Historical Sample of Damage from Natural Gas Transmission Pipeline Explosions

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Summary:

This report provides a historical sample of the observed damage resulting from the explosions of natural gas transmission pipelines. The explosions are the result of complete ruptures of the pipeline accompanied with subsequent ignition. As shown in pictures in this report, the resulting damages near the pipeline rupture are catastrophic. Knowing a "safe" distance from a natural gas pipeline assists in planning land uses in the vicinity of the pipeline. Pipelines are relatively safe compared to other risks we either accept voluntarily or involuntarily during the normal course of our lives. The problem is that although transmission and gathering pipeline ruptures at any selected location are rare, the consequences of being too close to such an event are dire. The risk at any specific location becomes a difficult combination of a very unlikely event that has extreme consequences if it does occur. In more urban areas, sometimes referred to as a high consequence area (HCA), it is not practical to locate the pipeline at a great enough distance to prevent damage and human fatalities should an explosion occur. In that case, significant wall thickness is added to the pipeline to increase structural integrity. This allows for more margin for corrosion. Corrosion is a common mode of failure for a pipeline that can result in an explosion. However, in rural areas the margins on wall thickness are significantly less. With the rapid expansion of natural gas pipelines in the Marcellus region in Pennsylvania, prudent planning needs to have information concerning safe distances from a pipeline. This is particularly true where pipelines in rural areas can be more readily located at substantial distances from existing structures then suburban areas. Having a grasp of a safe distance not only applies to the initial installation of the pipeline among existing habitable dwellings, but also to future development that may encroach on existing pipeline right ways by developers. Information based on historical experience needs to be readily available and easily understood.

It is important for those making decisions for the placement of natural gas transmission pipelines, those that choose to develop structures near existing right ways, and those that live next to right ways to clearly understand the potential risks and responsibilities. There should be no one that is not aware of the potential danger and respect a pipeline within the right way requires in its placement and maintenance. To this end, this paper provides a historical sample to these stakeholders.

Introduction:

Pipeline stakeholders all try to decrease the chances of a pipeline failure. A pipeline failure is of no benefit to any reasonable person or entity. But despite the best efforts of those involved, pipelines will fail and some pipelines will rupture and ignite. One obvious way to greatly decrease the risk is to be located far away from the pipeline. This approach requires knowing what this distance may be. There are different theoretical approaches to predicting distances to where damage occurs. These theoretical approaches involve many assumptions and empirical parameters. This can result in a wide range of results. This is not unexpected but the results become subjective.

A more pragmatic approach is to review the damage of prior pipeline rupture incidents. Then based on these observations determine a threshold distance from a pipeline rupture where substantial damage stops. One can imagine there will be differences in observations even for seemingly nearly the identical events. However, there are significant numbers of recorded pipeline ruptures to reasonably represent the situations nominally of interest for underground natural gas transmission pipelines. There is a subset of reported ruptures where enough information is available to define these incidents in terms of the important parameters. It is only necessary to obtain a representative sample that is likely to define the envelop for a damage threshold distance.

It could be argued that determining a safe distance is complex for any specific instant. There are many variables. However, as an analogy, predicting temperature at a location in the future is also complex. There are many unknown factors in predicting future temperatures. Yet, years of recording the temperature data makes possible guessing the temperatures to be expected even several years from now. This is despite ignoring many complex factors affecting the temperature. These temperature records afford predictions for the expected high and low temperature on any day. Knowing these temperatures is useful in planning but provides no guarantee that the average high and low temperature will not be exceeded. Further, due to unusual circumstances even previous record high and low temperatures can be exceeded. As more data becomes available the temperature extremes are less likely to be exceeded. These predictions of temperatures simply require only knowing the location and the day of the year. Including other factors increases the complexity of prediction but results in little additional precision gained for estimates 2 to 3 years in the future beyond the simple records. Similarly, observations of prior pipeline ruptures with ignition provide guidance as to a safe distance while ignoring other unknown complex factors. As a minimum to the prudent observer, the historical record simply shows circumstances where damage has occurred.

Over the last 50 years there have been many natural gas pipeline ruptures documented and investigated worldwide. These incidents can provide the information necessary to define an expected damage distance. Theoretical work in Reference 1 suggests knowing the pipeline diameter and pressure at the point of rupture allows an approximate correlation of a distance associated with an incident occurring in the future. There are enough recent events with available digital aerial photos combined with written descriptions to cover a practical range of pipeline diameters and operating pressures. Based on these past events, predictions with a minimum of assumptions can reasonably be made for the distance threshold for damage from a pipeline rupture. The current incidents included in this evaluation appear to be typical of a serious natural gas pipeline rupture and should not form an extreme sample. However, like predicting the temperature based solely historical records at a given location, one must accept that there will be different distances associated with what appears to be the same circumstance. Records of prior incidents can provide indications of these departures from nominal estimates. It is hoped this information presented is useful to the reader.

Historical Sample:

The historical sample data was collected from nineteen (19) separate rupture incidents spanning over a period of 47 years. They involve pipelines that are 12 inches to 42 inches in diameter, having pressures at the point of rupture ranging from 386 psi to 1207 psi. These factors relate to the damage distance for each incident, being the distance from the location of the pipeline rupture outward to where obvious significant property damage has occurred and/or the corresponding injury to unprotected people. The damage distance for each rupture incident varies due to diameter and pressure differences.

The historical incidents are summarized in Table 1, Summary of Incidents, and references are provided for each incident. The table includes more recent events not included in reference 1, GRI-00/0189, "A MODEL FOR SIZING HIGH CONSEQUENCE AREAS ASSOCIATED WITH NATURAL GAS PIPELINES", by Mark J. Stephens. Since this reference was done in 2000, there has been another 16 years of incidents to sample. This report contains a sufficient sample of incidents, 19, such that additional historical data are unlikely to alter the trends of observed damage of the sample incidents.

All the incidents documented are onshore and resulted in an explosion from an underground pipeline rupture. Pictures are provided where available to illustrate the type of damage caused by explosions of natural gas transmission pipelines. In most cases there is a substantial crater in the ground at the point of rupture. In many cases, a portion of the pipeline becomes a projectile. Some cases report portions of the pipeline being thrown hundreds of feet from the point of rupture. Preference is given to recent events where independent photographic evidence is available to collaborate written accounts. A portion of these photos is included in this section.

The damage distance for each incident is based upon the largest distance of the following observable damage and is shown on Table 1.

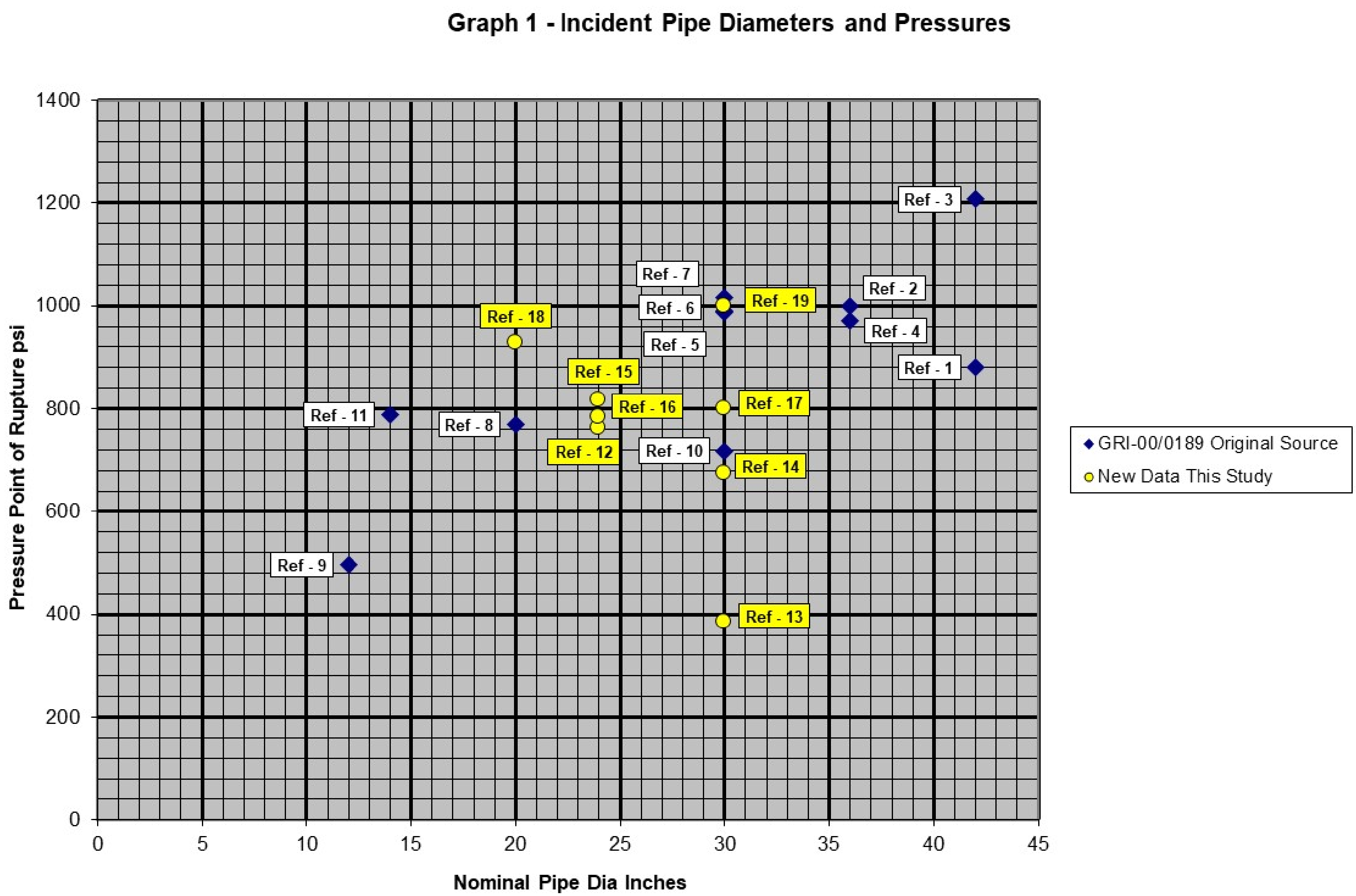
1. Actual burn distance from rupture point to severe ground burning
2. Effective burn radius from rupture point
3. Effective heat affected radius from rupture point
4. Distance to fatality from rupture at time of ignition point
5. Distance to injury of humans from rupture at the time of ignition point
6. Distance to significant structural damage from rupture point
7. Distance of projectiles from rupture point

Item 2 and 3 use an effective radius, which is somewhat problematic in describing the maximum distance to significant damage. Usually a circle does not accurately represent the damaged area. This method underestimates the maximum distance to substantial damage. The actual burn area is usually skewed as shown in aerial views for many reasons. When possible this report further investigates those incidents originally reported with an equivalent radius for additional information. In those instances where information to correct this effect could not be found, the incidences are indicated as such in Table 1, Summary Of Incidents". The pictures to follow clearly indicate by what is meant by the distance to "substantial" damage.

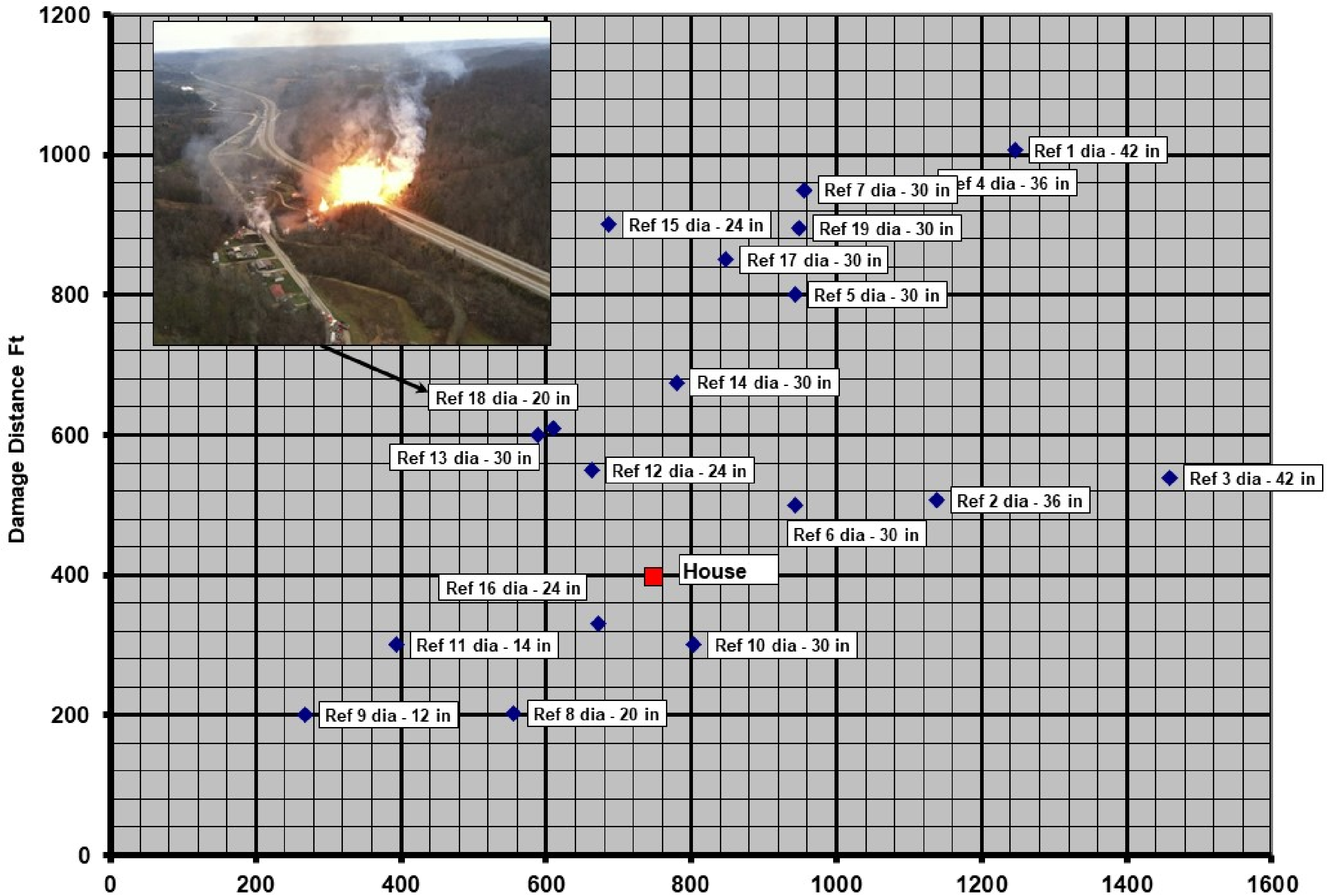
Table 1 Summary Of Incidents

Item	Date	Location	Pipe Dia (In)	Pressure at Rupture Point Psi	Distance Damage Ft	Type of Distance	Damage Point	Reference
1	7/29/1995	Rapid City, Manitoba	42	880	1007	Map measured		1, Table 3.1; TSB-P95H0036, Appendix A
2	7/23/1994	Latchford, Ontario	36	1000	507	Eq Heat Radius		1, Table 3.1; TSB-P94H0036
3	2/14/1994	Maple Creek, Saskatchewan	42	1207	539	Eq Burn radius		1, Table 3.1; TSB-P94H0003
4	3/23/1994	Edison, New Jersey	36	970	960	Direct Listing		1, Table 3.1; NTSB-PAR-95-1
5	2/21/1986	Near Lancaster Kentucky	30	987	800	Direct Listing		1, Table 3.1; NTSB-PAR-87-1
6	4/27/1985	Near Beaumont Kentucky	30	990	500	Direct Listing		1, Table 3.1; NTSB-PAR-87-1
7	11/25/1984	Near Jackson, Louisiana	30	1016	950	Direct Listing		1, Table 3.1; NTSB-PAR-86-1
8	8/9/1976	Cartwright, Louisiana	20	770	203	Eq Burn radius		1, Table 3.1; NTSB-PAR-77-1
9	3/15/1974	Near Farmington, New Mexico	12	497	200	Eq Burn radius		1, Table 3.1; NTSB-PAR-75-3
10	6/9/1974	Near Bealton, Virginia	30	718	300	Eq Burn radius		1, Table 3.1; NTSB-PAR-75-2
11	9/9/1969	Near Houston, Texas	14	789	300	Direct Listing		1, Table 3.1; NTSB-PAR-71-1
12	11/5/2009	Bushland Texas	24	762	550	Measured Aerial	Heat Damage	Failure Investigation Report – El Paso Pipe Failure at Saddle, PHMSA 10/20/2011, Richard Lopez; Channel 10 Aerial, NTSB ;
13	9/9/2010	San Bruno Ca	30	386	600	Measured Aerial	Houses major damage, Addresses	NTSB/PAR-11/01; Aerial www.mercurynews.com/bay-area-news/ci-16045510, September 17, 2010; NTSB/PAR-11/01,National Transportation Safety Board. 2011. Pacific Gas and Electric Company Natural Gas Transmission Pipeline Rupture and Fire, San Bruno, California, September 9, 2010. Pipeline Accident Report NTSB/PAR-11/01. Washington, DC.August 30, 2011;
14	8/10/2000	Carlsbad New Mexico	30	675	675	Measured	fatalities	NTSB/PAR-03/01,National Transportation Safety Board. 2003. Natural Gas Pipeline Rupture and Fire Near Carlsbad, New Mexico, August 19, 2000. Pipeline Accident Report NTSB/PAR-03/01. Washington, D.C. Feb 11, 2003;
15	2/2/2003	Voila, Illinois	24	816	900	Projectile	Impact point	CPF No.3-2003-1002 DOT CORRECTIVE ACTION ORDER Feb 7, 2003;
16	5/5/2009	Rockville, In	24	784	330	erial Visible Damag	Burn Area	NTSB 3-2009-1009H,newspaperdescription The Tribune-Star, May 6, 2010,Howard Greninger; WTHI TV Website Updated Wednesday, 30 Dec 2009; http://www.wthitv.com/dpp/news/news_wthi_rockville_pipeline_explosion_under_investigation_200905061652
17	9/14/2008	Appomattox Virginia	30	799	850	erial Visible Damag	Burn Area	NTSB CPF 1-2008-1004H, www.newsadvance.com, September 24, 2008 aerial photo;
18	12/11/2012	Sissonville, West Virginia	20	929	610	Ground Report Measured Aerial	Heat Damage	NTSB 4th Briefing 12/14/2012 Reported damage 490 ft to north, 610 ft to west, 330 ft to south, 470 ft to east, and projectile 40 feet from Rupture NTSB, NTSB/PAR-14/01 dated February 19, 2014.
19	4/29/2016	Salem Township, Pa	30	1050	895	erial Visible Damag	Heat Damage	Aerial Photos News 4 Copter, House Siding Melted

Graph 1, "Incident Pipe Diameters and Pressures" shows the range of the sample incidents with respect to pipeline diameter and pressure at the point of rupture.



Graph 2, " Damage Distance", compares the distance to observed damage among the historical sample of incidents. This graph correlates the damage distance to the pipeline diameter times the square root of the pressure at the point of rupture. The picture insert is for the recent Sissionville incident reference 18.



Graph 2 Damage Distance $\text{diameter(inches)} \cdot \sqrt{\text{pressure(psi)}}$

The red square labeled “House” represents the likelihood of damage, based on the historical sample, to a house located 403 feet from the rupture with ignition of a 20-inch natural gas pipeline with an operating pressure of 1404 psi. Based on direct observation of damage from a natural gas pipeline with very similar circumstances that did explode (reference 18), it is concluded the house would be destroyed.

The following is an excerpt from the NTSB/PAR-14/01 dated February 19, 2014 for the Sissionville incident (Reference 18).

“The escaping high-pressure natural gas ignited. Fire damage extended nearly 1,100 feet along the pipeline right-of-way and covered an area about 820 feet wide. Three houses were destroyed by the fire, and several other houses were damaged. There were no fatalities or serious injuries; however, Interstate 77 was closed for 19 hours until about 800 feet of thermally damaged road surface was replaced.”

The most recent incident in this report occurred on April 29, 2016 in Salem Township Pennsylvania (Reference 19). Several pictures of the Salem Township pipeline rupture provide further examples of damages that are observed in natural gas transmission pipeline explosions. In this case, there is a crater in the ground where the pipeline used to be. The crater is now surrounded by substantial areas of hardened, baked earth from the intense heat. Trees with green branches were consumed by the intense radiant heat, leaving only the trunks. In this case, a house 300 feet away was completely consumed by the fire. The nearby main road, Pennsylvania route 819, was badly damaged and completely closed in both directions for weeks for repair. Sadly, in this case, it cannot be said “we were lucky in this case that no one was injured”. A young healthy 26 old newly married man was badly burned struggling to flee his burning house which is shown in the figures. The intense heat burned him while he fled. As a result of his burns he has had multiple amputations of major limbs.

The reader needs to closely observe all the figures of the incidents. In general, the types of damage are very similar if structures, trees, or highways are present so that damage can be observed. The difference between the events is the distance that damage from the point of rupture is observed. The distance of the damage is correlated to the diameter of the pipeline and the square root of the operating pressure of the pipeline. These are the listing of the figures available corresponding to the reference events.

The more recent events have pictures to clearly show the typical type of damage that is observed. The additional figures are included for two more recent events. These are for references 18 and 19, the Sissonville, West Virginia and Salem Township Pennsylvania incidents respectively.

This is a list of figures to follow in this order:

References:

1. GRI-00/0189, "A MODEL FOR SIZING HIGH CONSEQUENCE AREAS ASSOCIATED WITH NATURAL GAS PIPELINES TOPICAL REPORT", Mark J. Stephens, C-FER Technologies, 200 Karl Clark Road, Edmonton, Alberta T6N 1H2, CANADA, C-FER Report 99068, October 2000

Figure 1- Pipe Rupture 11/5/2009 Bushland Texas Ref 12

Figure 2- Pipeline Rupture 9/ 14/2000 Appomattox Virginia Ref 17

Figure 3- Pipeline Rupture 5/5/2009 Rockville, In Ref 16

Figure 4- Pipeline Rupture 5/5/2009 Rockville, In Ref 16

Figure 5- Pipeline Rupture Carlsbad, New Mexico 8/10/2000 Ref 14

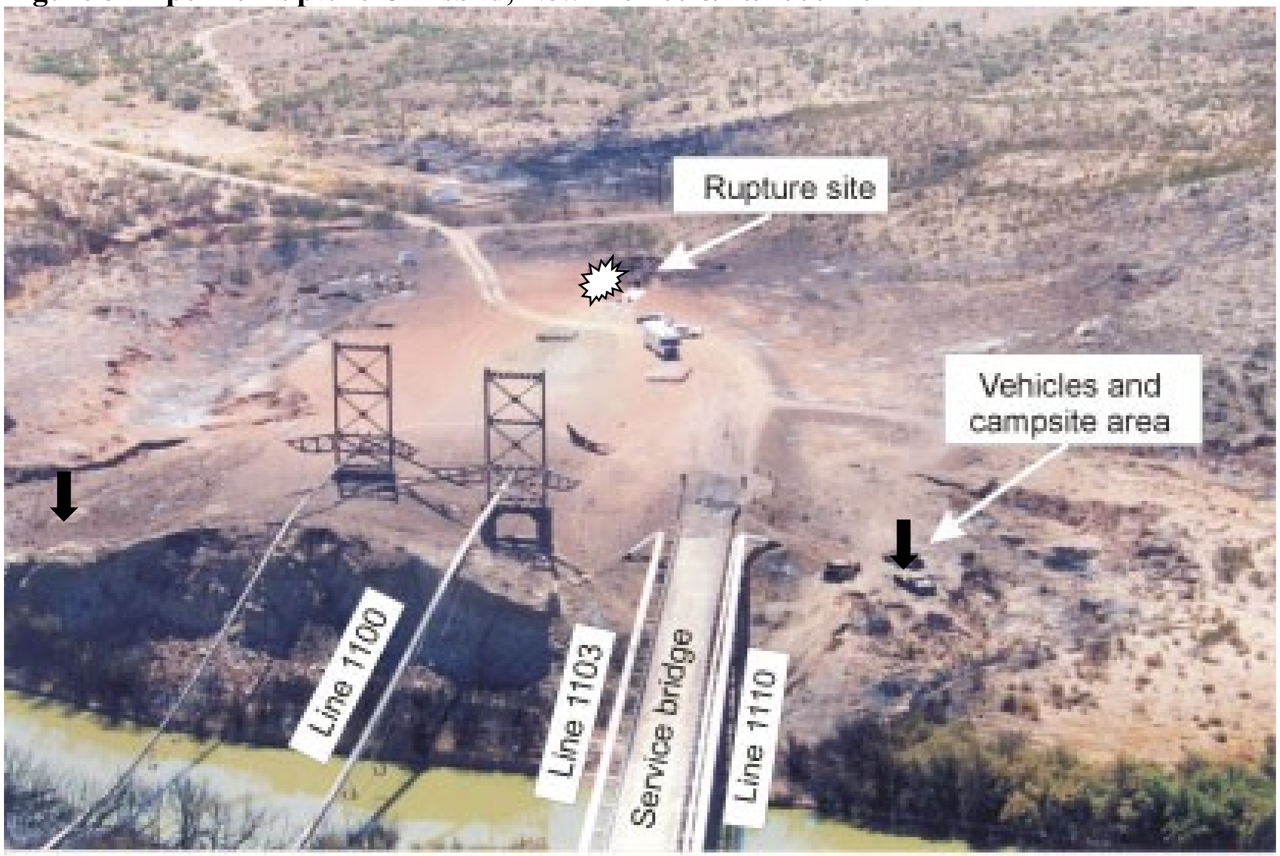


Figure 6- Pipeline Rupture 9/9/2010 San Bruno, Ca Ref 13

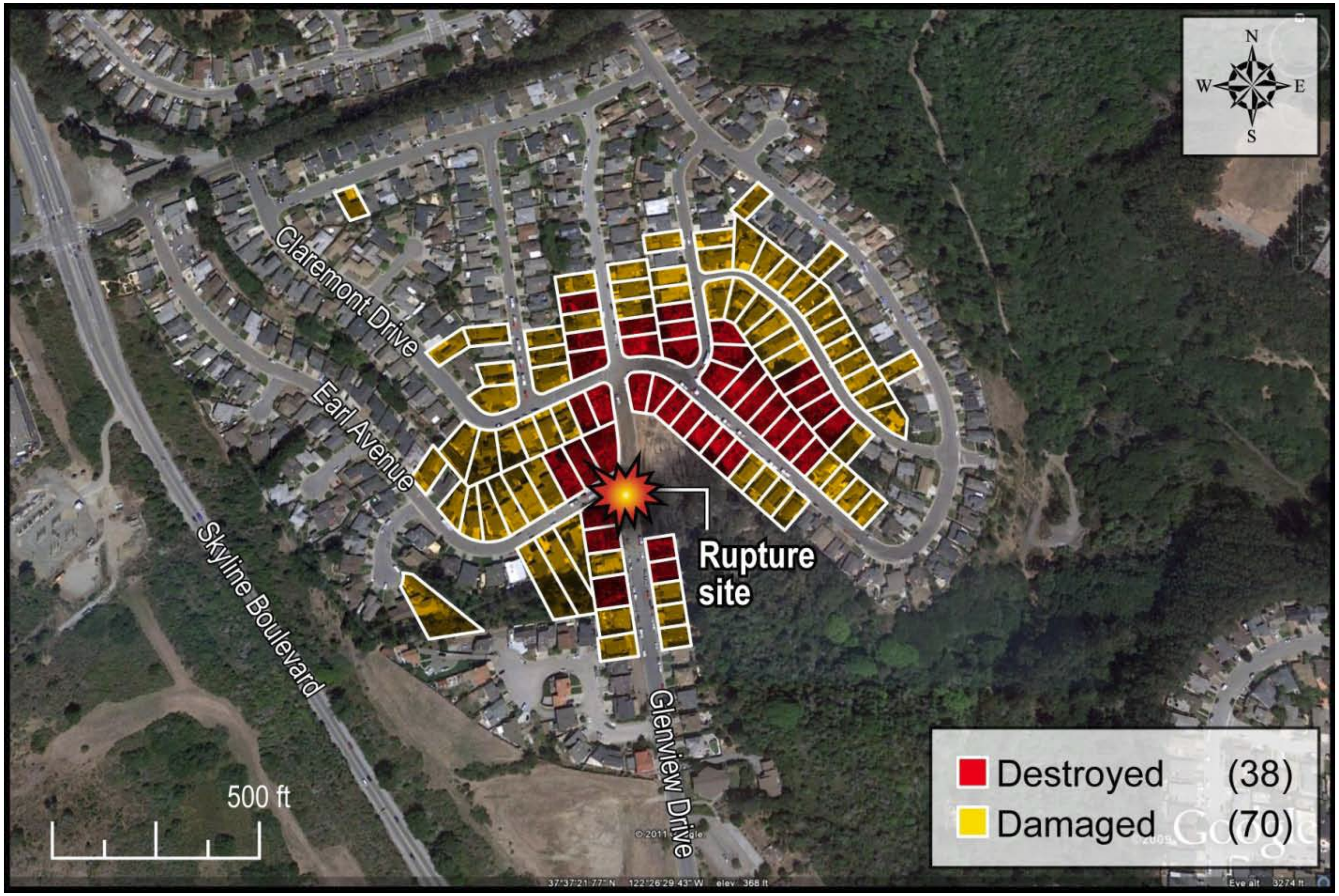


Figure 7- Pipeline Rupture 9/9/2010 San Bruno, Ca Ref 13

Figure 8- Pipeline Rupture Sissonville, West Virginia, 12/11/2012

Looking From the East toward the West, Sissonville, West Virginia. Note the large areas of baked soil and scorched I-77.

Figure 9- Aerial View showing approximate Locations of Heat Damage, Sissonville, West Virginia. Note the smoldering house to the west of the point rupture. This house was not replaced nor was the adjacent house to the south. See figure 8

Figure 10- Looking North During Pipeline Rupture Sissonville, West Virginia. I-77 totally engulfed in the explosion.

Figure 11- Crater at Sissonville, West Virginia. This is quite typical of a transmission pipeline explosion.

Figure 12- Pipe projectile Sissonville, West Virginia. Located 40 feet from the point of pipeline rupture.

Figure 13 - House destroyed Sissonville, West Virginia . This house is one not replaced as shown in Figure 8.

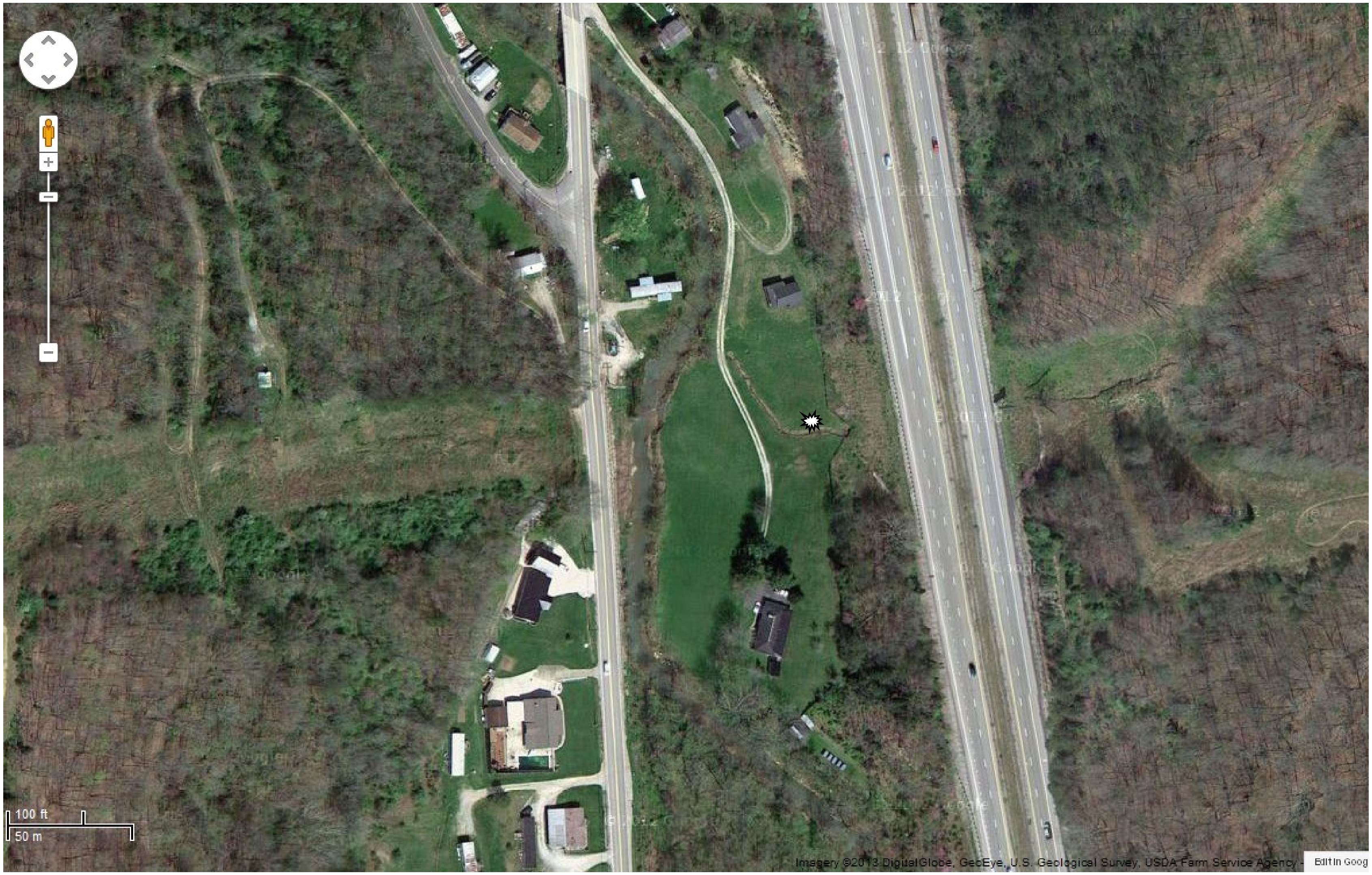


Figure 14 Aerial View Before Pipeline Rupture, Sissonville, West Virginia (Note Proximity of Houses to Right of Way) Compare to Figure 8.

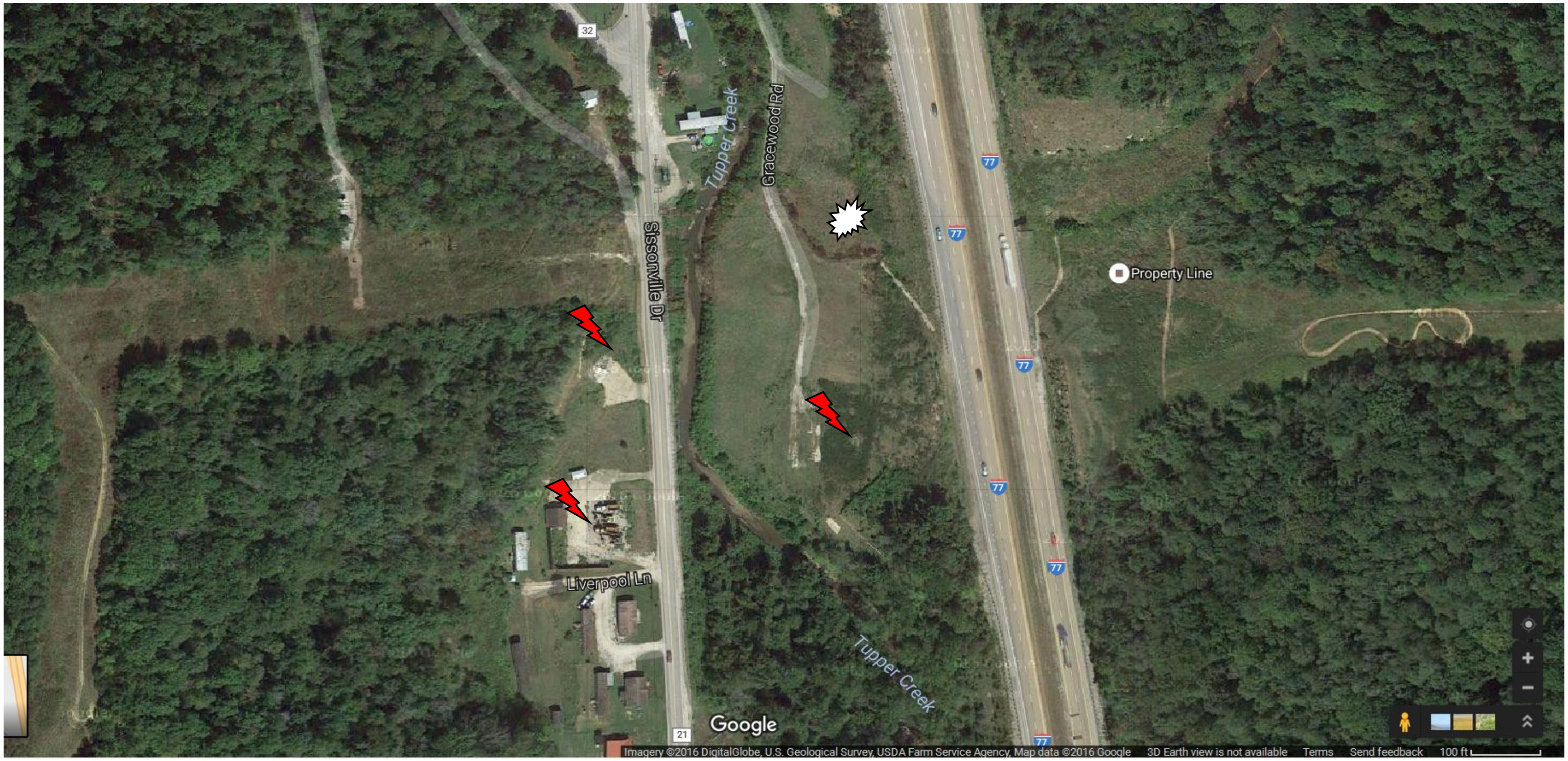


Figure 15- Incident area 3 years later Sissonville, West Virginia (2016)
Showing damaged houses not replaced 3 years later. The house in the lower left is about 500 feet from the explosion.

Figure 16- Salem Township, Pennsylvania Ref 19

Figure 17 - Salem Township, Pennsylvania Ref 19

Burned House Salem Township, Pa. Ref 19 Photo from Darrell Sapp

Figure 18 - Sliding melted on house 895 feet from rupture Salem Township, Pa. Ref 19