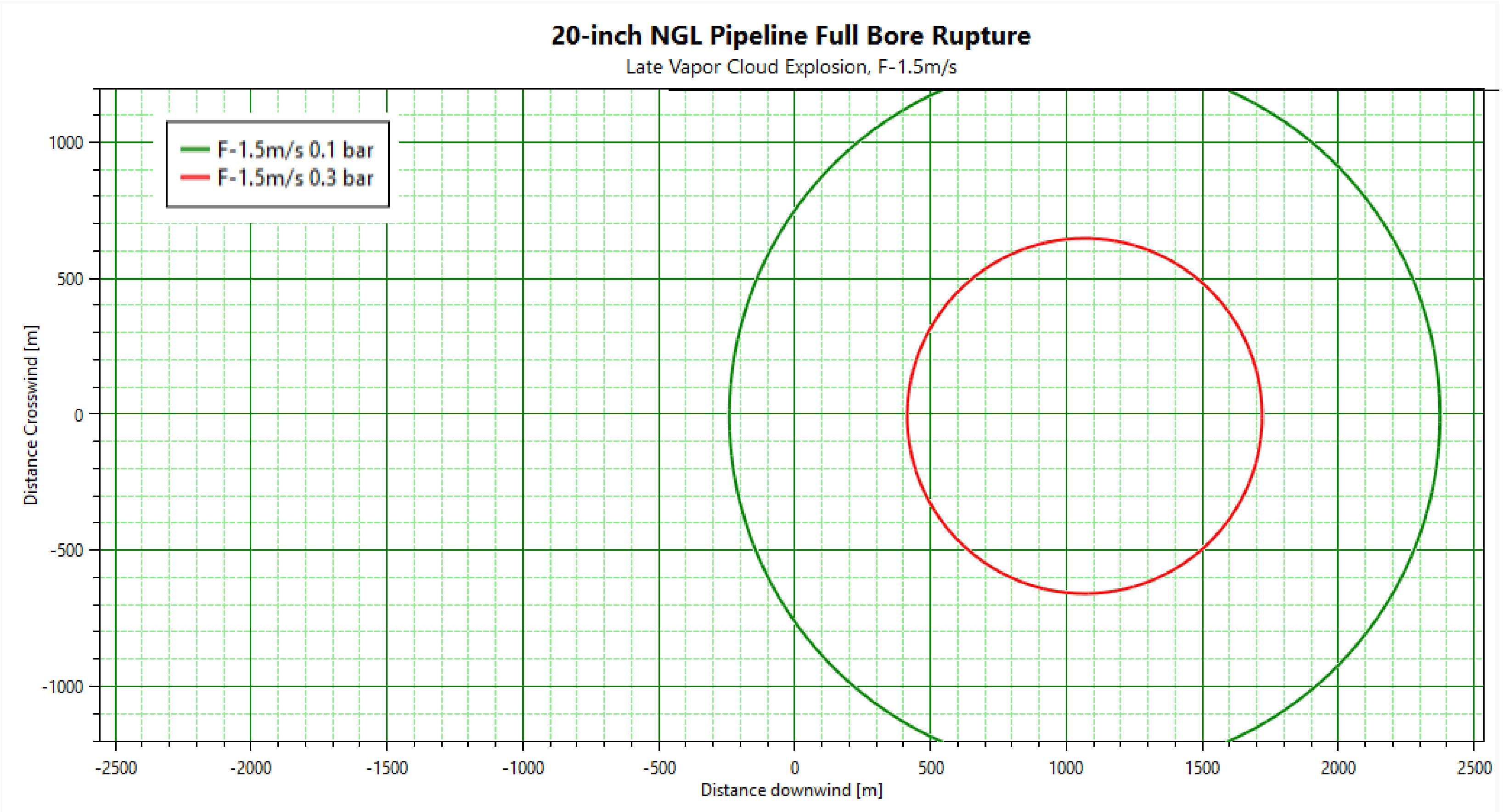

20-inch NGL Pipeline Full Bore Rupture
Early Flammable Cloud Footprint @5-minutes
F-1.5m/s @ 20000 ppm
Cloud Width [m]
500
0
-500
-500
0
500
1000
1500
2000
2500
Distance downwind [m]

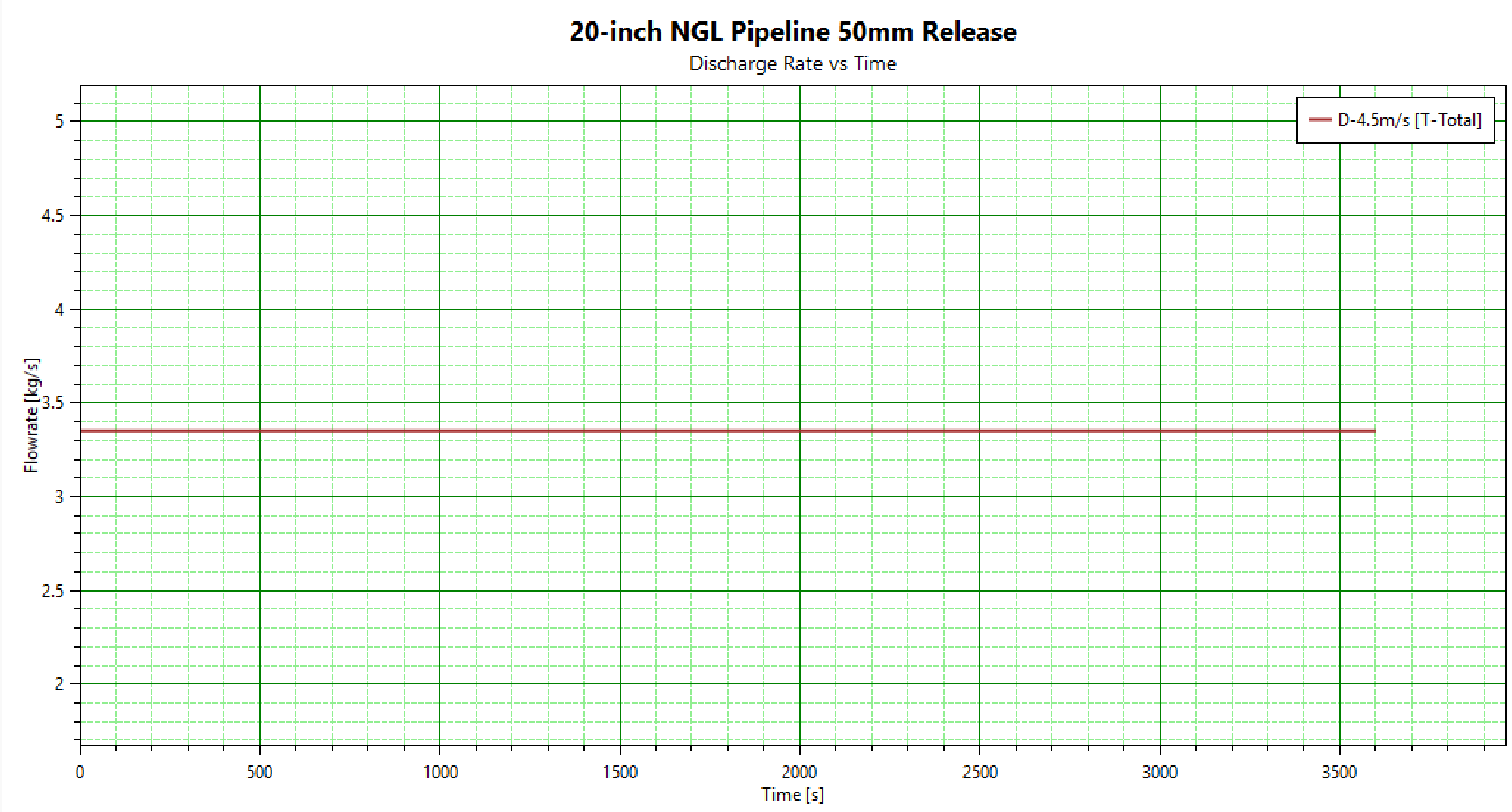

20-inch NGL Pipeline Full Bore Rupture
Early Vapor Cloud Explosion, F-1.5m/s @5-minutes
F-1.5m/s 0.1 bar
F-1.5m/s 0.3 bar
Distance Crosswind [m]
Distance downwind [m]
1000
500
0
-500
-1000
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500

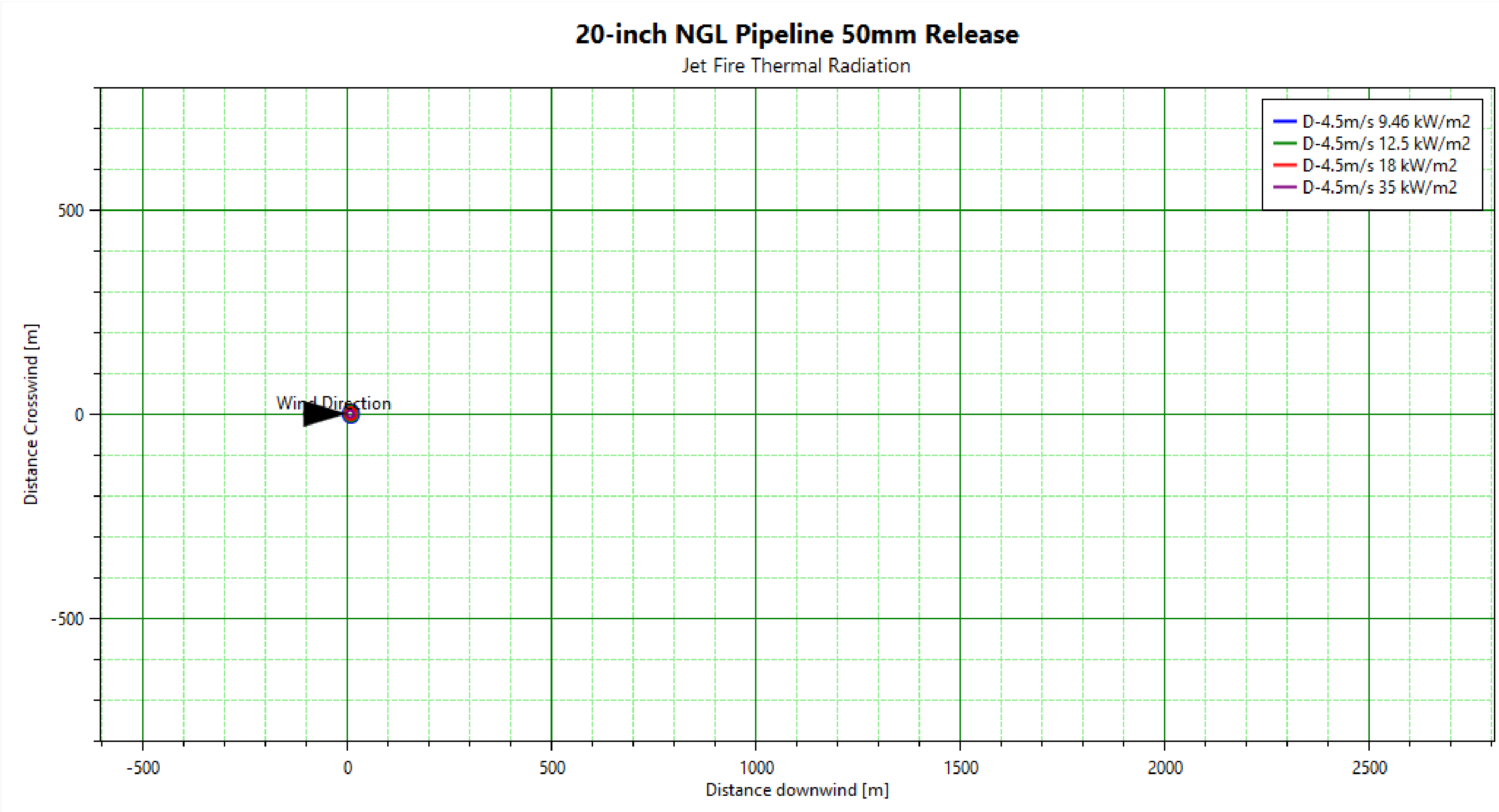

20-inch NGL Pipeline Full Bore Rupture
Late Flammable Gas Cloud Side View (Exaggerated Vertical Scale)
F-1.5m/s @ 20000 ppm
D-4.5m/s @ 20000 ppm
Cloud Height [m]
Distance downwind [m]
0
10
20
30
40
50
60
200
400
600
800
1000
1200
1400
1600
1800
2000
2200

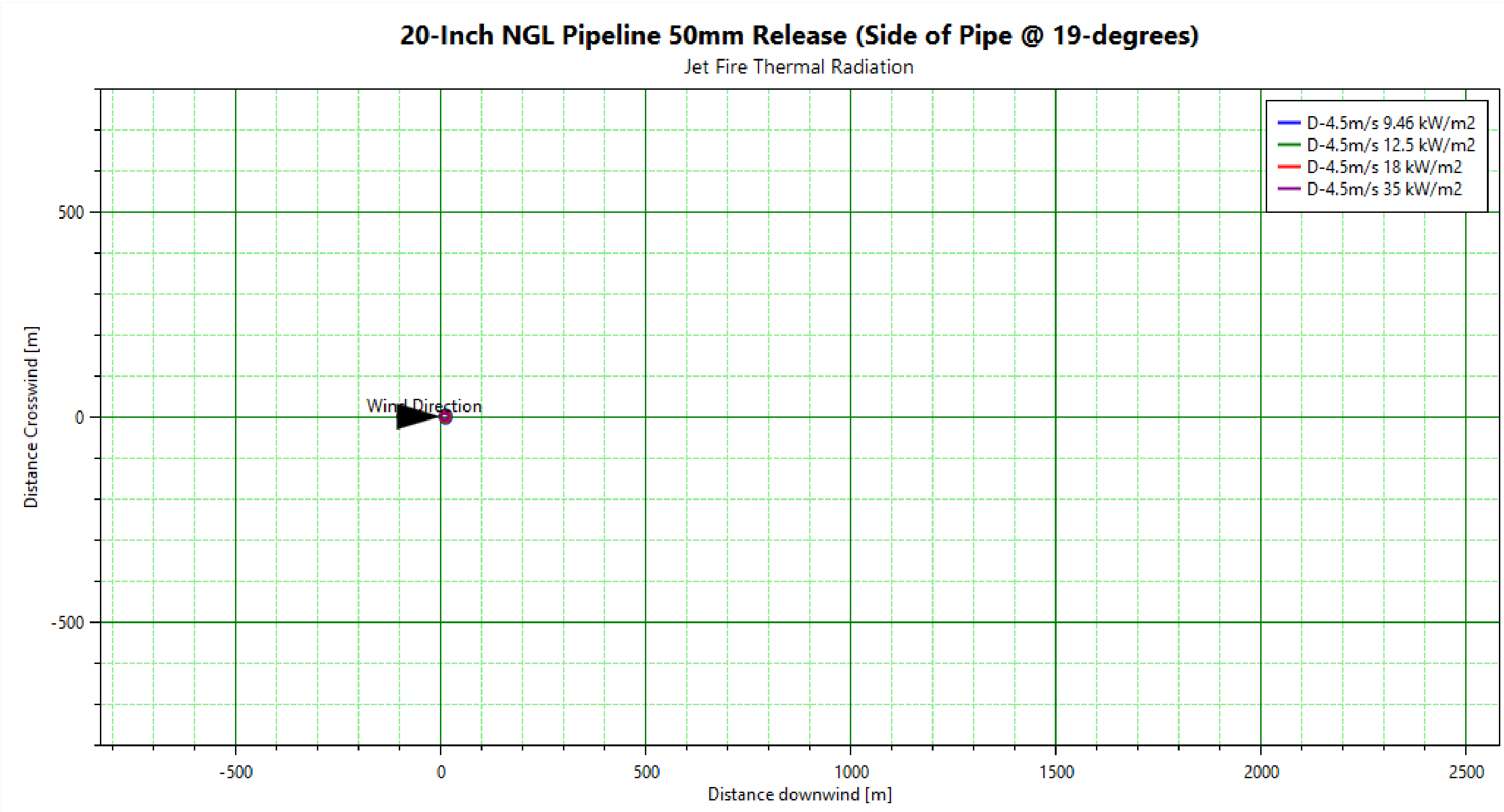

20-inch NGL Pipeline Full Bore Rupture
Late Flammable Cloud Footprint
F-1.5m/s @ 20000 ppm
D-4.5m/s @ 20000 ppm
Cloud Width [m]
500
0
-500
-500
0
500
1000
1500
2000
2500
Distance downwind [m]

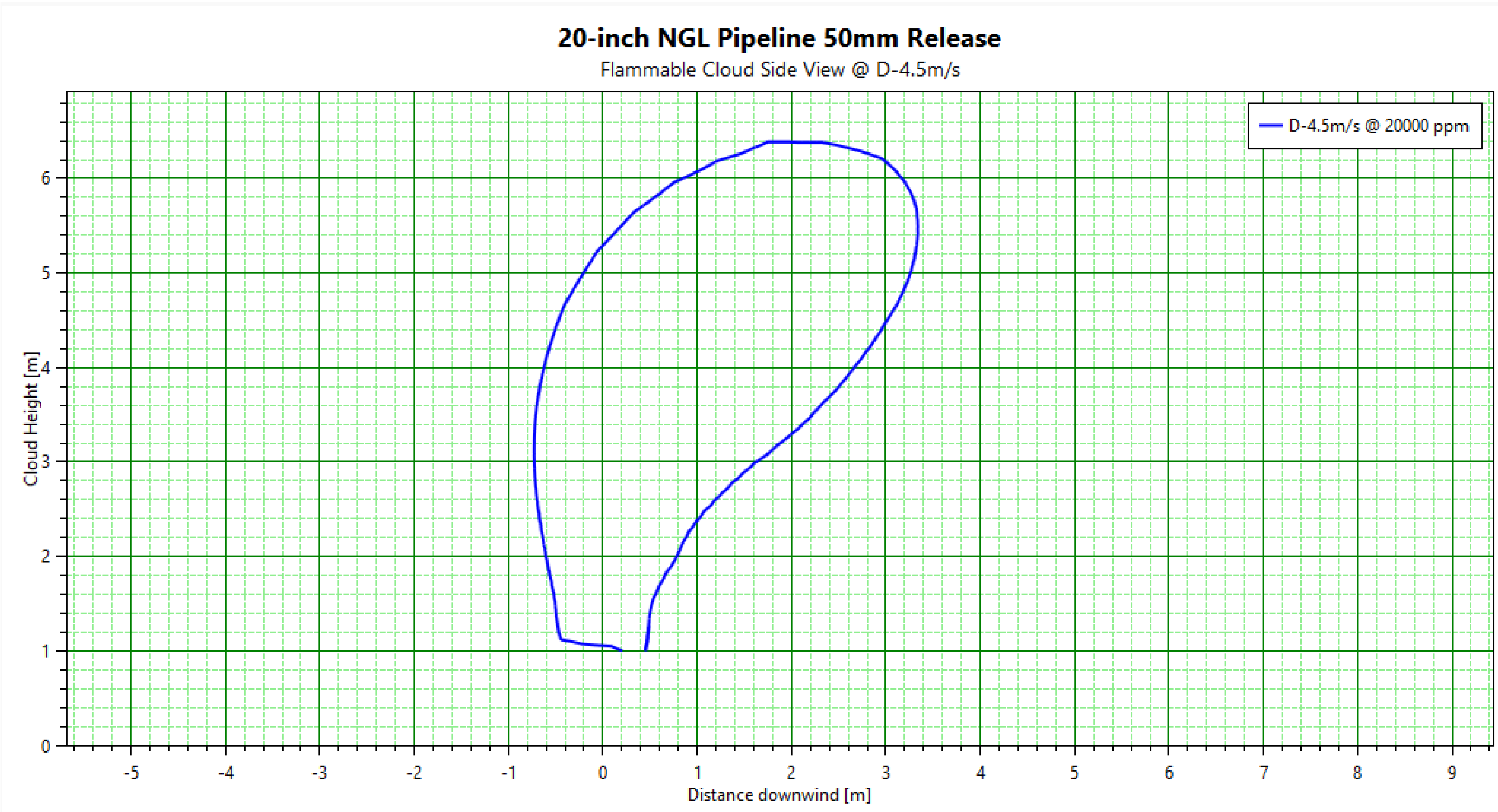

20-inch NGL Pipeline Full Bore Rupture
Late Vapor Cloud Explosion, D-4.5m/s
D-4.5m/s 0.1 bar
D-4.5m/s 0.3 bar
Distance Crosswind [m]
1000
500
0
-500
-1000
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
Distance downwind [m]

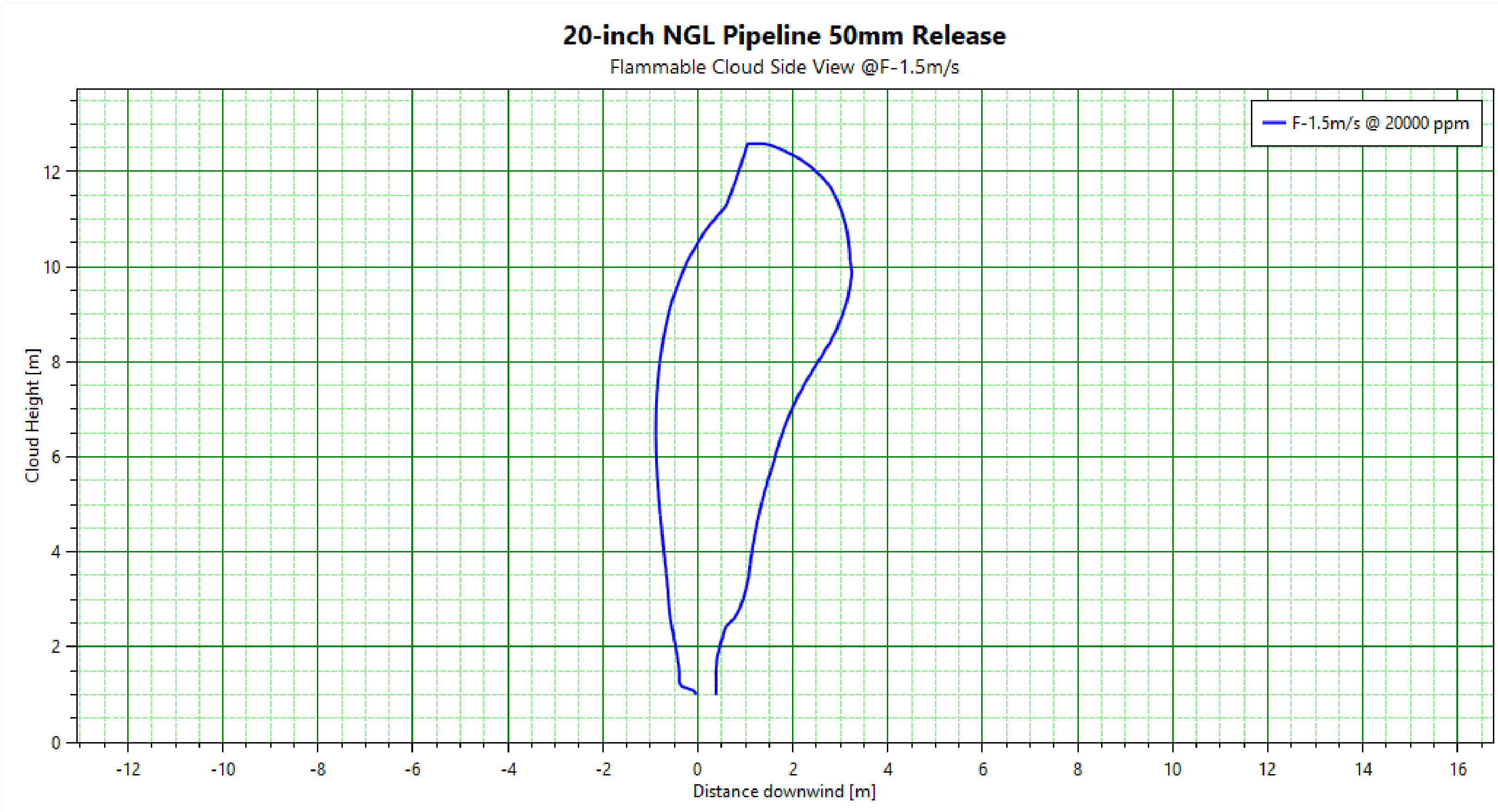

20-inch NGL Pipeline Full Bore Rupture
Late Vapor Cloud Explosion, F-1.5m/s
F-1.5m/s 0.1 bar
F-1.5m/s 0.3 bar
Distance Crosswind [m]
Distance downwind [m]
1000
500
0
-500
-1000
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500

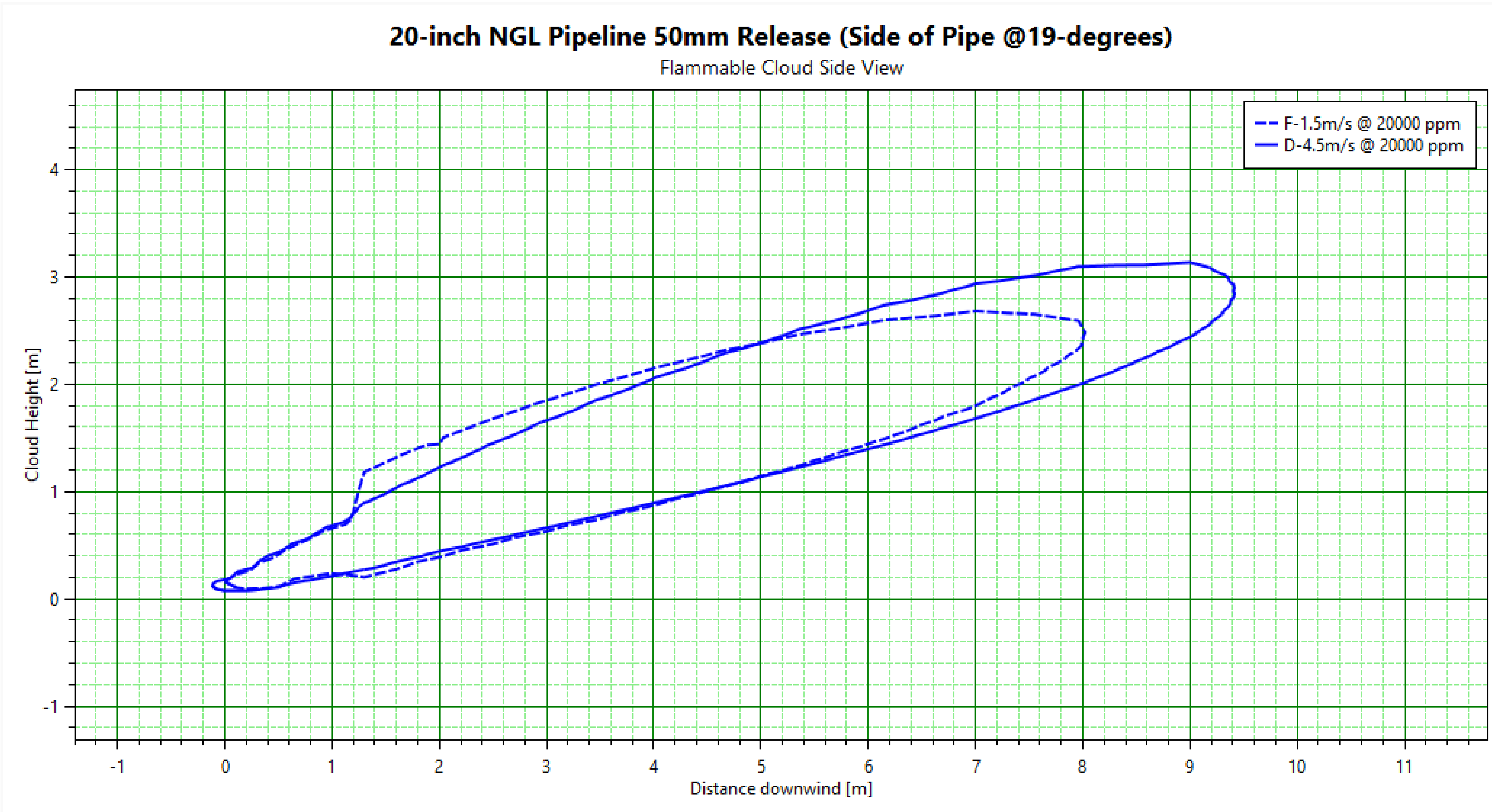

20-inch NGL Pipeline 50mm Release
Discharge Rate vs Time
D-4.5m/s [T-Total]
Flowrate [kg/s]
Time [s]
5
4.5
4
3.5
3
2.5
2
0
500
1000
1500
2000
2500
3000
3500


20-inch NGL Pipeline 50mm Release
Jet Fire Thermal Radiation
D-4.5m/s 9.46 kW/m2
D-4.5m/s 12.5 kW/m2
D-4.5m/s 18 kW/m2
D-4.5m/s 35 kW/m2
Wind Direction
Distance Crosswind [m]
Distance downwind [m]
500
0
-500
-500
0
500
1000
1500
2000
2500

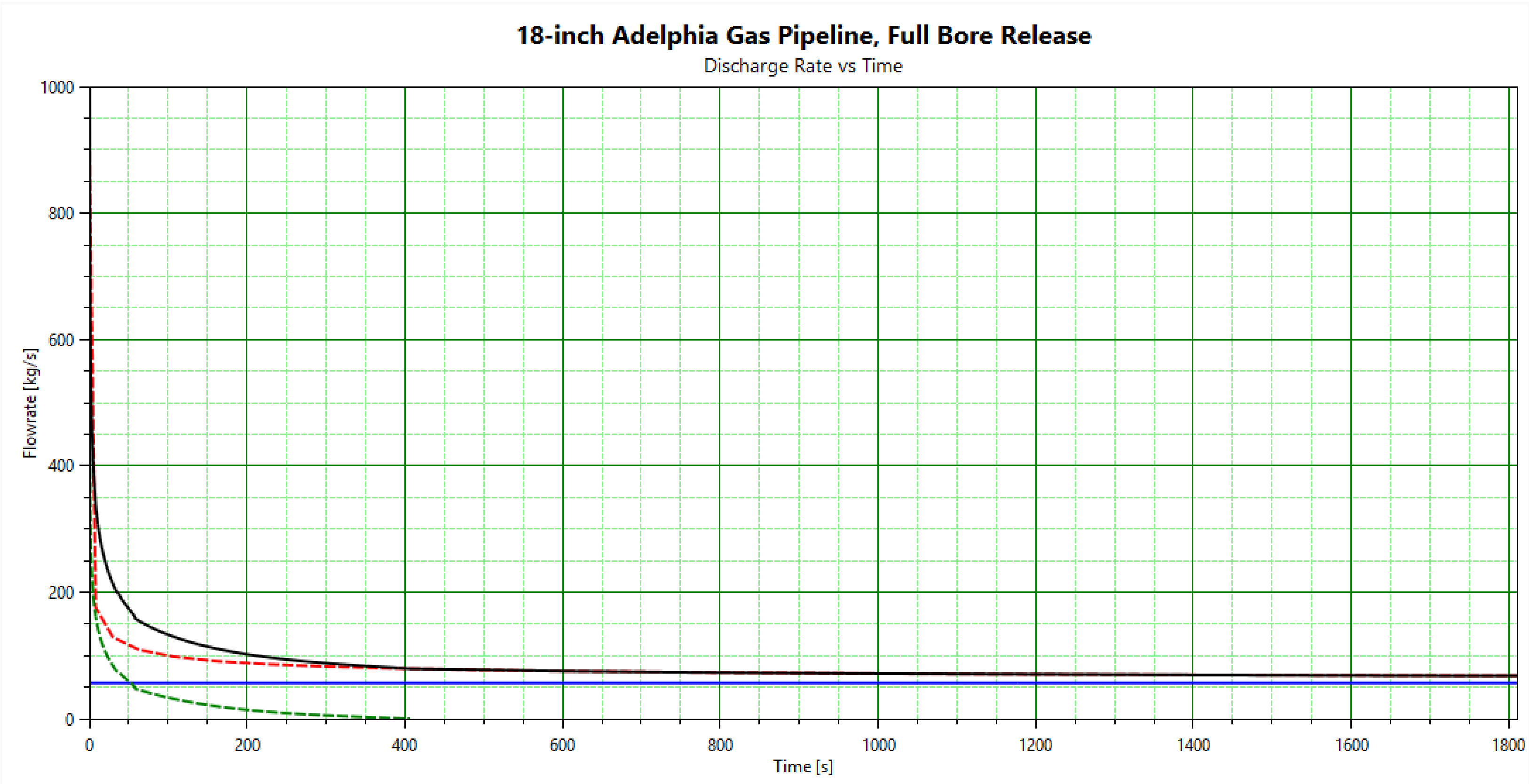

20-Inch NGL Pipeline 50mm Release (Side of Pipe @ 19-degrees)
Jet Fire Thermal Radiation
D-4.5m/s 9.46 kW/m2
D-4.5m/s 12.5 kW/m2
D-4.5m/s 18 kW/m2
D-4.5m/s 35 kW/m2
Wind Direction
Distance Crosswind [m]
500
0
-500
-500
0
500
1000
1500
2000
2500
Distance downwind [m]

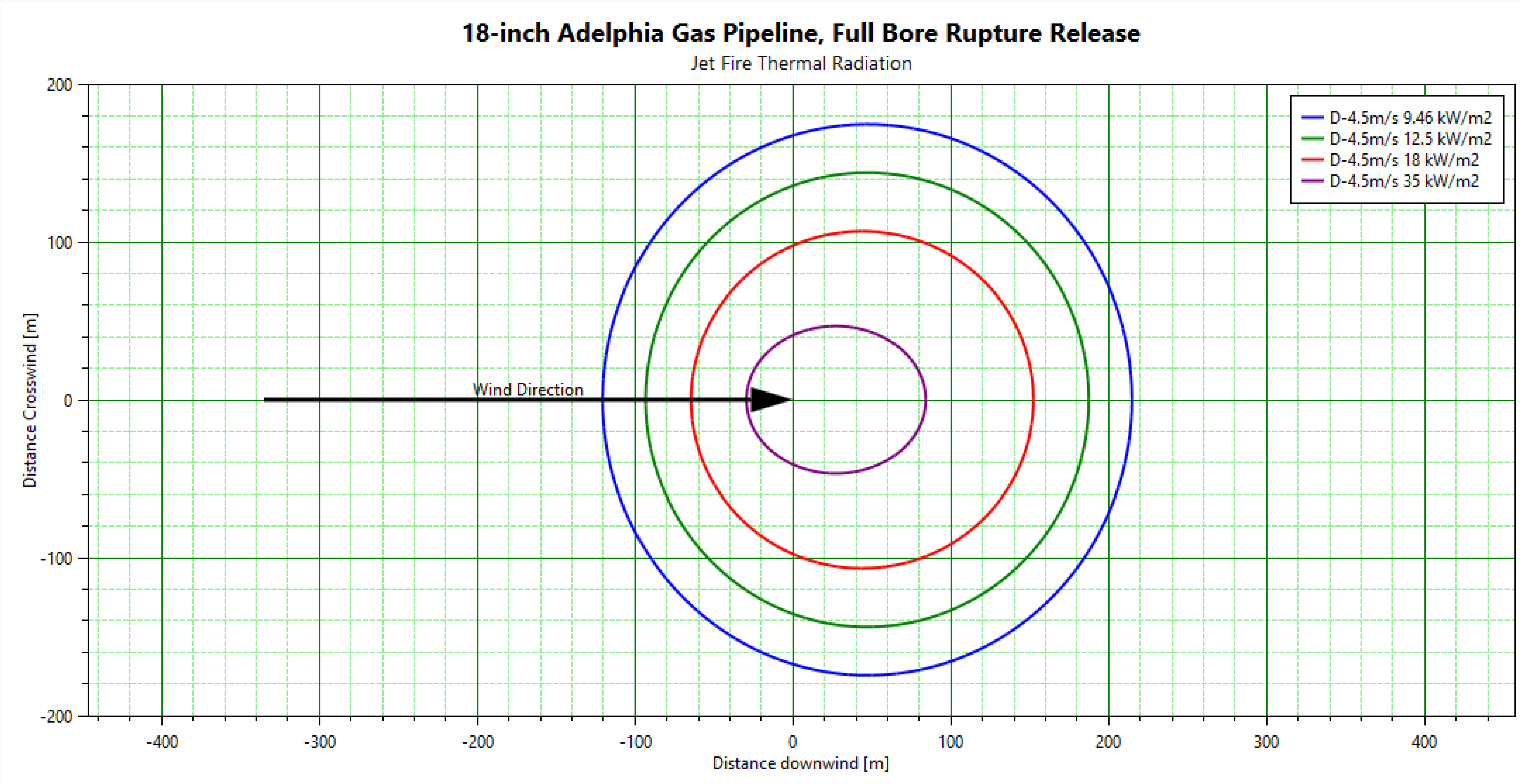

20-inch NGL Pipeline 50mm Release
Flammable Cloud Side View @ D-4.5m/s
D-4.5m/s @ 20000 ppm
Cloud Height [m]
Distance downwind [m]
0
1
2
3
4
5
6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9

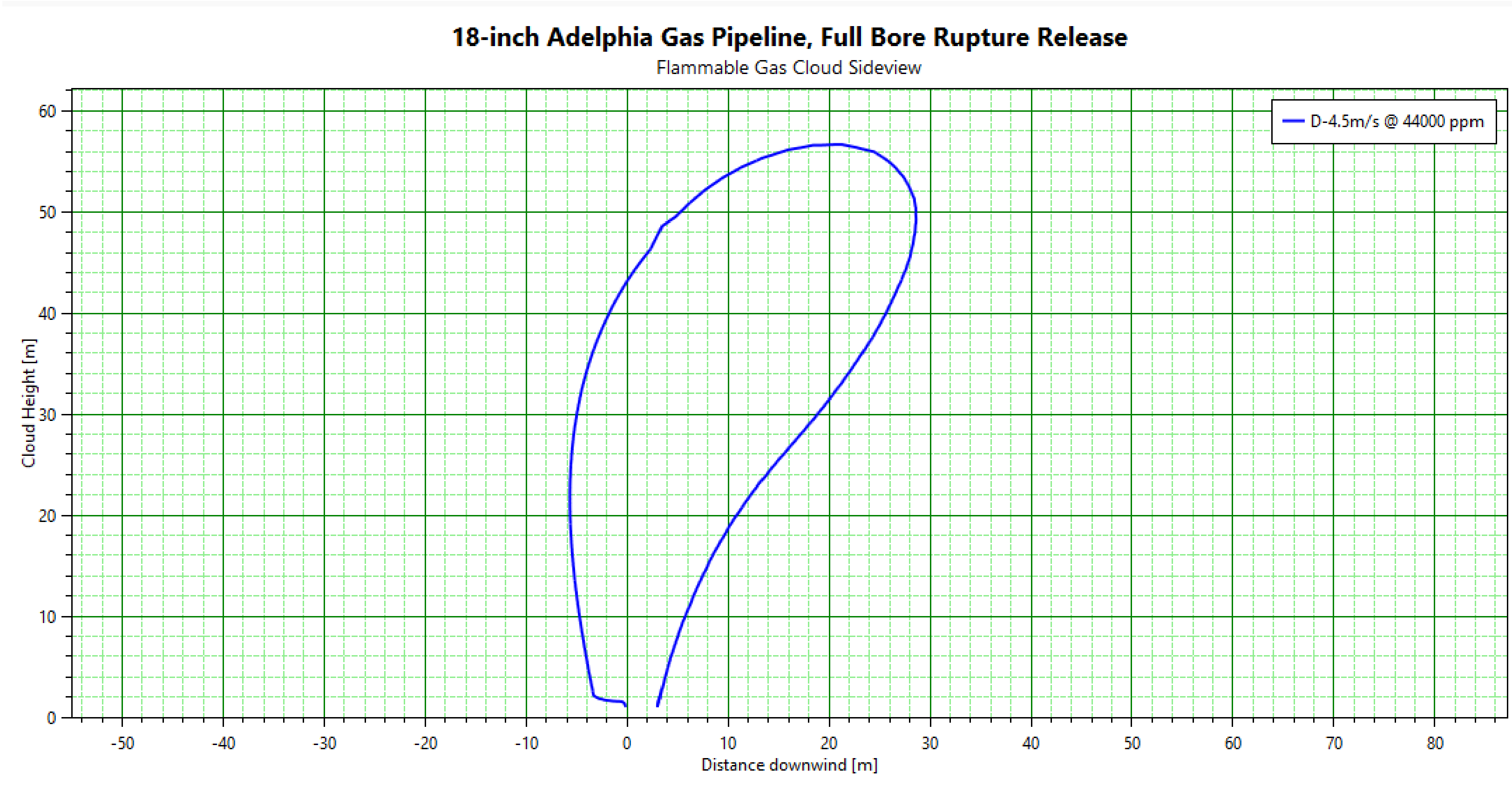

20-inch NGL Pipeline 50mm Release
Flammable Cloud Side View @F-1.5m/s
F-1.5m/s @ 20000 ppm
Cloud Height [m]
0
2
4
6
8
10
12
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
16
Distance downwind [m]

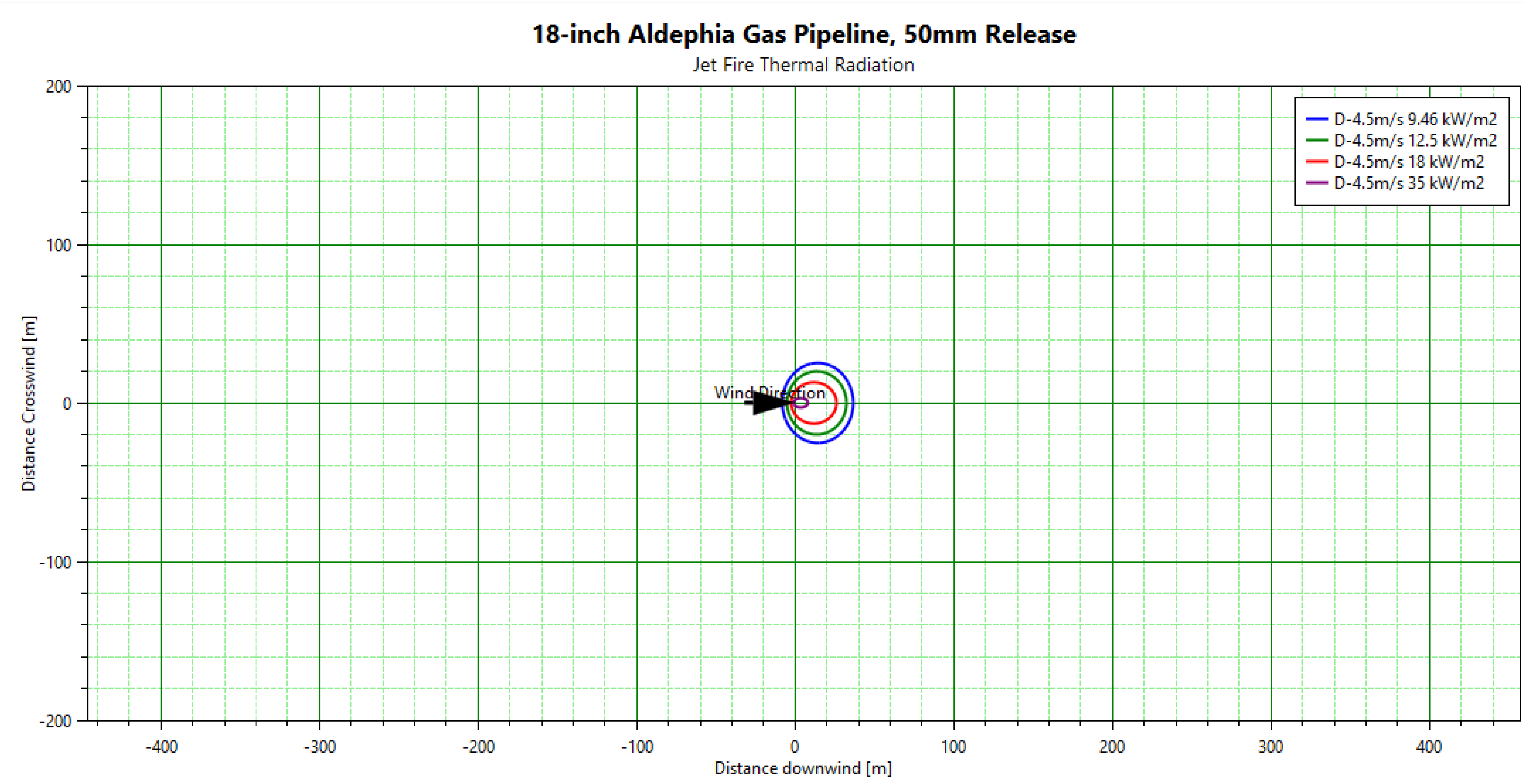

20-inch NGL Pipeline 50mm Release (Side of Pipe @19-degrees)
Flammable Cloud Side View
F-1.5m/s @ 20000 ppm
D-4.5m/s @ 20000 ppm
Cloud Height [m]
Distance downwind [m]
4
3
2
1
0
-1
-1
0
1
2
3
4
5
6
7
8
9
10
11

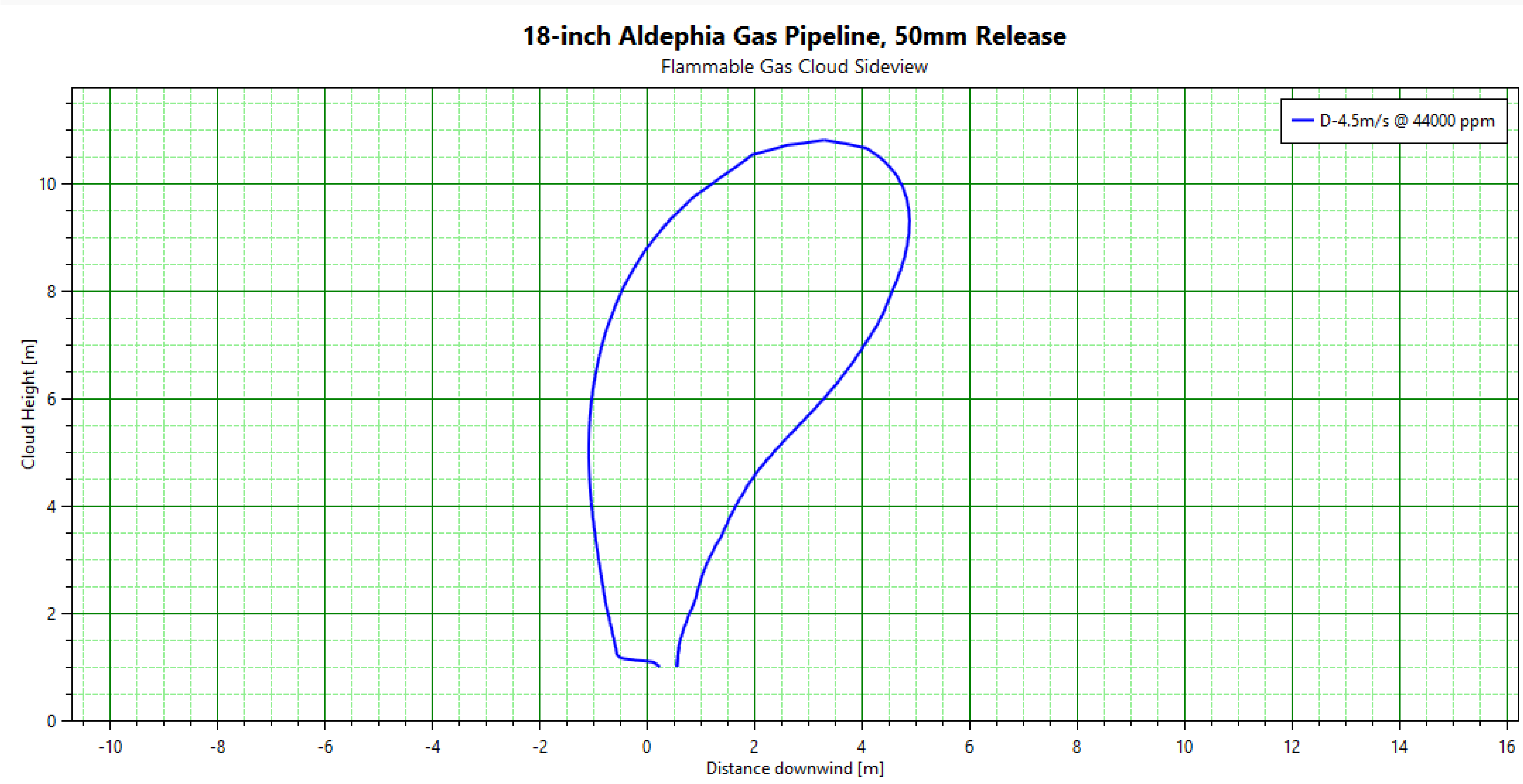
APPENDIX B: ADELPHIA PIPELINE CONSEQUENCE PLOTS


18-inch Adelphia Gas Pipeline, Full Bore Release
Discharge Rate vs Time
Flowrate [kg/s]
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
1400
1600
1800
Time [s]


18-inch Adelphia Gas Pipeline, Full Bore Rupture Release
Jet Fire Thermal Radiation
D-4.5m/s 9.46 kW/m2
D-4.5m/s 12.5 kW/m2
D-4.5m/s 18 kW/m2
D-4.5m/s 35 kW/m2
Wind Direction
Distance Crosswind [m]
Distance downwind [m]
200
100
0
-100
-200
-400
-300
-200
-100
0
100
200
300
400


18-inch Adelphia Gas Pipeline, Full Bore Rupture Release
Flammable Gas Cloud Sideview
D-4.5m/s @ 44000 ppm
Cloud Height [m]
Distance downwind [m]
60
50
40
30
20
10
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80


18-inch Aldephia Gas Pipeline, 50mm Release
Jet Fire Thermal Radiation
D-4.5m/s 9.46 kW/m2
D-4.5m/s 12.5 kW/m2
D-4.5m/s 18 kW/m2
D-4.5m/s 35 kW/m2
Wind Direction
Distance Crosswind [m]
Distance downwind [m]
200
100
0
-100
-200
-400
-300
-200
-100
0
100
200
300
400


18-inch Aldephia Gas Pipeline, 50mm Release
Flammable Gas Cloud Sideview
D-4.5m/s @ 44000 ppm
Cloud Height [m]
Distance downwind [m]
0
2
4
6
8
10
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
16

APPENDIX C: PHMSA HVL TRANSMISSION PIPELINE STATISTICS

Summary HVL Onshore Below Ground Pipeline Mileage, 2002 to Mid 2018 (inclusive)

Year	Diameter Less than 12-inch (mile-years)	Diameter 12-inch or greater (mile-years)	All Diameter Sizes (mile-years)	Comment
2002	41,135	10,621	51,757	Assume to be similar to 2004
2003	41,135	10,621	51,757	Assume to be similar to 2004
2004	41,135	10,621	51,757	
2005	40,236	10,970	51,207	
2006	41,090	11,442	52,532	
2007	42,485	11,896	54,382	
2008	43,794	13,231	57,024	
2009	43,667	13,565	57,233	
2010	43,887	14,090	57,977	
2011	44,178	14,401	58,578	
2012	44,154	15,684	59,839	
2013	44,445	18,321	62,766	
2014	45,585	20,208	65,793	
2015	46,500	21,169	67,670	
2016	46,473	22,385	68,858	
2017	46,037	22,763	68,799	
Mid 2018*	23,018	11,381	34,400	Assume 2018 similar to 2017 and prorate*
Total	**718,956**	**253,371**	**972,328**	

* Count only half of 2018 to align with incidents used

HVL Onshore Below Ground Pipeline Incident Frequency

Diameter	Number of Full Bore LoC Incidents 2002 to Mid 2018 (inclusive)	Full Bore LoC Incidents Frequency (LoC incidents/mile-year)
Less than 12-inch	22	3.1E-05
12-inch or greater	6	2.4E-05
All Diameter Sizes	**28**	**2.88E-05**

APPENDIX D: PHMSA NATURAL GAS TRANSMISSION PIPELINE STATISTICS

Summary Natural Gas Onshore Below Ground Pipeline Mileage, 2002 to 2017 (inclusive)

Year	Diameter 10-inches and less (mile-years)	Diameter Over 10-inches thru 28-inches (mile-years)	Diameter Over 28-inches (mile-years)	All Diameter Sizes (mile-years)	Comment
2002	93,339	135,496	67,013	295,849	
2003	88,242	138,374	68,333	294,949	
2004	88,409	137,564	70,882	296,855	
2005	89,295	133,985	68,716	291,996	
2006	86,887	136,430	70,329	293,646	
2007	89,576	134,039	71,136	294,751	
2008	88,530	135,070	73,617	297,217	
2009	86,379	135,952	76,527	298,857	
2010	89,264	134,793	75,307	299,364	
2011	88,255	132,434	79,035	299,723	
2012	86,670	133,155	78,830	298,654	
2013	86,150	133,015	79,228	298,392	
2014	85,586	132,746	79,583	297,915	
2015	85,994	132,060	79,279	297,333	
2016	85,286	131,766	79,866	296,918	
2017	84,273	131,823	81,474	297,570	
2018	42,136	65,912	40,737	148,785	Extrapolated 2017 mileage and prorated for the 6 months of 2018. This was done to match the incident data range 2002-2018 (half year)
Total	**1,444,269**	**2,214,615**	**1,239,890**	**4,898,775**	

Natural Gas Onshore Below Ground Pipeline Incident Frequency

Diameter	Number of Full Bore LoC Incidents 2002 to mid-2018 (inclusive)	Full Bore LoC Incidents Frequency (LoC incidents/mile-year)	Small to Large LoC Incident Frequency* (LoC incidents/mile-year)
10-inches and less	47	3.3E-05	8.1E-05
Over 10-inches thru 28-inches	128	5.8E-05	1.4E-04
Over 28-inches	37	3.0E-05	7.5E-05
All Diameter Sizes	212	4.3E-05	1.1E-04

* Assumed 50mm frequency to be 2.5X Full Bore Frequency, per OGP recommendation distribution for onshore oil pipelines