QUEST
CONSULTANTS INC.®

Mariner Pipeline Quantitative Risk Analysis

Chester & Delaware Counties, PA

About Quest Consultants Inc.

- Formed in 1989
- Process safety engineering consulting
  - Specializing in consequence and risk analysis, primarily regarding hydrocarbon hazards
- Clients include government entities, petrochemical industry, other organizations

About Quest Consultants Inc.

- Consequence and risk analysis studies for pipelines (natural gas, HVLs, liquids), gas plants, LPG transshipment facilities, refineries….
- Consultant to PHMSA for LNG project review, code compliance issues, inspector education
- Process hazards analysis (PHA) studies
- Training: consequence analysis, risk analysis, liquefied gas safety, LNG, PHA

CANARY by Quest®
Consequence Modeling Software

- Multicomponent thermophysical properties
- Release rate calculations

- Vapor dispersion analysis
- Explosion overpressure
- Fire radiation (jet, pool, fireball)

- All models adapted from public domain, validated

Research & Testing

Fire Radiation Tests

SPONSORS

DOE

Coast Guard

NBS

Private Companies

MATERIALS

Natural Gas, LPG, LNG

Carbon Disulfide, Hexane, Crude Oil

Research & Testing

Aerosol Tests

SPONSORS

EPA
DOE
CCPS
PERF
Individual Companies

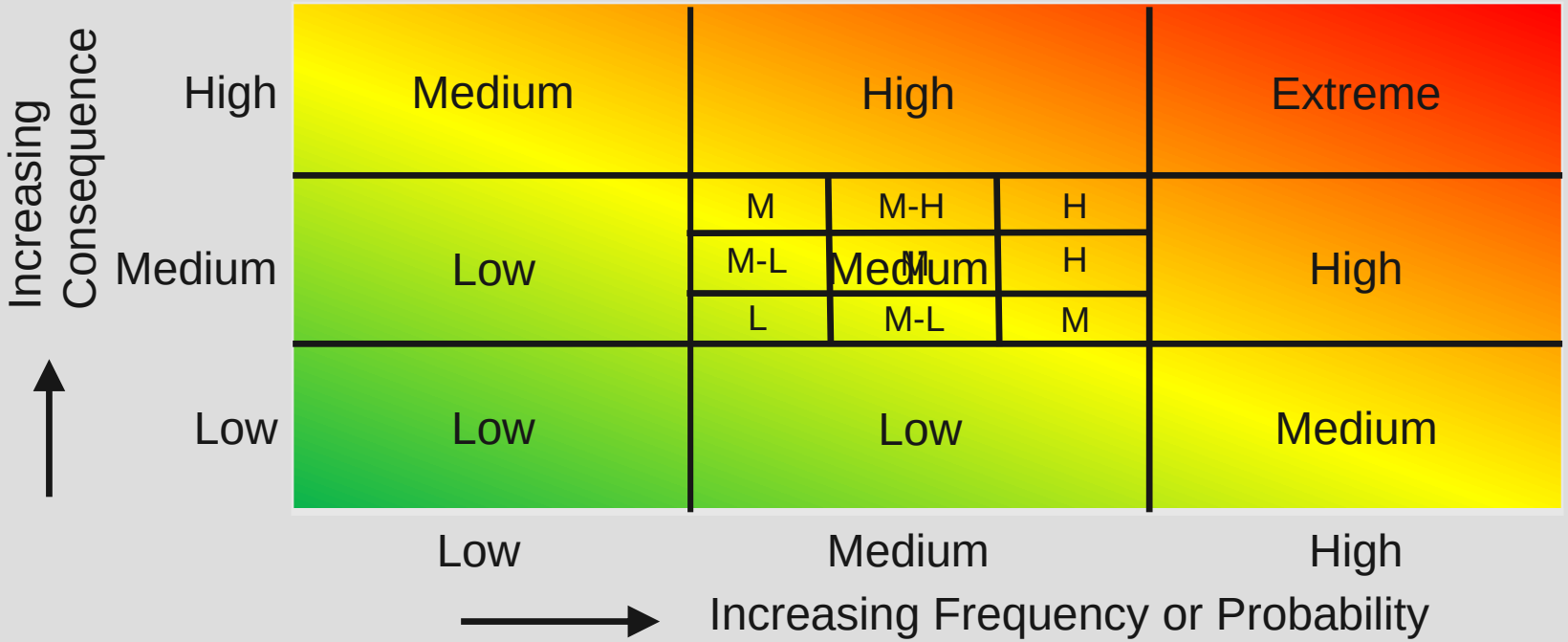
MATERIALS

Chlorine
Ammonia
Propane
Ethylene Oxide
Sulfuric Acid
Hydrofluoric Acid
Methylamine
Cyclohexane

So What Are We Doing?

- QRA = quantitative risk analysis
- QRA for the Mariner East pipeline(s) to describe the impacts to people
- Risk = consequence * frequency
- In this work, risk is: the calculated annual probability of fatality to a single individual, based on their proximity to the pipeline(s).

Understanding Risk



Why Risk of Fatality?

- The consequences of various hazards can be compared and added together.
  - Fire, explosion, etc.
- Calculated risk can be compared to other fatality risks.
- Calculated risk can be compared to international and regulatory risk acceptability criteria, which are ALL defined in terms of fatality.

Probability Numbers

- Consider an event whose probability is one in one thousand (1/1,000) per year
  - Probability of 0.001 per year
  - 1.0×10^{-3} per year (or 1E-03 or 10^{-3})
- Or an event whose probability one in one million (1/1,000,000) per year
  - Probability of 0.000001 per year
  - 1.0×10^{-6} per year (or 1E-06 or 10^{-6})

System Data

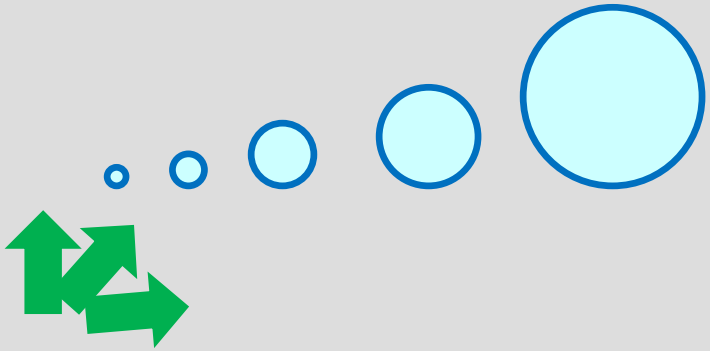
- Pipeline data collected from publically available sources
- ME1, 8”; ME2, 20”; ME2X, 16”
- Ethane, propane, butane (HVLs)
- 1480 psig = MOP
- Up to 275,000 barrels per day in ME2
- Pipeline route; pump stations

What is an HVL?

- Highly volatile liquid
- This class of materials can generally be described as those that are kept as liquid by pressure, but will return to a vapor state when released to the atmosphere.
- Includes ethane, propane, butane

Failure Case Definition

- Release from a Mariner pipeline
  - Buried sections
  - Valve stations
  - HDD sections
- Ruptures, punctures, leaks
- Release orientation
- Weather conditions



Frequency Analysis

- PHMSA database for HVL pipeline releases
- HCRD for aboveground equipment
- In Chester & Delaware Counties, 1 release every 79 years per Mariner pipeline (35 miles)
- If ME1 + ME2 + ME2X: 1 release every 26 years
- For ME1 + ME2 + ME2X in all of Pennsylvania: 1 release about every 2.8 years (1,000 miles)

Release Modeling

- System behavior and release rates modeled with CANARY
- HVL behavior in pipe
- HVL behavior at release point
- Time-varying release rate
- Release rate determines the extent of impacts

Kingman, KS, 2004, HVL Pipeline

Consequence Analysis

- Consequences modeled with CANARY
- Immediate ignition → jet fire
- Delayed ignition
  - Flammable vapor cloud → flash fire
  - Vapor cloud explosion possible
  - Jet fire
- No ignition = no impacts

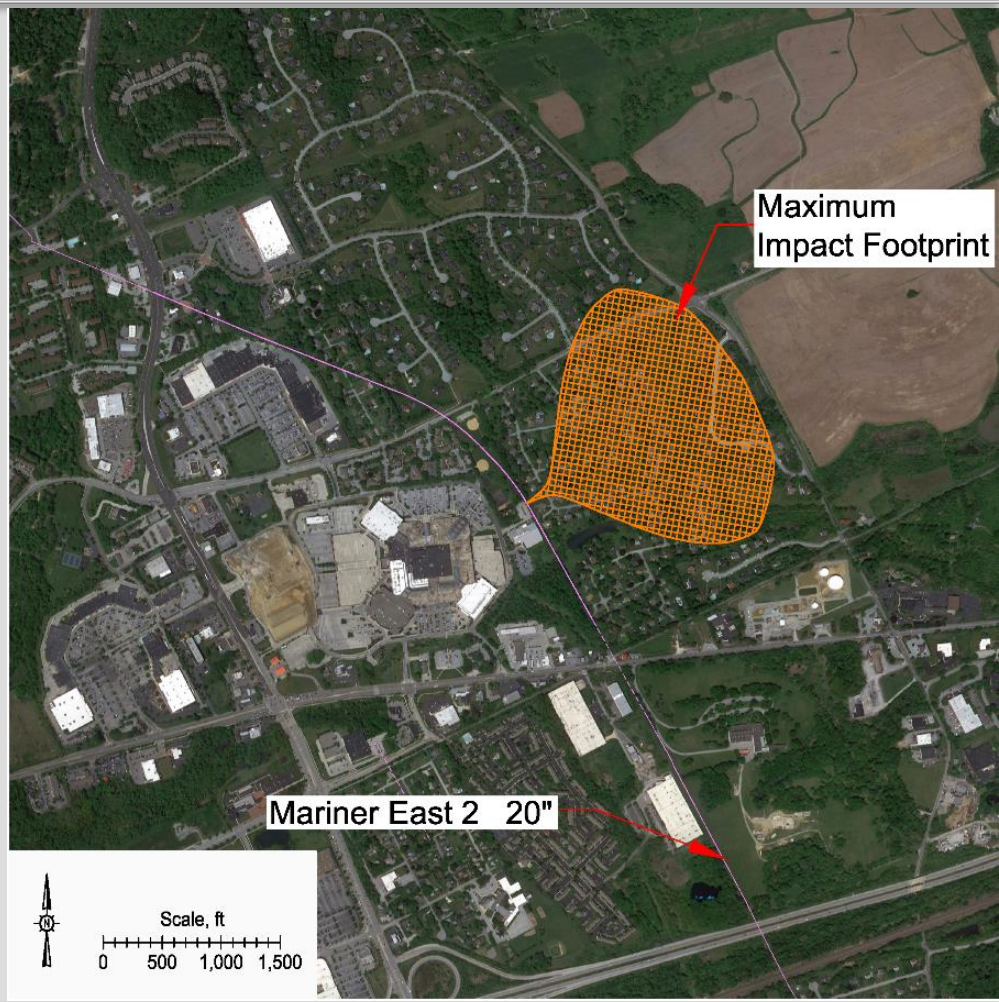
Cleburne, TX, 2010, Natural Gas Pipeline

Consequence Analysis

- ¼, ¾, 2, and 6-inch holes, plus pipeline rupture
- ¼ inch (leak) worst case for ME2/propane
  - Maximum 120 foot flammable cloud (flash fire)
  - Maximum 60 feet for burns from jet fire
- Rupture (20 inch) worst case for ME2/propane
  - Maximum 2,130 foot flammable cloud (flash fire)
  - Maximum 1,010 feet for burns from jet fire

Impact Zone (or Footprint)

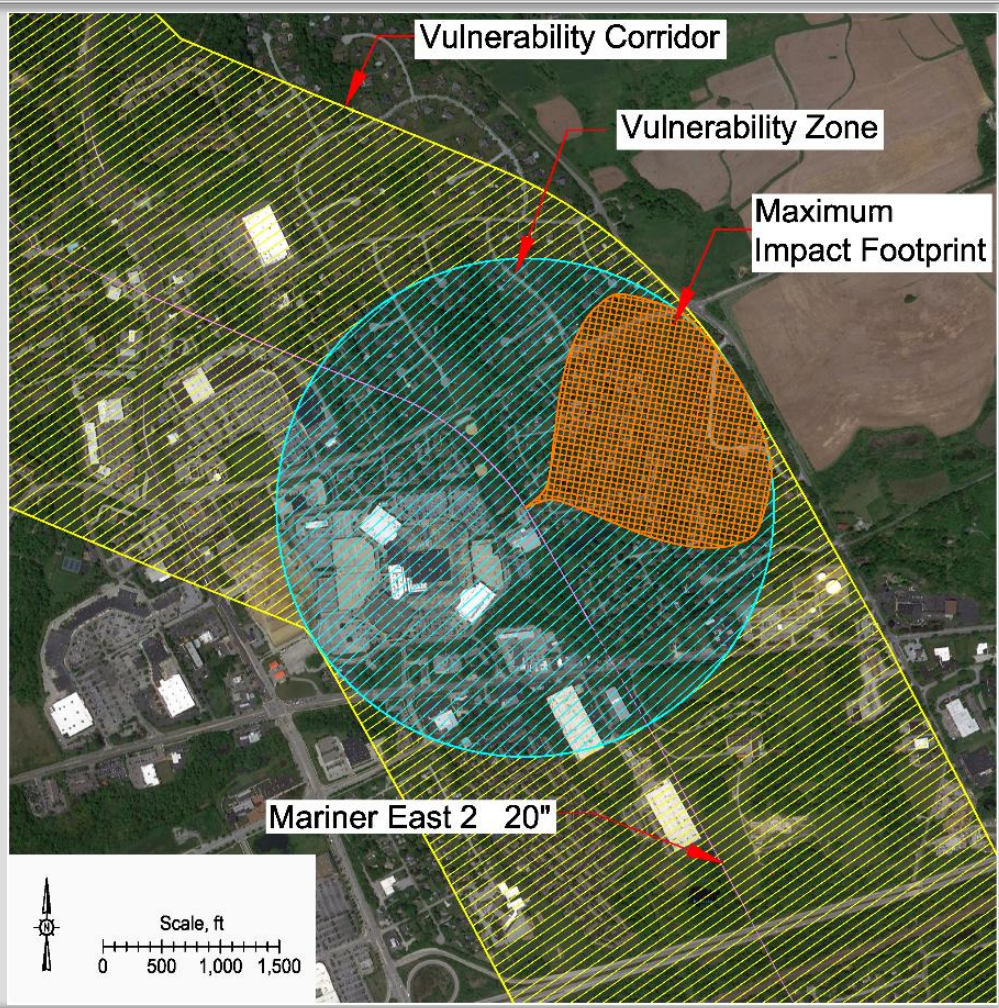
The area over which a given incident outcome is capable of producing undesirable consequences



Chester County Library Area

Vulnerability Zone

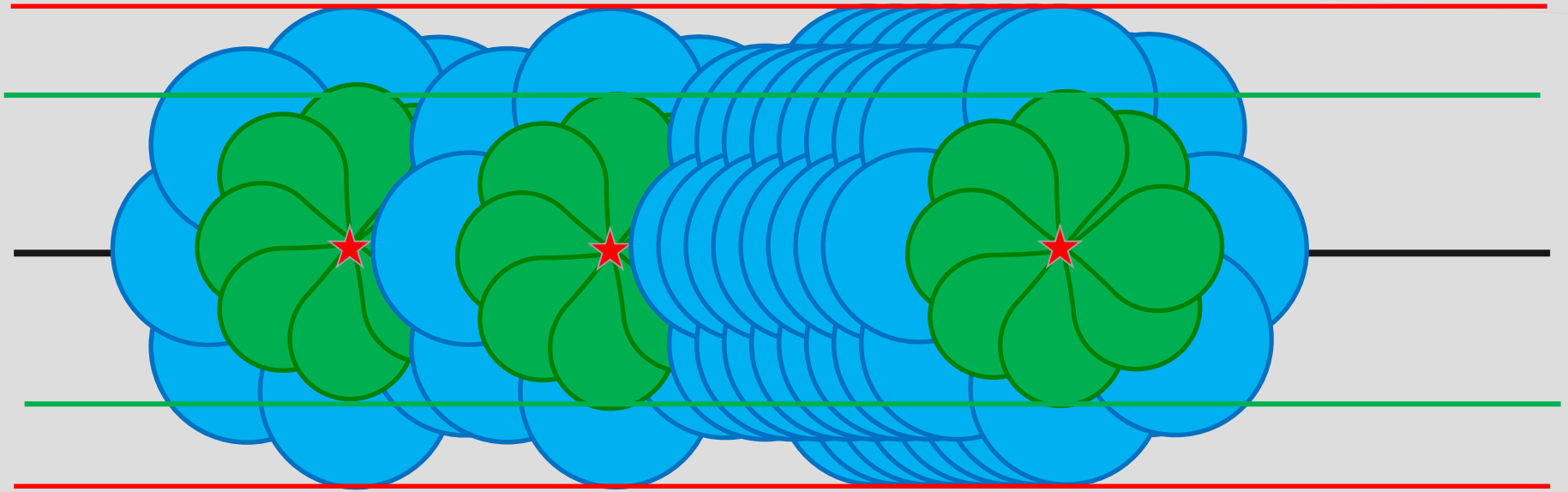
The area within the circle created by rotating an impact zone around its points of origin.



Risk Calculation

- Application of each possible impact area
  - Release location, orientation
  - Hole size, weather conditions
- For a location, risk is developed by summation of all possible impacts with each unique event's probability
- Over all possible events, the measure of risk is location-specific probability of fatality

Risk Calculation

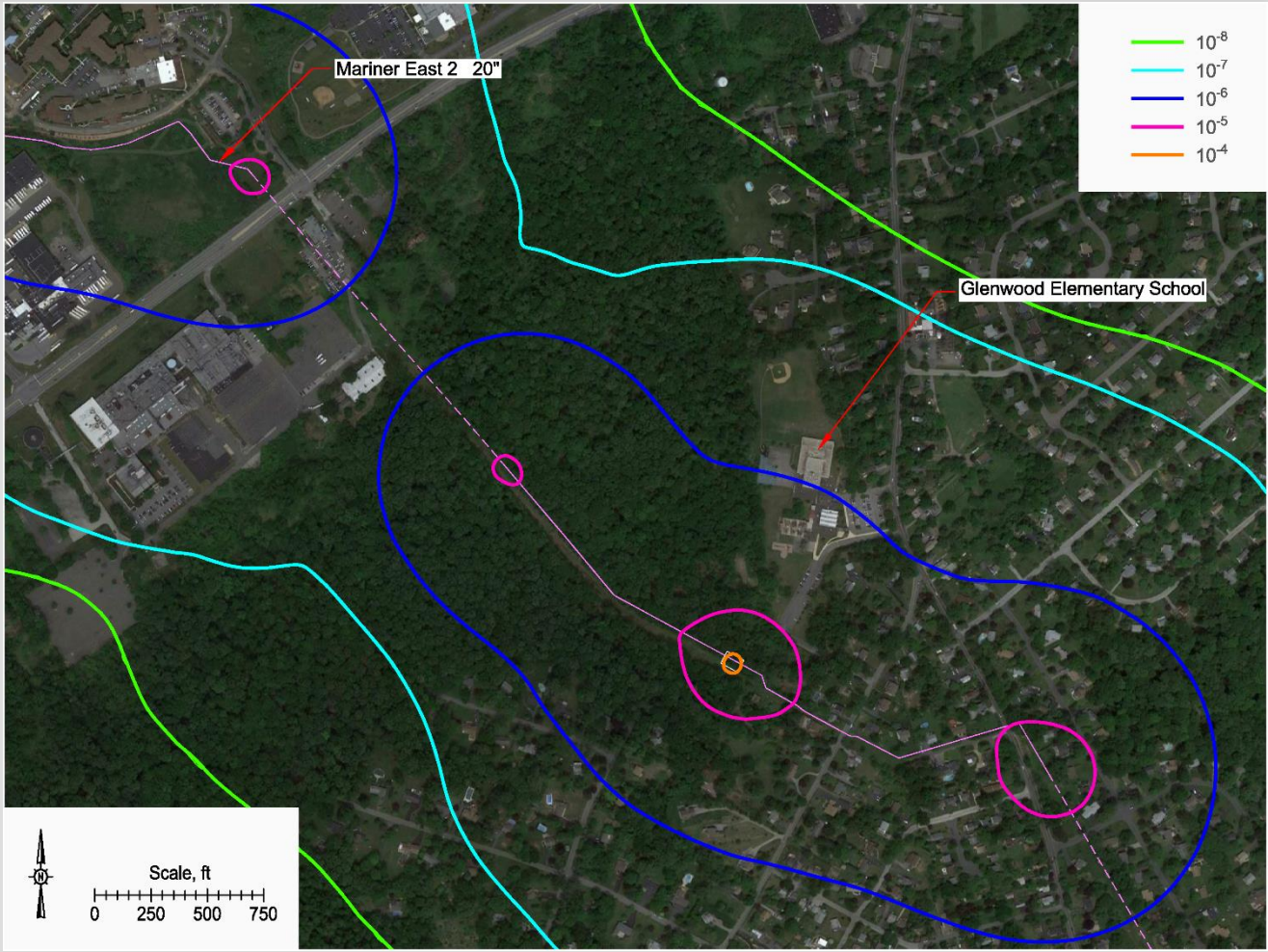


Site-Specific Risk

- Location-specific individual risk calculated for
  - Near Glenwood Elementary School
  - Near Delaware-Chester Counties line
  - Near Chester County Library in Exton
- Accounts for
  - Buried pipe vs. HDD, valve stations
  - Impacts to individuals, continuous occupancy
- Does not account for population in the area

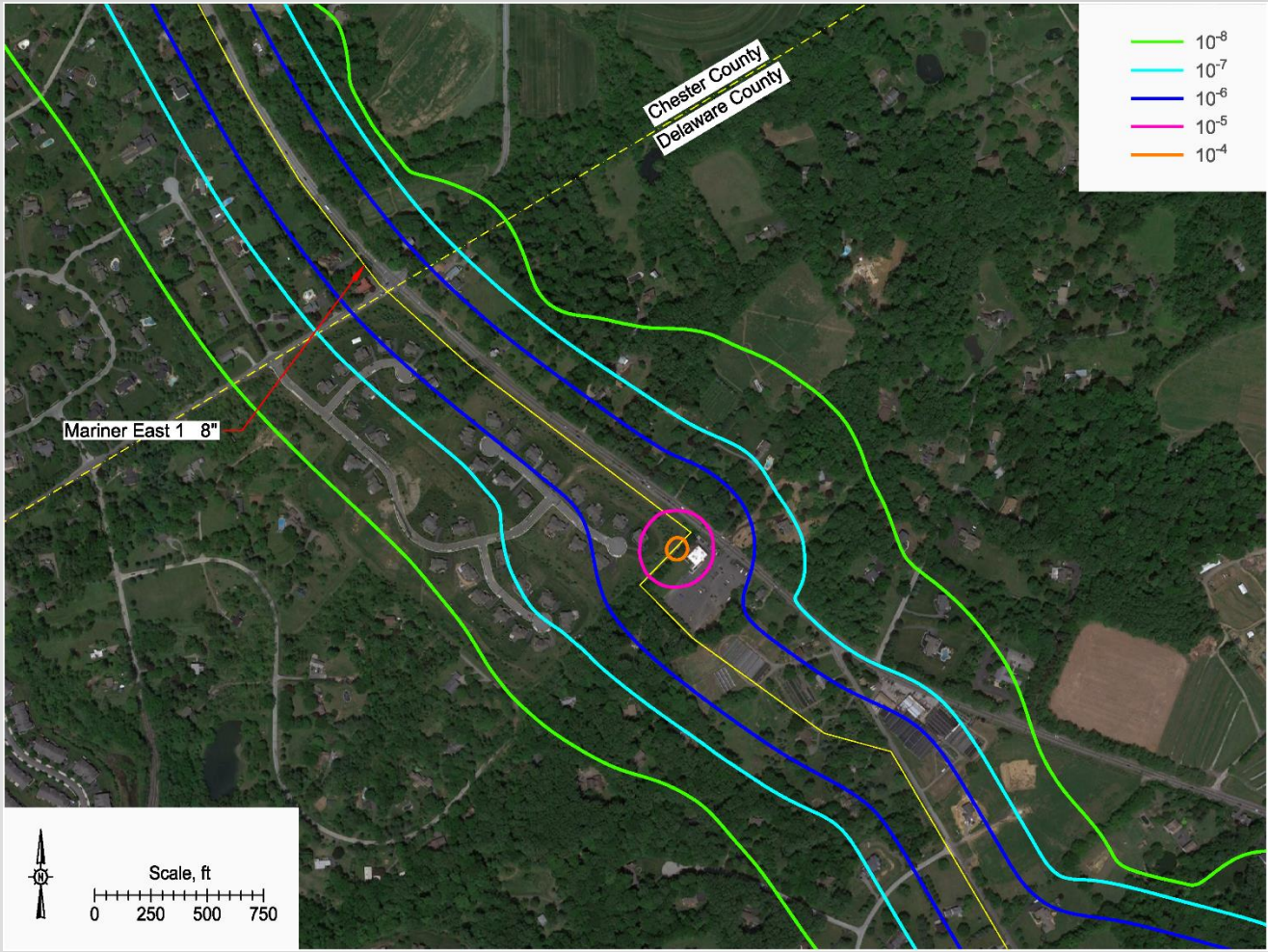
Delaware County, Glenwood Elementary School

ME2, Outdoor
(propane)



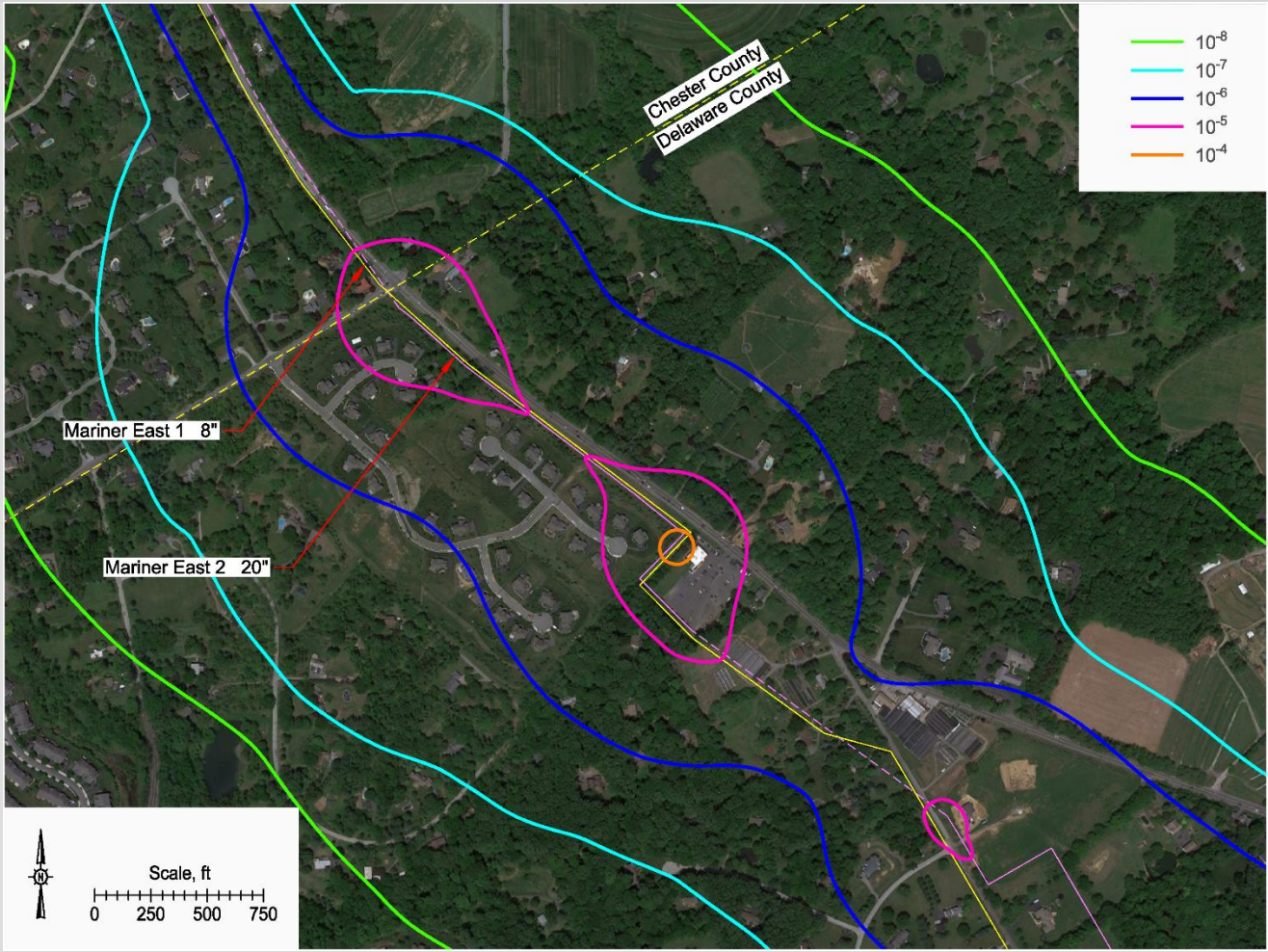
Chester-Delaware County Line

ME1, Outdoor
(propane)



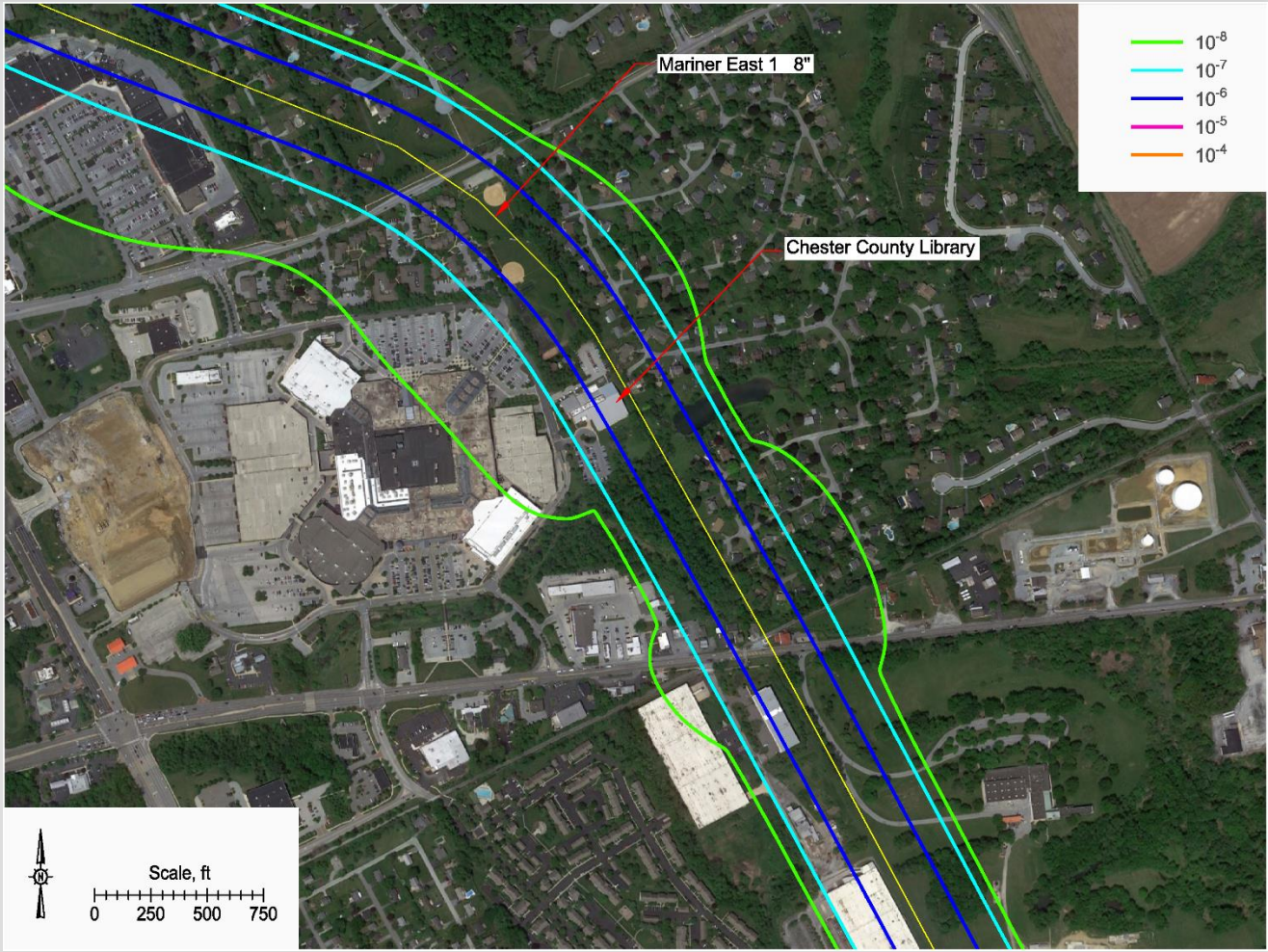
Chester-Delaware County Line

ME1 + ME2, Outdoor (propane)



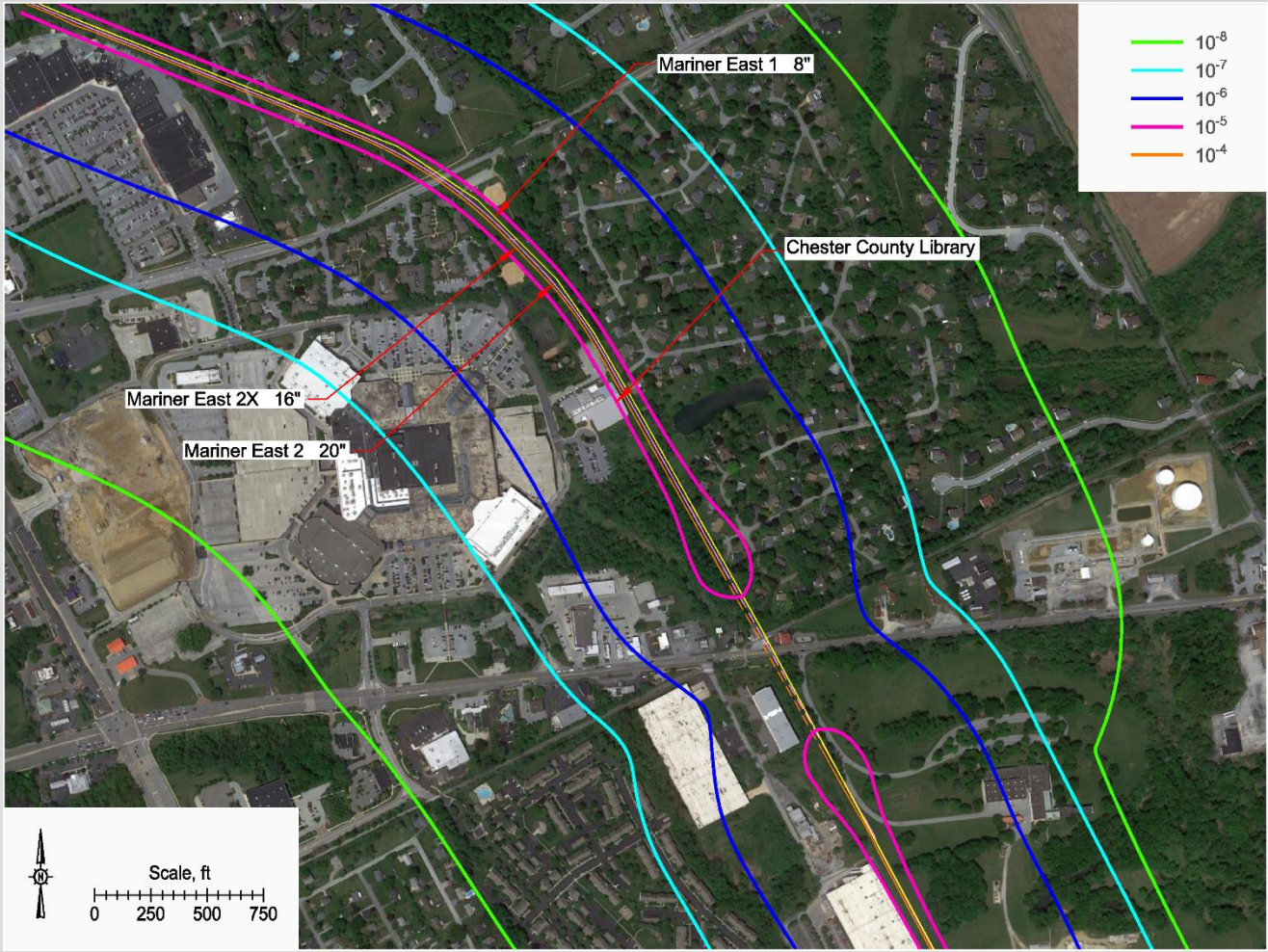
Chester County Library

ME1, Outdoor
(propane)



Chester County Library

ME1 + ME2 + ME2X, Outdoor
(butane, propane, ethane)



So What Risk is Tolerable?

- Many international criteria, for the public, define:
  - Risk less than one in one million (1.0×10^{-6}) per year chance of fatality per year is broadly tolerable/acceptable
  - Risk greater than one chance in ten thousand (1.0×10^{-4}) per year of fatality per year is intolerable/unacceptable
  - Between these two values, risk should be reduced as much as possible
- Risk reduction not always quantifiable

Risk Assessment

- Based on international criteria, intolerable risk is predicted around valve stations (> 100 in a million per year, > 1.0×10^{-4}/year)
- Risk is tolerable in most areas greater than about 600 feet from pipeline (< one in one million per year, < 1.0×10^{-6}/year)
- Results based on continuous occupancy

Comparative Risk

Comparison to Other Modes of Fatality (National Safety Council, 2017)

Event	Annual Risk of Fatality	One chance in ____ per year
Heart Disease	1.9×10^{-3}	519
Influenza/Pneumonia	1.7×10^{-4}	5,774
Motor Vehicle Accidents	1.2×10^{-4}	8,513
Directly Above ME1+ME2+ME2X (C.E.)	1.2×10^{-5}	80,972
Medical/surgical Care Complications	7.97×10^{-6}	125,534
Forces of Nature	4.3×10^{-6}	231,559
Lightning	7.8×10^{-8}	12,754,282

Key Findings

- Risk is essentially zero greater than ½ mile away from the ME2 pipelines (¼ mile for ME1)
- Highest risk is near valve stations (about like motor vehicle fatality risk)
- Heightened risk near the HDD entry/exit points
- Heightened risk above the co-located ME1/2/2X (about 10% of motor vehicle fatality risk)