HydroQuest

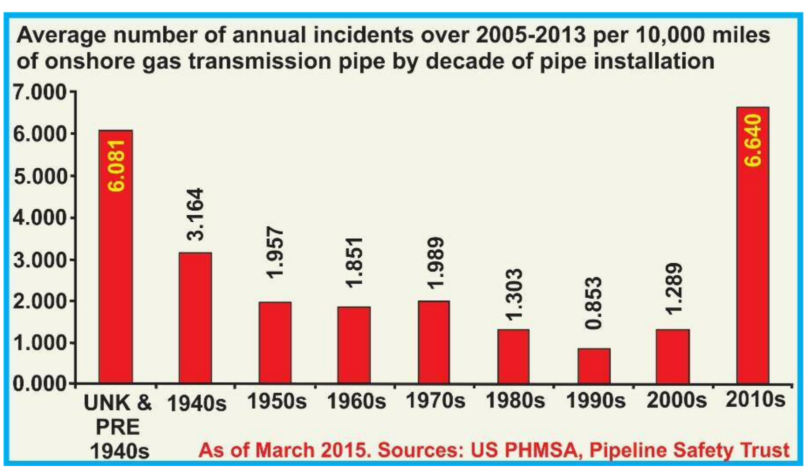
414 E. Kerley Corners Rd.
Tivoli, New York, 12583
845-657-8111
hydroquest@yahoo.com

<u>Blast Impact Fact Sheet</u> – Atlantic Sunrise Pipeline - In Harm's Way - Public Awareness Nov. 19, 2018

Project & Concern: Williams Partners have constructed the 42-inch diameter Atlantic Sunrise Pipeline that is permitted to conduct natural gas at a maximum operating pressure of 1,480 psi. Devastating pipeline failures continue to occur. People electing to live and work within expansive blast impact zones must recognize and accept that pipeline rupture and failure may result in instant death of loved ones, as well as loss of property. This Fact Sheet and GIS map set assess the potential blast impact zone along a 10.4-mile section of the pipeline.

Issue: Pipelines conducting highly flammable and explosive gases at high pressures pose a great health and safety risk to people and structures. The release of gases stemming from pipeline failures have burned and killed unsuspecting people. Unlike cigarette smoking where people have a choice of avoiding slow death by cancer, gas-bearing pipelines routed through private property selected by the Oil & Gas industry, and approved by the Federal Energy Regulatory Commission (FERC), may explode and instantly result in severe burns or death of families and individuals. Corporate profits trump individual and community choice, resulting in unnecessary and unacceptable public health and safety risk. **Many people do not recognize the inherent dangers.**

Blast Impact Radius (aka Incineration Zone, Potential Impact Radius): New and older studies have been conducted to document and model the maximum distance outward from gas pipeline ruptures where building failure, human death, and property damage may occur. Analyses have included assessment of empirical data collected from well-documented explosion catastrophes and detailed engineering-based modeling studies. These analyses, much like predicting flood return intervals, result in increasing accuracy as the number of catastrophic failures increase over time. Statistical analysis of pipeline incidents by the Pipeline and Hazardous Materials Safety Administration (PHMSA) and the Pipeline Safety Trust reveal that new pipeline incidents continue over time (see histogram below) and are failing at a rate on par with gas transmission lines installed before the 1940s. According to a 2004 Transportation Research Board report, residential development along pipeline corridors has contributed to an increase in the number of pipeline incidents involving fatalities, injuries or significant property damage. Similarly, as more pipelines are placed in service within blast zones, especially within documented blast impact radii, it is highly likely that the mortality count will increase.



Appomattox, VA NG Pipeline Explosion

Shock Waves & Detonation

Sklavounos and Rigas (2006) describe the dynamics of flammable gas releases:

> *"Large amounts of flammable gases released in the open air pose a significant hazard for the surroundings, due to their ability to yield disastrous fires and explosions. ... If considerable confinement exists and in addition the oxygen content within the cloud is around the Zero Oxygen Balance (stoichiometric fuel–air mixture), the flame propagation speed increases rapidly producing a blast wave (Phillips, 1994). In this case, the flame front propagates at a supersonic velocity and a strong shock wave develops in the cloud, which is characterized by an abrupt high overpressure front. The general term for explosions in which a shockwave develops is called* ***detonation****."*

Causes of Pipeline Failures Potentially Leading to Deaths, Burn Victims, and Property Destruction: Malfunctions of control systems or relief equipment, external corrosion, outside force damage (e.g., by third parties during excavation), construction defects and mechanical or material failure (e.g., girth weld failures), operational errors (e.g., over pressurization), manufacturing defects, ground movement or natural hazards (e.g. landslides, earthquakes, subsidence, meteorological), and other (e.g., stress corrosion cracking, seam corrosion, coupling failures, inadequate cathodic protection, internal corrosion, fatigue, material aging).

Natural Gas Pipeline Failure Examples: Gas pipeline ruptures can and have resulted in loss of human life and property. Uncontrolled release and ignition of flammable, high or low-pressure, gas can cause explosions and jet fires with high thermal radiation. Catastrophic pipeline ruptures are documented as creating large craters (to 40 feet deep and 167 feet long) into surrounding geologic materials (*e.g.,* Sklavounos and Rigas, 2006). The rapid release of 1,480 psi natural gas from a 42-inch diameter pipe would create a high velocity pressure wave that would immediately asphyxiate and rupture the lungs, stomach, and intestines of nearby people and animal life. While pipeline releases have caused relatively few fatalities in absolute numbers, a single pipeline accident can be catastrophic in terms of public safety, environmental damage, and related costs. Notable natural gas pipeline incidents, among many in the United States and worldwide, include the following:

- 1993: A natural gas pipeline explosion in Venezuela killed 50 people and injured 40 others.
- 1994: A natural gas pipeline explosion in New Jersey, USA, resulted in 1 death and 50 injuries. Massive flames could be seen more than 50 miles away and a crater of approximately 164 feet in diameter resulted. Cause: Damage by excavation works.
- 2000: A 30-inch natural gas pipeline explosion in an isolated New Mexico area killed 12 people camping about 900 feet from the below-ground explosion. A fireball was visible for 20 miles, a "*virtual flamethrower*" after rupture.
- 2010: A 30-inch natural gas pipeline explosion occurred in San Bruno, CA. A fireball killed 8 people, injured 58 others, destroyed 38 homes, damaged 70 additional homes, and destroyed a children's playground. Cause: Pipeline rupture due to a faulty weld. A wall of fire more than 1,000 feet high resulted.
- 2011: A natural gas pipeline explosion in Allentown, PA, killed 5 people, damaged 50 buildings, and caused 500 people to be evacuated.
- 2014: A natural gas distribution pipeline explosion in New York City killed 8 people, injured 50 others, and destroyed two 5-story buildings.
- 2014: A 30-inch natural gas pipeline buried 30 feet underground in rural Kentucky exploded throwing large rocks and pipe into the air, flattened homes, burned barns and cars, and killed one person – leaving behind a 60-foot crater.
- 2016: A 30-inch, 1,039 psi, natural gas pipeline in Salem Township, PA exploded with flames extending above tree tops, burning trees thousands of feet away, seriously burned a fleeing homeowner, destroyed a home, and melted siding on another.
- 2018: Over-pressurization in a natural gas distribution pipeline to 75 psi in the MA towns of Lawrence, Andover, and North Andover resulted in explosions and fires in ~40 homes, one death, two dozen injuries, and forced the evacuation of 30,000 customers. Scores of homes and buildings were demolished.

Blast Radius Distance, Blast Zone Maps & Analyst Information: Maps were constructed to document potential blast impact zones within which buildings and people may be damaged, killed or injured. A number of structural engineers and analysts have developed formulas to determine the likely blast zone distance (aka Potential Impact Radius) outward from a ruptured or failed pipeline, including examining worst case scenarios.

Russo and Parisi

Russo and Parisi (2016) have conducted and published rigorous blast impact assessments. They are PhD structural and thermomechanical engineers and professors who have published over 170 technical papers in international journals. They used state-of-the-art modeling to assess the blast risk posed by natural gas pipelines to structures and people, and to make risk-targeted safety distance recommendations. They specifically modeled the explosive damage to reinforced concrete columns under several different atmospheric conditions and high momentum blast strengths coinciding with high-pressure jet release conditions. Structures located close to or within range of an explosion and ignited gas clouds are subjected to severe overpressures that can lead to building collapse.

Their model examined many variables including wind velocity, atmospheric stability, pipe failure mode, explosive power, blast strength, concrete type, concrete strength class, blast capacity of single concrete columns, blast load, blast demand level, blast fragility surface, impulse, shear resistance, peak overpressure, and damage index. The authors determined that acceptable risk-informed safety distances outward from full-bore rupture of natural gas pipelines (blast centers) define a de minimis risk distance of 2,300 meters (7,544 feet) for atmospheric stability class C conditions (slightly stable) for blast strength 9 (high overpressure) impact on structures (i.e., structural collapse of reinforced concrete building columns), which may be accompanied by human injury or death. For stability class A (unstable atmospheric conditions) for blast strength 9, they found the minimum safety distance was 2,624 feet (800 meters). This 800-meter safety distance is somewhat lower than that derived by Sklavounos and Rigas' modeling work (greater than 3,445 ft; 1050 m) based on real pipeline failure data (2006; School of Chemical Engineering, National Technical University of Athens, Greece).

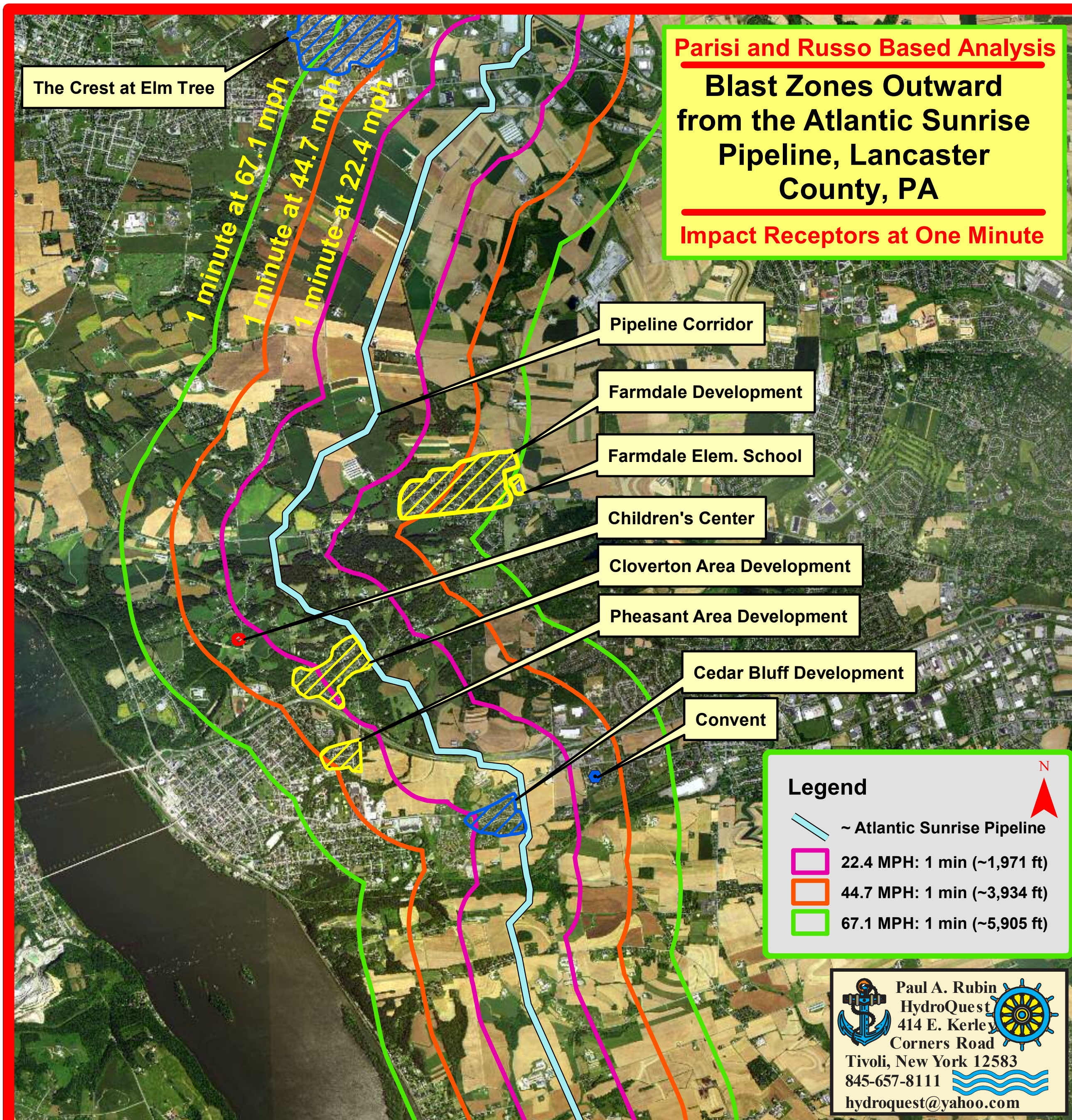
Russo and Parisi concluded:

- "*[t]his distance is significantly important for risk-informed urban planning. ... In fact, an important aspect of land use planning is that consideration be given not only to the pipelines themselves, but also to buildings that come near to existing pipelines*."

- "*If a new building or pipeline has to be constructed, their relative distance should not be smaller than the safety distance. Therefore, urban planners should implement such a safety distance in their territorial plans in order to regulate the location of buildings and the path of pipelines.*"

Based on their analyses, Figures A, B and C were constructed to portray the outward distance of blast impact (i.e., concrete column failure) on structures (and indirectly on people) along a portion of the proposed Atlantic Sunrise Pipeline route under three different modeled wind velocities: 22.4 miles per hour (mph), 44.7 mph, and 67.1 mph (10 m/s, 20 m/s, 30 m/s) at one minute after pipeline rupture. These represent worst-case scenarios. The number of buildings within these three highlighted zones increases outward from 1,400, to 3,425, and to 7,300. An example segment of the pipeline 10.4 miles in length was used. These buildings are used by families, schools, churches, fire departments, businesses, a convent, airports, farms, Amtrak - some located less than 200 feet from the Atlantic Sunrise pipeline. Highly volatile natural gas transmitted at 1,480 psi poses a real public health & safety risk. Rapid propagation of a compression wave would not allow sufficient time for emergency warning.

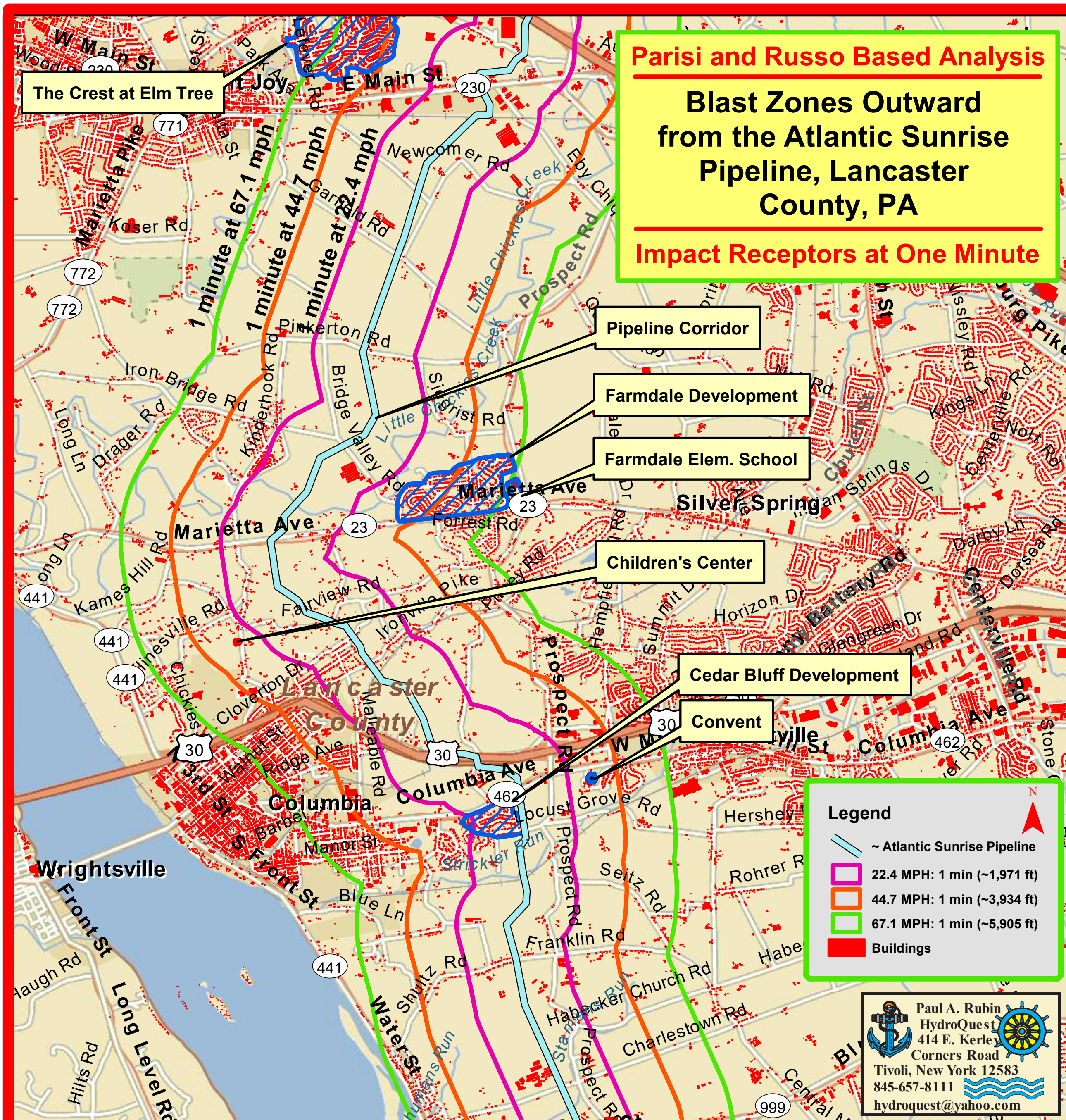
Fact Sheet and GIS maps constructed by Paul A. Rubin [HydroQuest] for: Lancaster Against Pipelines



Much of the Atlantic Sunrise Pipeline corridor routes through highly populated areas of homes, schools, town houses, and assorted businesses. Parisi and Russo (2016) determined a maximum acceptable risk-informed safety distance outward from ruptured natural gas pipelines for reinforced concrete columns of 2,300 meters. Here, their modeled wind velocities of 22.4 MPH, 44.7 MPH, and 67.1 MPH within the blast zone are presented for one minute blast and/or fireball arrival times (outward from the Atlantic Sunrise Pipeline). The number of buildings within these three high-lighted zones increases outward from 1,400, to 3,425, and to 7,300. This example segment of the pipeline is 10.4 miles in length. Highly volatile natural gas transmitted at 1,480 psi poses a similar public health & safety risk. Clearly, there is notime for emergency warning. 2017 Orthoimagery Source: USDA NAIP. Nov. 19, 2018. Graphic presentation of Parisi and Russo' work prepared by Paul A. Rubin [HydroQuest].

Feet
0 5,000 10,000 20,000

Figure A

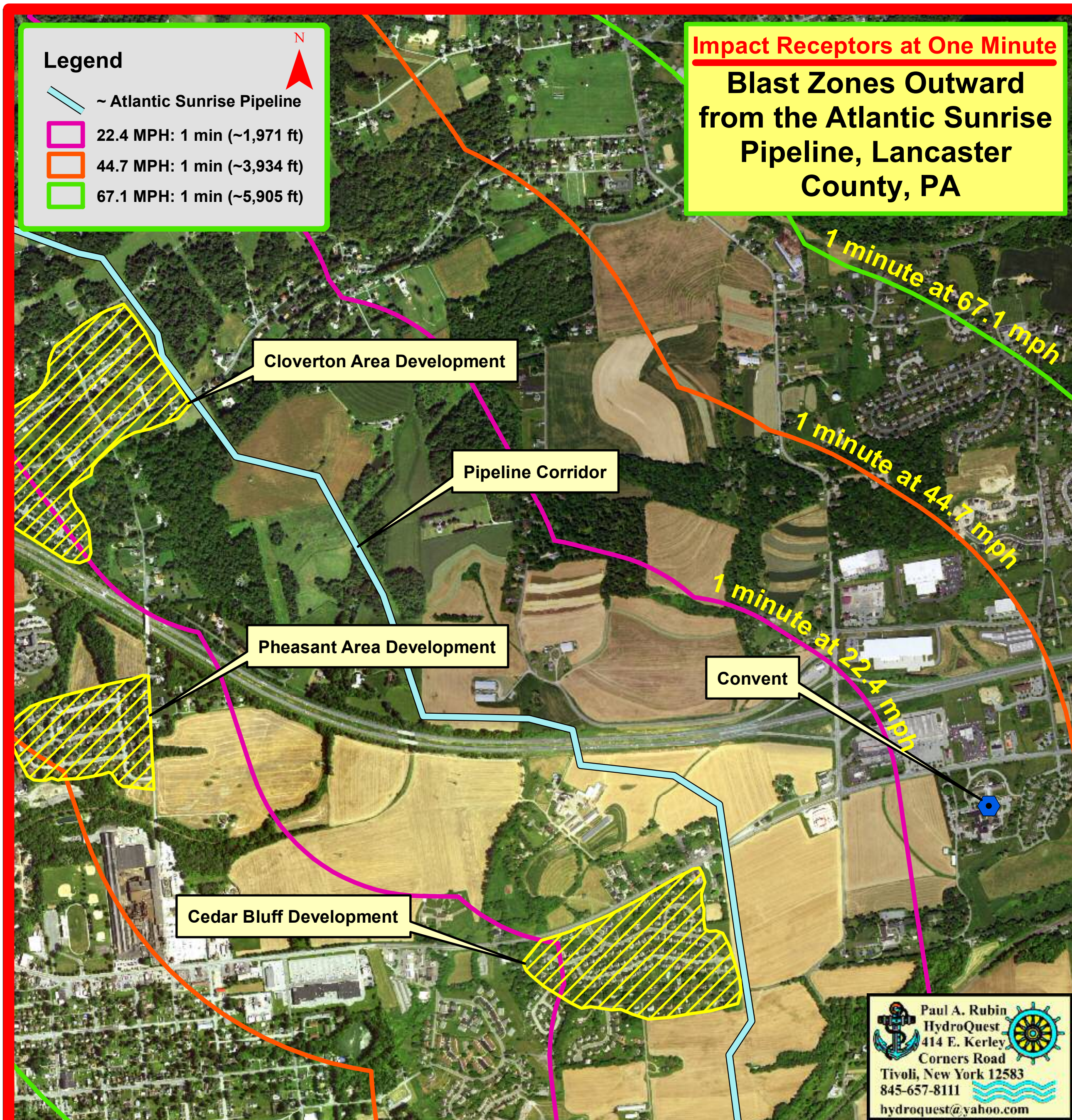


Much of the Atlantic Sunrise Pipeline corridor routes through highly populated areas of homes, schools, town houses, and assorted businesses. Parisi and Russo (2016) determined a maximum acceptable risk-informed safety distance outward from ruptured natural gas pipelines for reinforced concrete columns of 2,300 meters. Here, their modeled wind velocities of 22.4 MPH, 44.7 MPH, and 67.1 MPH within the blast zone are presented for one minute blast and/or fireball arrival times (outward from the Atlantic Sunrise Pipeline). The number of buildings within these three high-lighted zones increases outward from 1,400, to 3,425, and to 7,300. This example segment of the pipeline is 10.4 miles in length. Highly volatile natural gas transmitted at 1,480 psi poses a similar public health & safety risk. Clearly, there is no time for emergency warning. 2017 Orthoimagery Source: USDA NAIP. Nov. 19, 2018. Graphic presentation of Parisi and Russo' work prepared by Paul A. Rubin [HydroQuest].

Feet

0 5,000 10,000 20,000

Figure B



Much of the Atlantic Sunrise Pipeline corridor routes through highly populated areas of homes, schools, town houses, and assorted businesses. Russo and Parisi (2016) determined a maximum acceptable risk-informed safety distance outward from ruptured natural gas pipelines for reinforced concrete columns of 2,300 meters. Here, their modeled wind velocities of 22.4 MPH, 44.7 MPH, and 67.1 MPH within the blast zone are presented for one minute blast and/or fireball arrival times (outward from the Atlantic Sunrise Pipeline). The number of buildings within these three highlighted zones increases outward from 1,400, to 3,425, and to 7,300. This example segment of the pipeline is 2.8 miles in length. Highly volatile natural gas transmitted at 1,480 psi poses a similar public health & safety risk. Clearly, there is no time for emergency warning. 2017 Orthoimagery Source: USDA NAIP. Oct. 25, 2018.

Figure C

Sklavounos and Rigas

Sklavounos and Rigas conducted detailed engineering assessment and modeling to estimate safety distances in the vicinity of fuel gas pipelines (2006). Dr. Sklavounos is a chemical engineer and Safety Engineering Specialist with expertise in Environmental and Safety Engineering. Dr. Rigas is a chemical engineer at the School of Chemical Engineering in Greece. He has published or presented over 150 technical papers. These authors used a combination of Event Tree Analysis and real data to determine safety distances outward from ruptured pipelines when considering worst-case scenarios of jet fire and gas dispersion for pressurized natural gas and liquified petroleum gas.

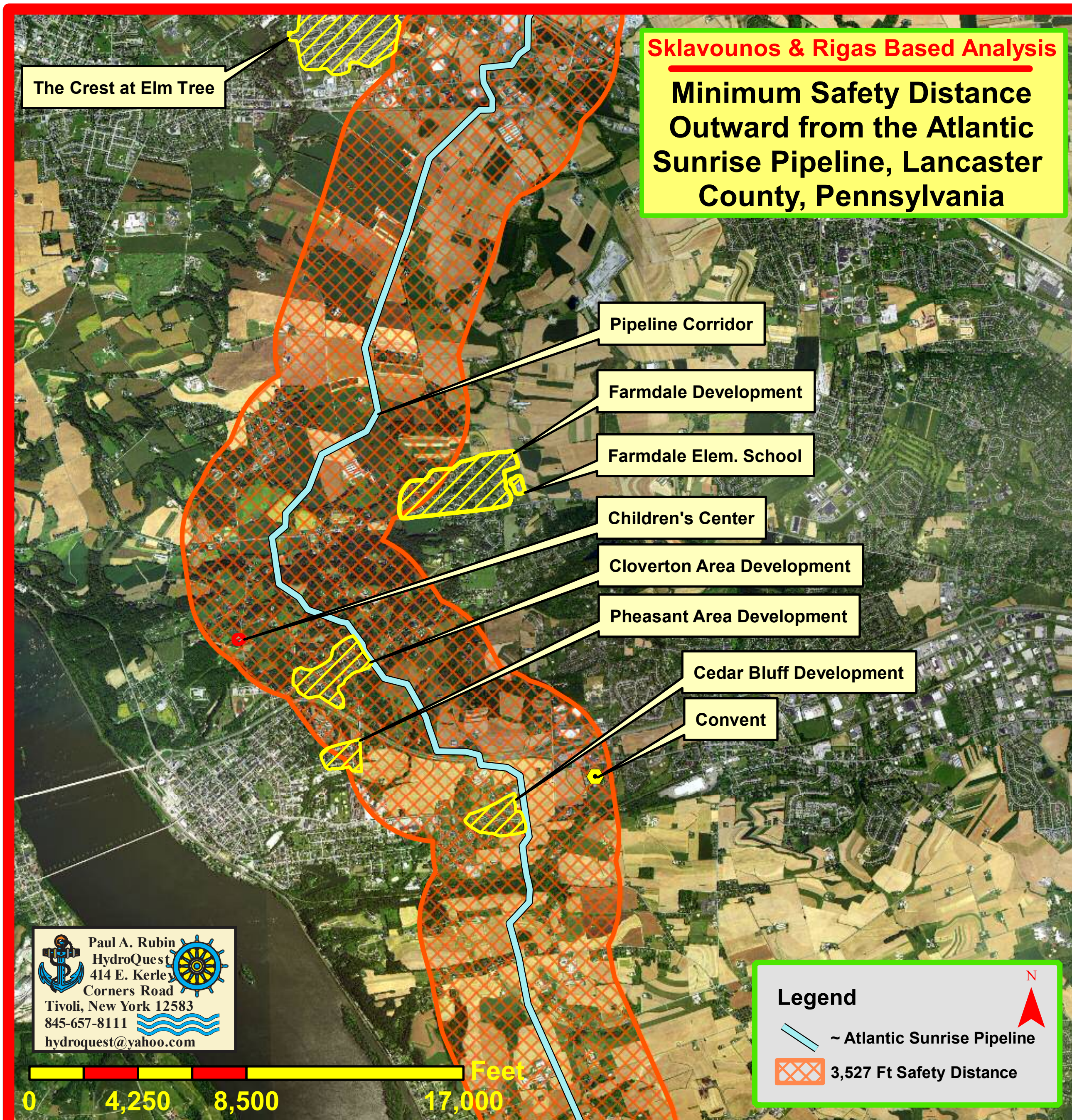
Their analyses included assessment of flame front propagation which occurs at a supersonic velocity where a strong shock wave develops, which is characterized by an abrupt high overpressure front. The term for explosions in which such shockwaves develop is **detonation**. Explosive releases may severely damage buildings. Shock waves and high thermal radiation levels within their calculated safety distances may kill or injure human beings. Apparently, at the time of their study, Sklavounos and Rigas did not anticipate industry use of high-pressure natural gas pipelines with diameters in excess of 35.8 inches (91 cm) or operating pressures in excess of 1015 psi (70.0 bars). As such, their calculated maximum safety distance beyond which blast impact and thermal radiation intensity would not adversely impact buildings and people, at these pipeline diameter and operating pressure values is 3,527 feet (1075 m). The Atlantic Sunrise Pipeline is 42-inches in diameter and seeks to operate at a maximum pressure of 1480 psi. Thus, the safety distance of 3,527 feet plotted within the orange hachured area on Figure D is <u>conservative</u>. Lives, homes, and businesses are jeopardized by the Atlantic Sunrise Pipeline.

C-FER Technologies (Mark Stephens) & 2010 San Bruno, CA Pipeline Explosion

The Gas Research Institute and C-FER Technologies (Mark Stephens, civil engineer, 2000) developed a formula to estimate the Potential Impact Radius (PIR) (aka Hazard Area Radius or Blast Radius or Incineration Zone) based on pipe diameter and maximum internal pressure. Gas Research Institute, the sponsoring agency, was founded in response to the Federal Power Commission encouraging increased gas research and development. Using Stephens' formula, Figure F was constructed. It shows a PIR of 1,107 feet for a 42-inch diameter pipeline conducting natural gas at a pressure of 1,480 psi. This study and derived formula have been superseded by more sophisticated analyses conducted by chemical engineers (see above sections). However, the 2000 C-FER formula is still in use by the Pipeline and Hazardous Materials Safety Administration (PHMSA).

Since 2000, a number of major pipeline accidents have occurred that provide real world empirical examples against which the C-FER formula may be evaluated. One such example occurred in the San Bruno, CA area on 9-09-10. There, a 30-inch natural gas pipeline with an operating pressure of 386 psi exploded in a neighborhood, resulting in a wall of fire more than 1,000 feet high and a shock wave with an earthquake magnitude of 1.1. The blast explosion leveled homes 600 feet outward from the blast center, sometimes through two or three other homes first. This suggests that the PIR would be greater than 600 feet if other homes had not first reduced the blast force. Figure E shows Google Earth photographs of this San Bruno, CA neighborhood before and after the 2010 pipeline explosion. The pipeline failure resulted in 8 fatalities, 58 injured people, 38 leveled homes, 70 damaged homes, and destroyed a children's playground.

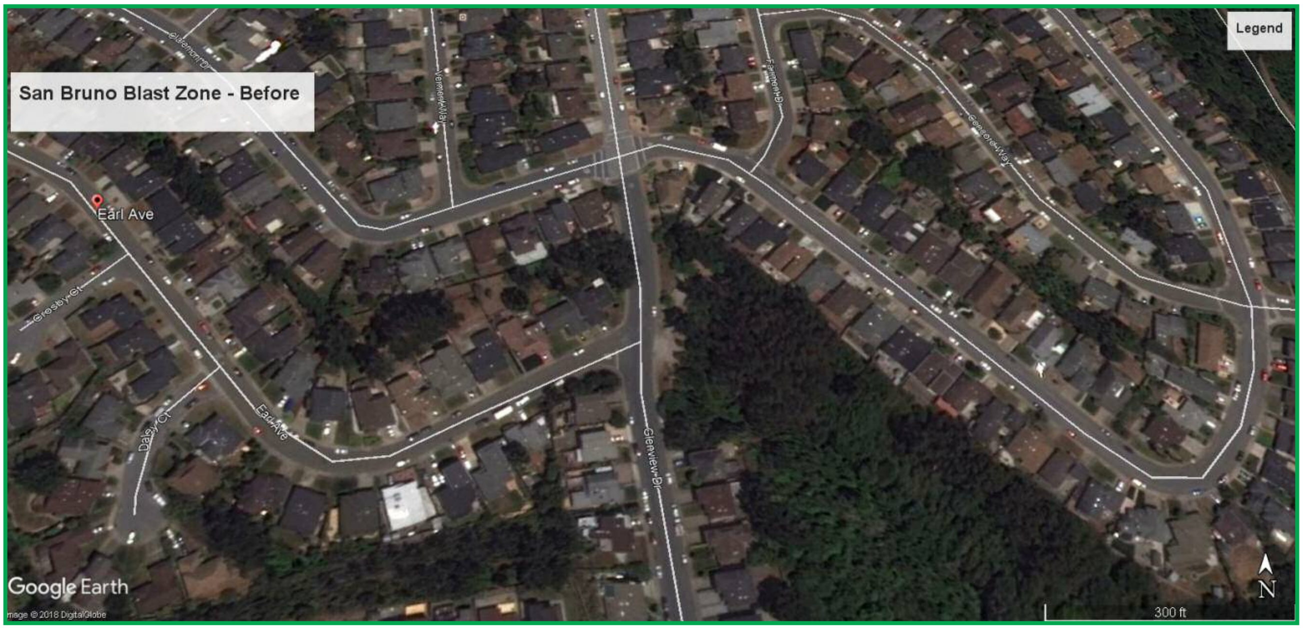
In the San Bruno, CA example, the outdated C-FER formula underpredicts the actual measured blast impact radius/explosive power distance by about 50%, making its use by PHMSA and others of questionable merit relative to protecting public health and safety and land use planning. When applied to the San Bruno pipeline conditions, the C-FER formula yields a potential blast impact radius of 404 feet vs. the actual, measured, 600-foot impact radius with leveled homes (Figure E). If a very conservative linear relationship between pipe diameter, operating pressure and blast impact radius is assumed, the corrected blast impact radius for the Atlantic Sunrise Pipeline would be in excess of 1,644 feet (depicted between blue lines on Figure F).



Sklavounos and Rigas conducted detailed engineering assessment and modeling to estimate safety distances in the vicinity of fuel gas pipelines (2006). Their analyses included assessment of flame front propagation which occurs at a supersonic velocity where a strong shock wave develops, which is characterized by an abrupt high overpressure front. The term for explosions in which such shockwaves develop is detonation. Explosive releases may severely damage buildings. Shock waves and high thermal radiation levels within their calculated safety distances may kill or injure human beings. Apparently, at the time of their study, Sklavounos and Rigas did not anticipate industry use of high-pressure natural gas pipelines with diameters in excess of 35.8 inches (91 cm) or operating pressures in excess of 1015 psi (70.0 bars). As such, their calculated maximum safety distance beyond which blast impact and thermal radiation intensity would not adversely impact buildings and people, at these pipeline diameter and operating pressure values is 3,527 feet (1075 m). The Atlantic Sunrise Pipeline is 42-inches in diameter and seeks to operate at a maximum pressure of 1480 psi. Thus, the safety distance of 3,527 feet plotted here on Figure D is conservative. Clearly, lives, homes, and businesses are jeopardized by the Atlantic Sunrise Pipeline.

This example segment of the pipeline is 10.4 miles in length. Highly volatile natural gas transmitted at 1,480 psi poses a real public health & safety risk. 2017 Orthoimagery Source: USDA NAIP. Map Date: Nov. 18, 2018. Presentation of Sklavounos and Rigas' work prepared by Paul A. Rubin [HydroQuest].

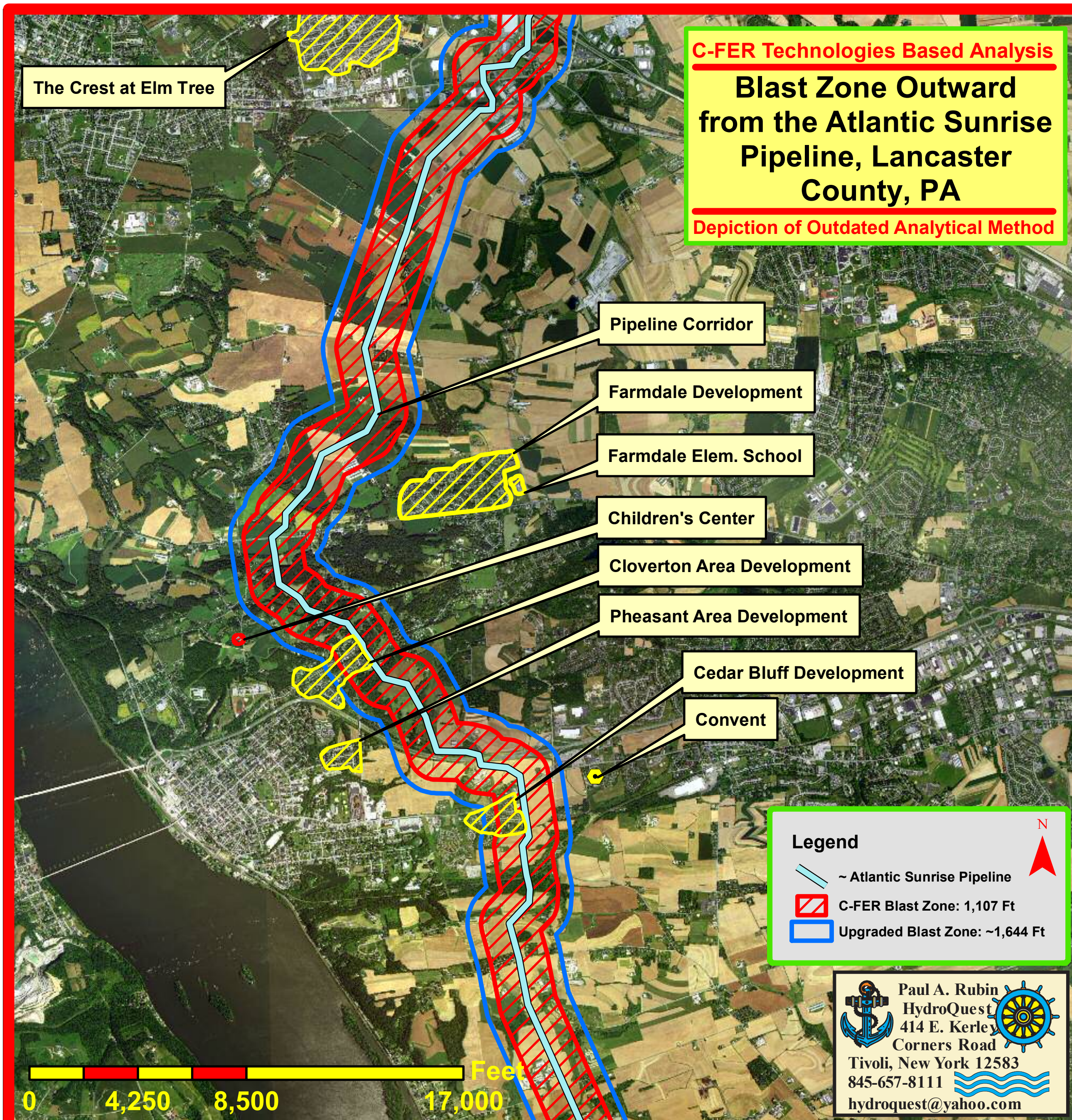
Figure D



Red polygon: ~Blast zone with homes leveled on Sept. 9, 2010. Google Earth photos.

Google Earth areal photographs depict an intact housing development in July 2010 before the San Bruno pipe rupture (top) and after in September 2010. The failed pipeline had a 30-inch diameter and an operating pressure of 386 psi at the time of rupture. Many lives and homes were lost. The 42-inch Atlantic Sunrise Pipeline, if operational, would operate at 1,480 psi.

Figure E



Much of the Atlantic Sunrise Pipeline corridor routes through highly populated areas of homes, schools, town houses, and assorted businesses. The formula developed by Gas Research Institute and C-FER Technologies (2000) to estimate the Potential Impact Radius (PIR) based on pipe diameter and maximum internal pressure yields a 1,107-foot blast radius for a 42-inch diameter pipe with a pressure of 1,480 psi. This distance is depicted on this figure - outward from the Atlantic Sunrise Pipeline. The number of buildings within the 1,107 foot, red hachured, blast zone depicted on this figure is approximately 650.

In the San Bruno pipeline explosion example discussed in the Fact Sheet text, the outdated C-FER formula underpredicts the actual measured blast impact radius/explosive power distance by about 50%, making its use by PHMSA and others of questionable merit relative to protecting public health and safety and land use planning. When applied to the San Bruno pipeline conditions, the C-FER formula yields a potential blast impact radius of 404 feet vs. the actual, measured, 600-foot impact radius with leveled homes (Figure F). If a very conservative linear relationship between pipe diameter, operating pressure and blast impact radius is assumed, the corrected blast impact radius for the Atlantic Sunrise Pipeline would be in excess of 1,644 feet (depicted between blue lines on this figure). 2017 Orthoimagery Source: USDA NAIP, Map Date: 11-18-18. Presentation of C-FER Technologies work and upgraded C-FER-based PIR by Paul A. Rubin [HydroQuest].

Figure F

Conclusions

This expanded Fact Sheet presents the work of engineers in graphic format tailored to a 10.4-mile long segment of the Atlantic Sunrise Pipeline. It documents potential damage to thousands of buildings and people now living and working within the blast zone. All told, analyses presented by engineering experts correlate real world pipeline catastrophes with engineering-based technical calculations and model-based studies document areally-wide blast impact zones extending outward from gas pipelines. Here, the work of experts documents a potential blast impact range of between 0.3 and 1.4 miles, even when considering use of the outdated C-FER formula still relied upon by PHMSA. Thus, at a bare minimum, expert analyses provide solid justification for not constructing and operating gas pipelines within 1,600 feet of people's homes and buildings.

Pipelines conducting natural gas are a significant source of hazard for people living within the Potential Impact Radius (PIR). While hazard risk (measure of the probability and severity of adverse effects) due to explosion or fire is present for anyone living, working, or traveling within a pipeline's PIR, societal risk is especially high in urban areas and near roads where there is a high population density. Many people are not aware of this risk or erroneously believe that pipeline permitting agencies (FERC) would only approve pipeline applications to conduct high pressure flammable gases in locations that would not place the public at risk. While statistically, based on documented incidents per pipeline mile, risk may be low – this is not the case for those who unwittingly lost their lives, loved ones, and homes at the front end of a high-pressure wave and/or fireball.

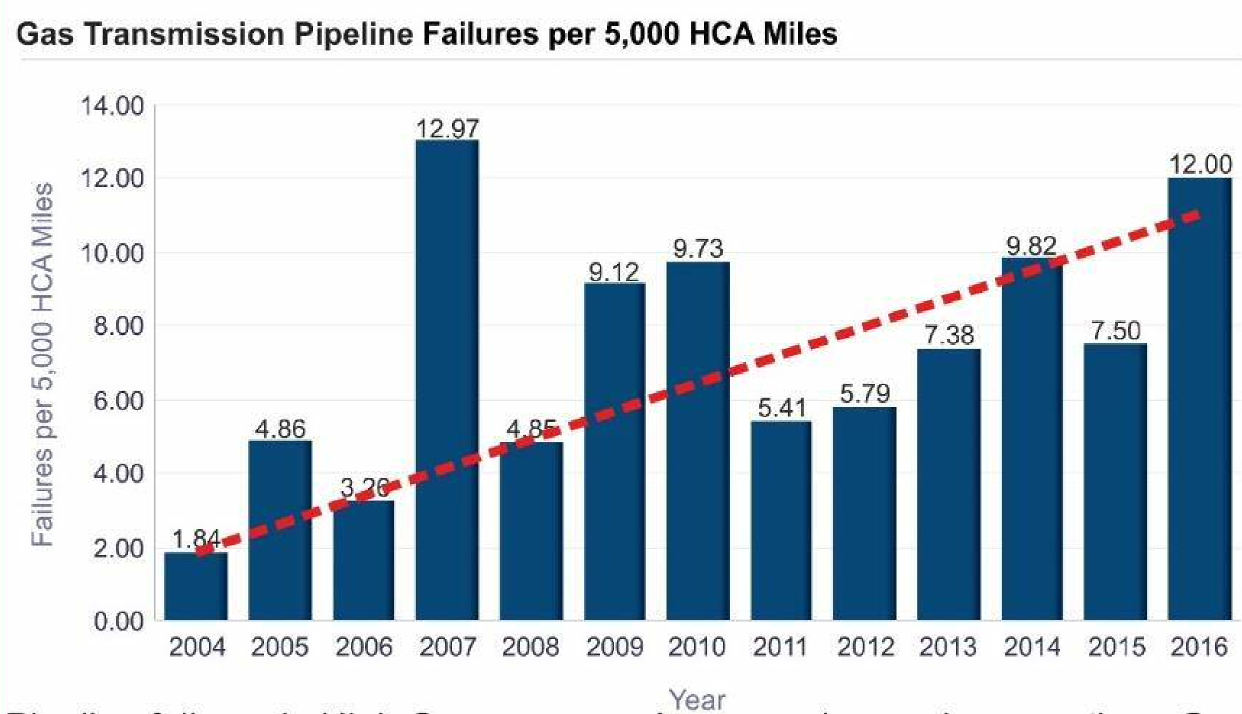
Analysis of pipeline incidents shows that fatal incidents continue to occur, including on new pipeline placements. As these pipelines age and as more and more are placed in high consequence urban areas, it is likely that incidents and fatalities will increase. Ultimately, the decision as to whether to place people in harm's way within a high-pressure pipeline's Potential Impact Radius is made by a permitting agency, not by people whose lives, loved ones, and property are unwittingly placed at risk. The permitting agency has not made clear what they consider as an acceptable range of probability of death or failure per mile of pipeline as a result of pipeline accidents. Statisticians examine societal risk based on the probability of pipeline failure and the expected number of fatalities from an accident that can be calculated based on factors including population density. Logically, once these statistically-derived "*acceptable*" values of probability of death have been exceeded, pipelines should be abandoned (not incrementally upgraded), thereby removing risk. An important question that stems from this is: Who is legally responsible for both making these decisions and paying damages for premature death, injury, and loss of property (e.g., gas companies, pipeline permitting agencies, insurance companies)?

As put forth on this expanded Fact Sheet and map set, recent analyses of potential blast impact distances are based on rigorous engineering-based models and documented real-world pipeline failures. **While there is variability in blast impact distances presented here based on a number of factors** (e.g., wind speed, incident-specific data, atmospheric conditions, gas dispersion, extent of pipeline rupture, internal gas pressure, pipe diameter), **there is a reasonable degree of scientific certainty that the Potential Impact Radius for a 42-inch diameter pipeline conducting flammable natural gas at 1,480 psi is on the order of one-half mile (2,640 ft; ~ 800 meters), or more, when considering worst-case failure scenarios**.

A number of analysts' determinations are presented here to assess safety distances outward from ruptured gas pipelines, with emphasis on the Atlantic Sunrise Pipeline in Lancaster County, Pennsylvania. Again, while there is some variability based on numerous factors, they all document expansive Potential Impact Radii outward from ruptured high-pressure pipelines, thereby justifying health and safety concerns of county residents. There is a distance beyond which the exact determination of the PIR becomes of "*lesser*" importance because the high number of potential building failures and human mortality that will occur first dwarfs those closer to the outer fringes of the blast impact zone. This is especially true in high consequence areas with high population densities and transportation infrastructure. Ultimately, the lives and property of families living within the Potential Impact Radius of ruptured pipelines is determined by pipeline permitting agencies who approve pipeline routes through private and public properties and determine what the acceptable range of probability of death is.

A destroyed home in Lawrence, MA on Sept. 13, 2018. As many as 40 buildings were burned due to a natural gas explosion. Katherine Taylor for the New York Times

A Salem Township, PA home destroyed by a 30-inch pipeline explosion on April 29, 2016. Keith Srakocic AP photo.



Pipeline failures in High Consequence Areas are increasing over time. Gas transmission performance National Summary data. Source: PHMSA 2018

Fact Sheet and GIS maps constructed by Paul A. Rubin [HydroQuest] for: Lancaster Against Pipelines