COMPARISON OF ACTUAL BUILDING DAMAGE AND REPAIR COSTS FROM THE PEPCON EXPLOSION TO INHABITED BUILDING DISTANCE EXPECTATIONS

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ABSTRACT

On 4 May 1988, an accidental fire and several explosions destroyed the Pacific Engineering Company (PEPCON) plant in Henderson, Nevada. The largest explosion, estimated as 500,000 pounds TNT equivalent weight, caused significant damage to the surrounding community, including portions of the Las Vegas metropolitan area.

In 1990, property insurers joined in a lawsuit to recover their damage claim payments. With over 17,000 claims, the total alleged payment from the insurers totaled about $77 million. Through the legal discovery process, the defense team obtained copies of all damage claims; pertinent information was subsequently entered into a database. In 1992, Lloyd's of London, the basic defense underwriter, agreed to a $70 million settlement.

Using the damage claim database, the authors were provided with a rare opportunity to evaluate actual damage costs resulting from an explosive detonation. The results are striking. According to DoD 6055.9-STD, the expected repair cost for an unstrengthened building, located at the Inhabited Building Distance (IBD) from an accidental detonation, is approximately 5 percent of the building's replacement cost. In the PEPCON accident, the nearest residences to the plant were located at distances much greater than the IBD. However, despite these greater distances, paid damage claims for these residences approached 20% of their replacement values. If the residences had been located at the IBD, they would have suffered significantly more damage, resulting in even higher claim costs. Clearly, DoD 6055.9-STD vastly underpredicts damage costs for these exposures.

In this paper, we will first review current DoD safety regulations. Next, we will discuss the PEPCON accident and the calculation of blast overpressures resulting from the accident. We will then present the actual damage claims and will analyze their variation with overpressure. Since the claims were primarily for single family residences, this type of construction will be emphasized. Finally, we will compare the actual damage and repair costs with those postulated by current DoD safety regulations. Particular attention will be paid to expected damage costs at Inhabited Building Distances.

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DoD Safety Regulations and Inhabited Building Distance

The Department of Defense Explosives Safety Board (DDESB) is responsible for establishing uniform safety standards applicable to DoD ammunition and explosives, to associated personnel and property, and to unrelated personnel and property exposed to the potential damaging effects of an accidental explosive detonation. The resulting safety requirements are published in the "DoD Ammunition and Explosives Safety Standards," DoD 6055.9-STD[1].

In DoD 6055.9-STD, the preferred method for protecting personnel and the public from blast effects is the maintenance of a minimum separation distance between potential explosive donor and acceptor facilities. For the public, the required separation distance is termed the Inhabited Building Distance (IBD). The IBD is applied along the boundary of military installations and storage areas. Beyond this distance, uncontrolled residential and commercial development must be accepted.

For net explosive weights (NEWs) of 250,000 pounds or greater, the IBD is calculated using the formula $D = 50W^{1/3}$, where D is the IBD distance in feet and W is the NEW in pounds. The incident blast overpressure at this distance is approximately 0.9 psi. According to DOD 6055.9-STD, the expected damage repair cost for unstrengthened buildings, located at the IBD from an accidental detonation, is approximately 5 percent of the building's replacement cost.

In recent years, explosive safety specialists have voiced increasing concern over the validity of this damage expectation, particularly for modern commercial and residential construction[2]. In explanation, the 5% of replacement cost value is based largely on tests, performed between 1945 and 1969, of wood frame residential construction. During the last 30 years, changes in design and construction technology have resulted in residential and commercial structures which are much lighter, are more flexible, and make greater application of glass as an exterior cladding material. Consequently, although they are more economical, these structures also are expected to be more vulnerable to blast overpressures.

Through analysis of the PEPCON damage claim database, the authors were provided with a rare opportunity to evaluate actual paid damage claims resulting from an explosive detonation. As feared, although the nearest residences were located at distances significantly greater than the IBD, the actual damage claims approached 20% of replacement values, far exceeding DoD expectations.

PEPCON Accident

A series of explosions beginning about 1851 UTC (1151 PDT) on May 4, 1988, destroyed the Pacific Engineering Company (PEPCON) plant in Henderson, Nevada, that manufactured ammonium perchlorate (AP) for rocket fuel[3]. The plant was located in a relatively open desert area between Las Vegas and Henderson, shown in Figure 1, but its original isolation was being rapidly encroached in 1988 by residential construction southward from Las Vegas and into the northern city limits of Henderson.

The author, Jack Reed, then at Sandia National Laboratories in Albuquerque, New Mexico, was immediately sent to investigate this incident because of concern for Sandia employees at Nevada Test Site (NTS) and Tonopah Test Range who lived in the plant vicinity. Reports[3],[4] were produced which established that the largest individual explosion was an equivalent airblast generator to a Standard 1 kt NE (nuclear) explosion, free-air burst, or about 250 ton (227 Mg) TNT surface burst equivalent[5].

There were strong southerly storm winds at the PEPCON explosion time which enhanced northward airblast propagation across Las Vegas, but no upper-air wind details were available below about 1500 ft (500 m) above the surface. At greater heights radiosonde and pibal wind observations from near Indian Springs and Mercury provided wind vectors which were linearly connected to the McCarran Airport anemometer vector for interpolative estimate and weather-dependent airblast prediction.

These data allowed preparation of circular contours of airblast overpressure, which were then adjusted for weather effects, specifically a strong wind storm which swept the area and probably contributed to spread of the initial fire. These winds significantly extended the damage area northward across Las Vegas.

Many large windows were broken, and their sizes and locations were used to compare with an airblast damage model for low overpressures derived from an explosion incident at Medina Facility, San Antonio, Texas, in 1963[6]. Airblast overpressure estimates were made from the 250-ton HE (TNT) surface burst with the BLASTO © weather-dependent airblast prediction program[7] and applied at damage claims locations to estimate window damages. Preliminary results roughly confirmed the Medina model for window breakage from low and intermediate overpressures of 200 to 2000 Pa (0.029 to 0.29 psi).

Damage Claim Database

In 1990, and following retirement from Sandia, this author was engaged by a legal team headed by Mendes & Mount, P.A., Los Angeles, CA, to help defend against a lawsuit filed by a consortium of insurance companies seeking to recover their $77 million paid in nearly 17,000 damage claims settlements. Copies of these claims were provided to the legal defense team through the *discovery* process. It was easily determined that there were sufficient discrepancies and irregularities in these claims to warrant a full-scale review and damage cost re-evaluation. An actual damage figure near $25 million seemed to be more reasonable. In the tumult of disaster recovery, rapid claims processing by insurers precluded normal claim investigation, resulting in duplicated and repeated claims, some apparent price gouging, and other problems which were overlooked in order to maintain the insurers' advertised images for prompt and equitable settlements.

To the end of defending a lower *actual* cost figure, the entire claims collection was transcribed to computer disks, each claim was located with respect to the explosion, and a pattern of claims density was developed for correlation with predicted explosion airblast overpressures. About $1.5 million was spent on these preparations and initial technical reviews. Total legal defense preparation costs, however, were approaching $5 million per year, largely for collecting witness depositions. The bottom-line defense insurer, Lloyds of London, was in other financial difficulties at that time, so they decided to make a quick settlement for around $70 million in late 1992. Thus ended analysis and research of these damage claims being supported by the legal system.

But this termination left a unique, large, and valuable information database of nearly 17,000 airblast damage claims that needed further analysis and reporting to the entire scientific and engineering community with interests in explosion airblast effects. Also, it demonstrated insurer cost inflation in major disasters that needs to be recognized and rebutted lest legal precedents be set, so that liability for actual explosion damage is not extended to include the costs of maintaining an *image* of insurer service quality. Consequently, in 1995, the Department of Defense Explosive Safety Board (DDESB), through the U. S. Army Engineering and Support Center, Huntsville (USAESCH), authorized the studies summarized in this paper[8].

Standard township survey maps[9] have been used in these analyses, providing streets and other data on quarter-quarter-section grids (40 acres). Insurance claim addresses were geographically located with Census Bureau "Tiger Files," using GIS computer systems by the University of New Mexico Department of Government Research. Further, they obtained property records from Clark County NV Clerk's (CCC) files for each address, containing property use code, floor area, construction year, and last sale date and price. Figure 2 shows the distribution of floor areas for claim addresses. Large scale aerial photographs were used to determine the number of SFRs in each grid square over the most damaged areas; smaller scale photos were used to estimate SFR density in more distant grid squares. Figure 3 shows the distribution of SFR counts per grid square. Figure 4 shows the number of claims from each square mile of the two adjacent cities.

Extensive editing, corrections, and duplicate claim deletions resulted in a final number of 12,535 claims from SFRs, 1,405 of which did not state a dollar amount. Window damage was specified in 6,405 of these claims. Multi-family residences and mobile homes generated 2,149 claims, and 524 claims were received from non-residential properties. Total SFR claim numbers are shown in Figure 5, total dollars in Figure 6, and average claim dollars in Figure 7. The pie chart in Figure 8 shows the portions of total claims dollars paid for window, door, and other repairs. Other damages consisted of everything except windows and doors, including structural damage, broken bric-a-brac, carpet and curtain replacement or clean-up, etc. Door damages were not categorized between entry, interior, garage, or glass patio doors. Only 7% of damage costs were attributed specifically to windows, yet they are the most ubiquitous and relatively uniform features that were damaged by low overpressures and amenable to quantification and damage modeling. Claims did not, however, often specify a number of broken panes.

Total claims damages were divided by CCC property improvement values, considering their 33% assessment ratio, to obtain the percent of replacement cost caused by the PEPCON explosion. Show versus overpressure in Figure 9(a), cost ratios were significantly greater than previous values[10] obtained from structures built near large explosion tests. Several factors are involved. Much boom town construction around Las Vegas has been weak and shoddy; claims included cleaning as well as repairs to carpeting, curtains, bric-a-brac; claims adjustor's investigations were cursory at best versus detailed evaluations of test houses; and repair costs were inflated by this disaster's magnitude in a limited community.

Damage Intensity Estimation

Damage intensity analyses were based on a glass damage model (GDM), derived from studies of another accidental explosion at Medina Facility, San Antonio, TX, in 19635], as well as residential-type structures built and exposed near large explosion tests. This GDM1] assumes that each window in a community may be represented by a "typical" square pane (TP), 2 ft x 2 ft (0.37 m^2) single-strength glass, facing random directions. It has a geometric mean[11] breaking loading of 7.5 kPa (1.09 psi), with geometric standard deviation (SD) factor of 2.5. This lognormal model gives 15.9% breakage (-1 SD) at 3 kPa (0.44 psi) overpressure, 2.3% breakage (-2 SD) at 1.2 kPa (0.17 psi), etc. Based on the Medina incident, the same number of these panes would be broken as in the actual distribution of pane sizes in that community. A corollary result was that there were 19 panes per capita in San Antonio.

Applied to PEPCON, CCC records showed an SFR average 1600 ft^2 floor area, so that 10% of that in window area by building codes, gave 40 TP/SFR. The expected number of broken panes per 1,000 SFRs could thus be calculated as a function of incident overpressure. Since there was no broken pane count included in the claim reports, this expected number had to be reduced to an expected number of *claims* by application of the hypergeometric equation[12]. That is, in a total population (40,000) with some percent broken, what is the probability of N broken in a subset (40)? The claims probability is the complement of the probability of no broken panes, $N = 0$. These predictions could be compared to actual claim numbers for each grid square.

The number of claims from each square was then collected from the database and divided by the number of SFRs in the square to give a claims fraction. This was normalized to 1,000 houses for damage intensity (DI) comparison with predictions. Results were scattered by a number of factors, including the small grid size, so smoothing over multiple grids was performed over 5 x 5 squares, less corner square (21 squares; 1.31 mi^2, 3.4 km^2). Variance tests showed that smoothing over larger areas encountered difficulties with assuming uniformity of property development. Results, comparing smoothed values with the GDM prediction curves, are shown in Figure 10. This shows that assuming 50 panes/SFR might have been a better choice over the 400 Pa to 800 Pa (0.058 psi to 0.12 psi) overpressure range, possibly indicating a scenic or climatic preference compared to national norms. Other deviations from the 40 pane curve, however, can probably be explained by weather effects. Underpredictions fell in three geographic groups, which likely experienced "hot spots" of airblast enhancement caused by turbulence in the strong, gusty winds. Overpredictions at 200 Pa to 400 Pa (0.029 psi to 0.058 psi) are the likely result of shallow (10 meter (33 feet)) down-wind airblast ducting which was attenuated by buildings, trees, and small terrain irregularities.

The map in Figure 11 shows weather dependent predicted overpressure isobars (contours) ranging from 2 kPa (0.29 psi) skirting the residential developments to 200 Pa (0.029 psi) extending beyond most development. Inside the 2 kPa (0.29 psi) isobar there is little weather effect where shock strength smooths out most weak distortions. Lower contours were noticeably extended northward and downwind. Claims DI contours are shown as solid lines in Figure 12, along with dashed predicted contours, for comparison. Ballpark agreement is quite clear, and DI contour wandering represent only a few decibel variations, which is relatively precise in acoustic applications.

It may thus be concluded that BLASTO weather dependent overpressure predictions, applied to a SFR community through the provided GDM, predicts claim results quite well, at least for San Antonio, Texas and Las Vegas/Henderson, Nevada. Application for distinctly different climatic regimes or architectural norms, or to other countries, may require considered adjustments.

Damage Versus Airblast Overpressure

SFR damage claims, numbers and average dollar amounts are shown in Figure 13 versus overpressure. The dip in numbers between 800 Pa (0.12 psi) and 1300 Pa (0.19 psi) resulted from chance; several parks, golf courses, and undeveloped areas fell in that zone. Average claim costs increased regularly and exponentially with overpressure. Window damages, in Figure 14 showed an average around $250 up to 900 Pa (0.13 psi), representing single pane repairs, then a general increase with overpressure as more panes were damaged per claim. Figure 15 shows percentages of SFRs that did not submit damage claims versus overpressure. Again, data generally follow the GDM trend, with the majority of SFRs making claims exposed to more the 1 kPa (0.15 psi).

Statistical distributions of total claim amounts are shown in Figure 16, with separate curves for each 100 Pa (0.015 psi) overpressure increment. Overall, the lognormal distribution appears to fit these data with parameters varying with overpressure as shown in Figure 17. Scatter factors seemed to be generally constant, except for reduced scatter on the high side in approaching 2 kPa (0.29 psi) overpressure. This should be expected as more panes were broken to improve their statistics.

Other Residential and Non-Residential Claims

Total dollar amounts for multi-family and mobile residences are shown in Figure 18; these averaged about $1500 per claim. The number of non-residential claims, from commercial, industrial and public structures, are shown in Figure 19, with dollar totals in Figure 20. The pie chart in Figure 21 shows a smaller fraction of claim amounts for door and window damages than Figure 4 showed for SFRs.

By comparison with SFRs, there was little uniformity in multi-family and non-residential properties, so it appeared that overall relative cost factors should be applied in estimating costs from such claims. Some judgment will be required, considering the large number of multi-family and mobile residences in Las Vegas. In relation to its permanent population, there is also a large commercial sector to accommodate tourist, and a very small industrial base.

Summary of Damage Claims

In summary, only $47 million in claims were accompanied by dollar amounts. One can only speculate how the insurors came up with their $77 million lawsuit amount. And, most significantly, SFRs accounted for $41 million of these claims, 88.5% of the total, which can be estimated from airblast overpressure and glass damage modeling and similarly applied to other explosions, weather, and communities.

Conclusions

In DoD 6055.9-STD, the expected repair cost for an unstrengthened building, located at IBD from an explosive detonation, is given as approximately 5 percent of the building's replacement cost. Unfortunately, as demonstrated in this report, this damage expectation is unrealistically low.

In the PEPCON accident, the single-family residences nearest to the explosion site were located at distances much greater than the IBD. However, despite these greater separation distances, paid damage claims for these residences approached 20% of their replacement values. If these residences had been sited at IBD, they would have suffered significantly more damage, resulting in even higher repair costs.

The PEPCON damage claims often included costs for repair, cleaning, or replacement of furniture, curtains, draperies, and carpets. Such furnishings were not present in most explosion test structures and therefore, were not normally included in damage and repair cost estimates. Structural damage was primarily reported to relatively weak structural elements including overhead garage doors, household doors, and windows.

Recommendations

As discussed in this report, the damage expectation provided in DoD 6055.9-STD for structures sited at the Inhabited Building Distance from an accidental detonation is not consistent with the actual paid damage claims from the PEPCON accident. Consequently, to ensure that the guidance provided in DoD 6055.9-STD is accurate, we strongly recommend that the DDESB consider revising the standard.

We suggest two options for implementing this recommendation. First, the IBD separation distances provided in the standard could be modified to agree with the current damage expectation. Under this option, IBD distances would vary and would depend upon with the vulnerability and occupancy of the acceptor structure. In explanation, recent research[2] has established that certain modern, lightweight structures are much more vulnerable to blast overpressure than other structure types, resulting in an increased likelihood of injury to their occupants. Examples of more vulnerable structures include pre-engineered metal buildings, which are typically designed to minimize material costs and consequently, are very lightweight, and schools and churches which due to their high occupancy and extensive use of glass, present a greater risk of injury from glass breakage. Greater separation distances would be required for the more vulnerable structure types.

Under the second option, the IBD damage expectation provided in DoD 6055.9-STD could be revised to agree with the actual damage and repair costs reported for recent explosive accidents, including the PEPCON explosion. To be accurate, this description should include a brief discussion of the expected increase in damage and repair costs for larger explosive weights. Caused by the longer blast load duration, this relationship is recognized by the safety standard through its use of greater IBD separation distances for explosive weights above 100,000 pounds NEW. However, despite this increase in separation distances, damage at IBD distances is still expected to be significantly greater for accidents involving larger explosive weights.

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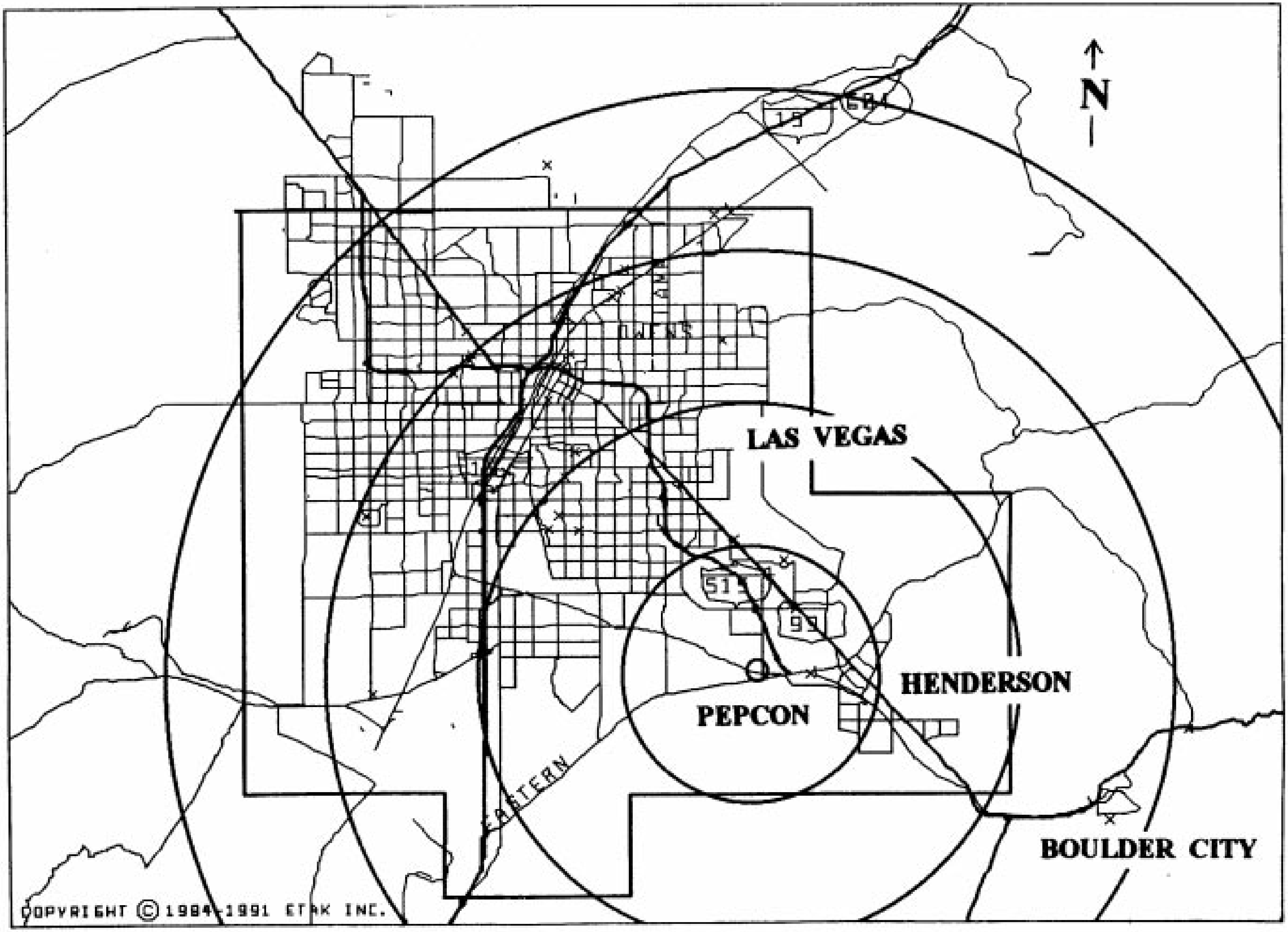


Figure 1. Map of Las Vegas and Henderson, Nevada, with PEPCON location and five-mile incremented distance circles.

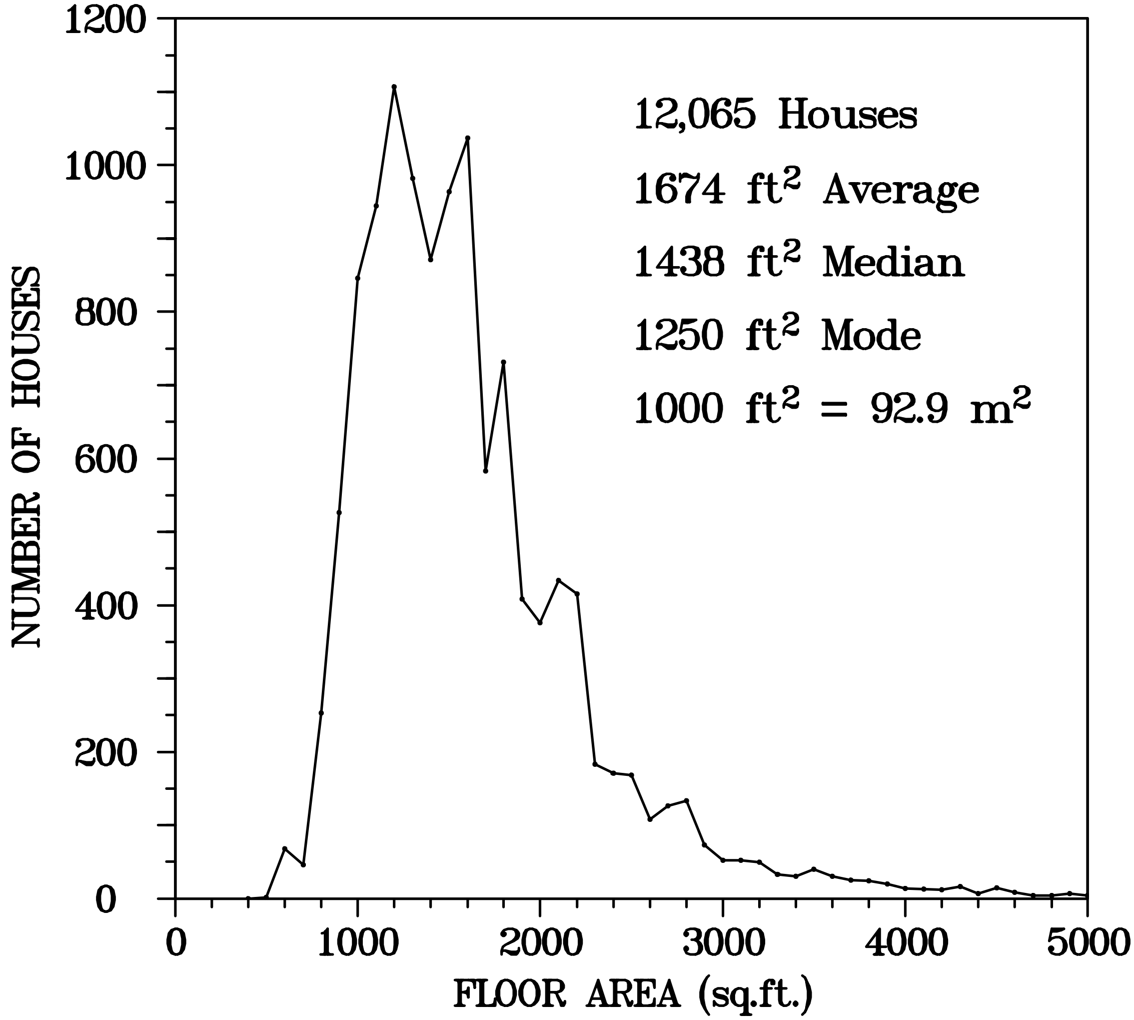


Figure 2. SFR floor area distribution

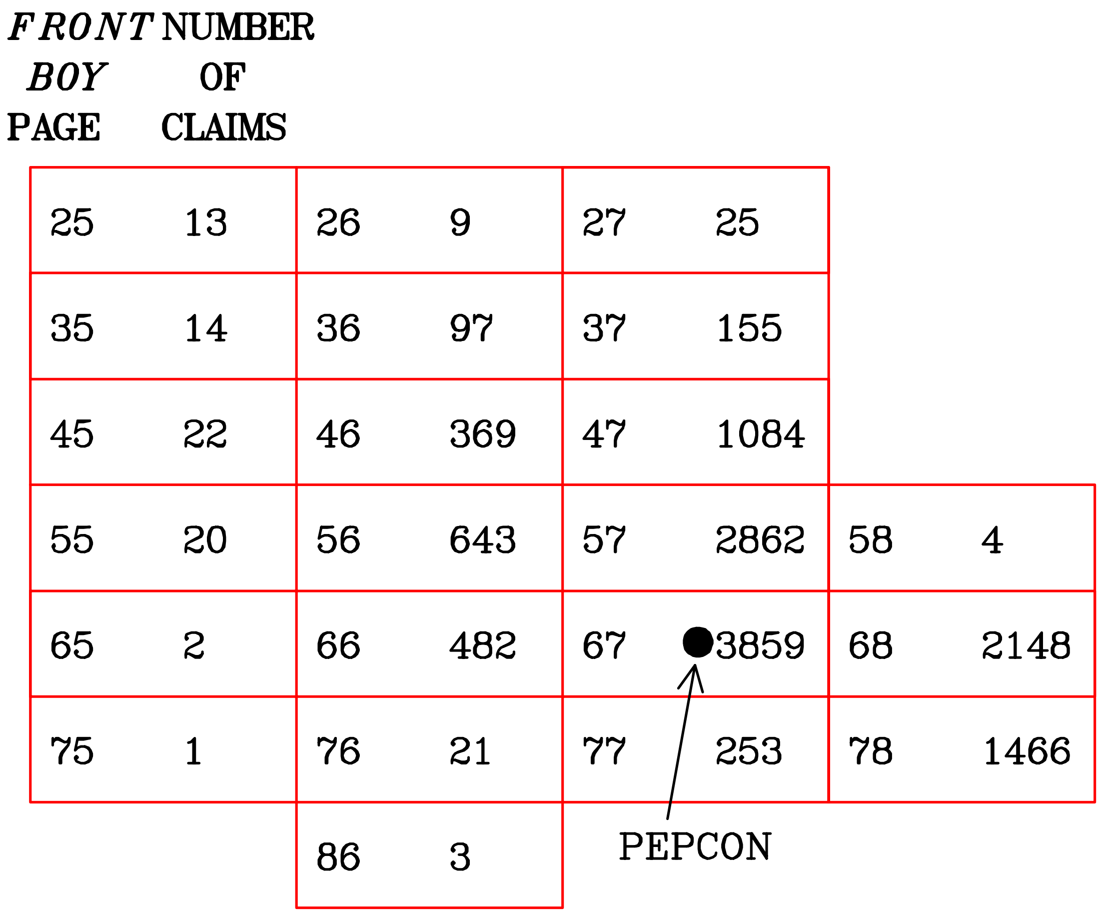


FIGURE 3. *Front Boy* map page numbers containing priced damage claims.

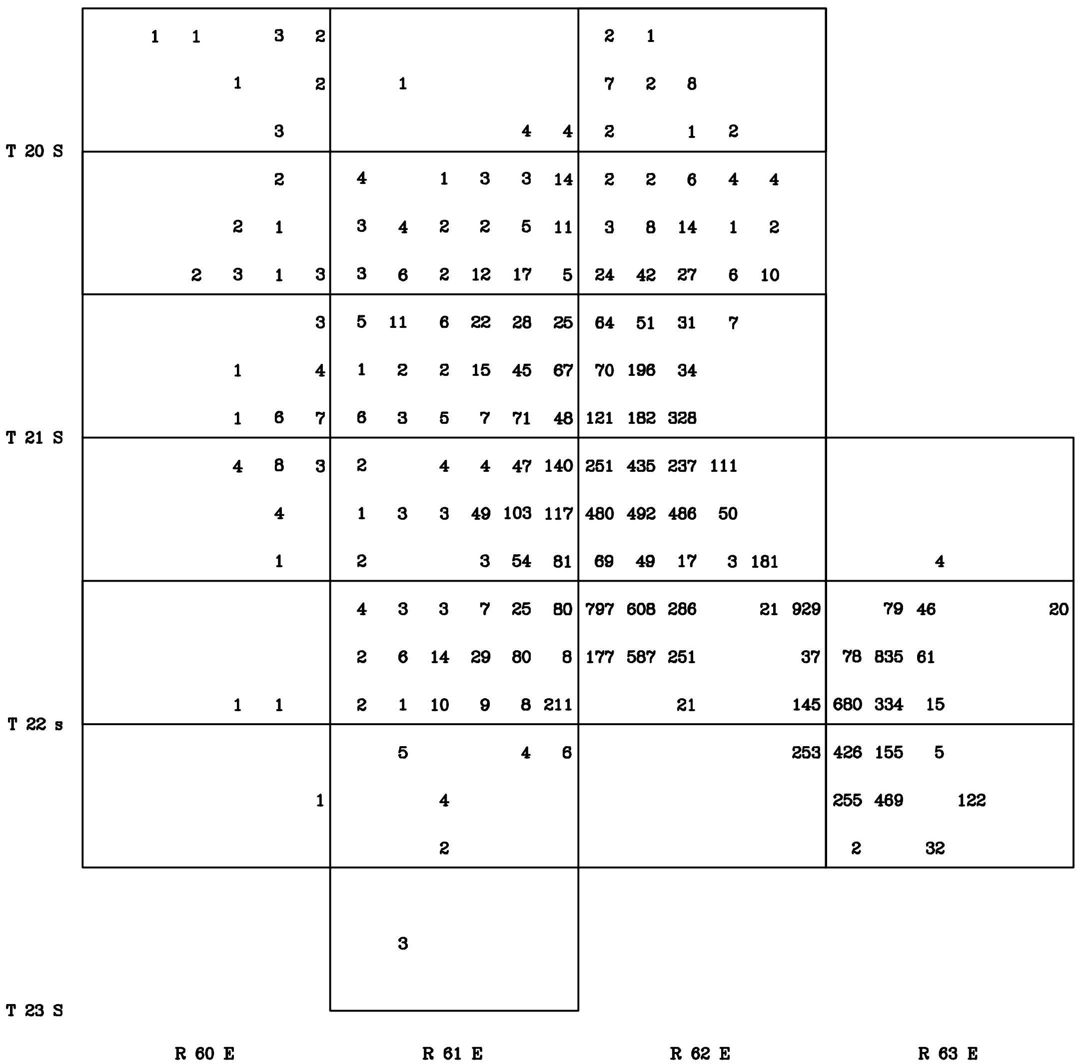


Figure 4. Number of claims from each square mile of *Front Boy* map pages.

Figure 5. Number of SFR claims.

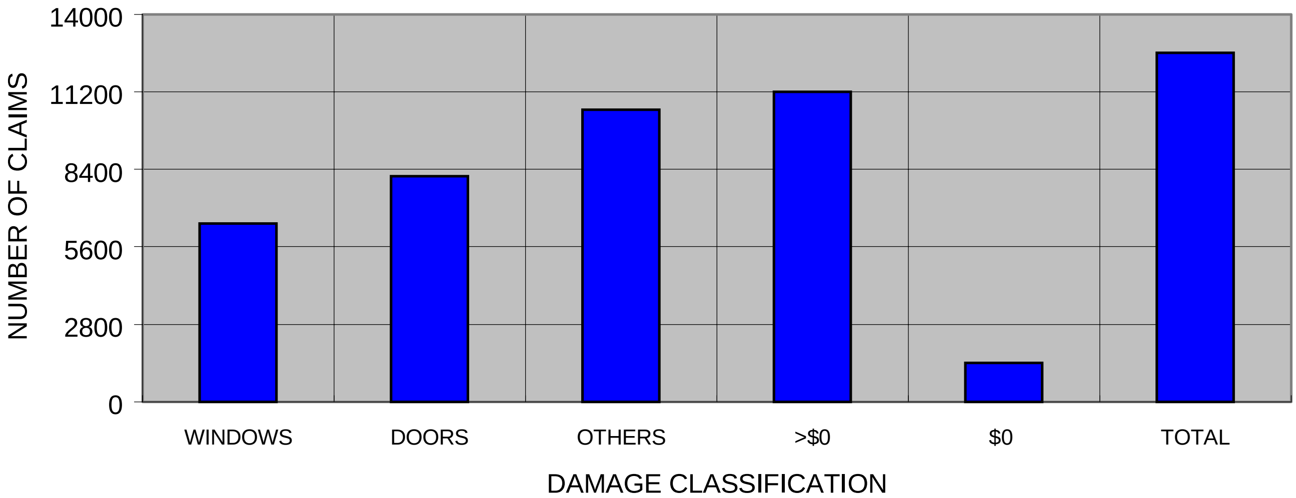


Figure 6. Total claims dollars.
Single-family residences

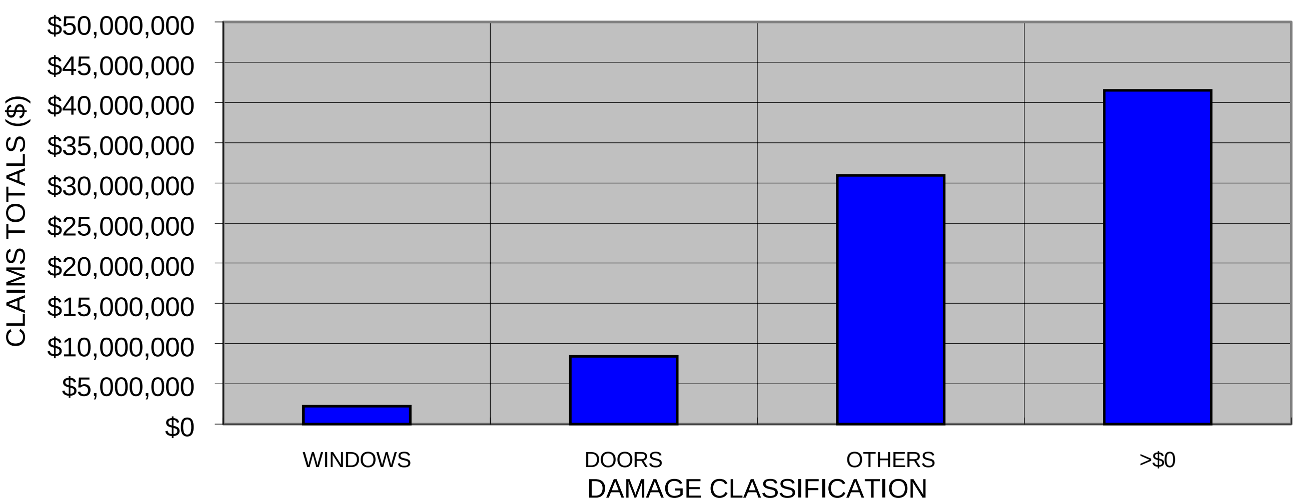


Figure 7. Average claim dollars
Single-family residences

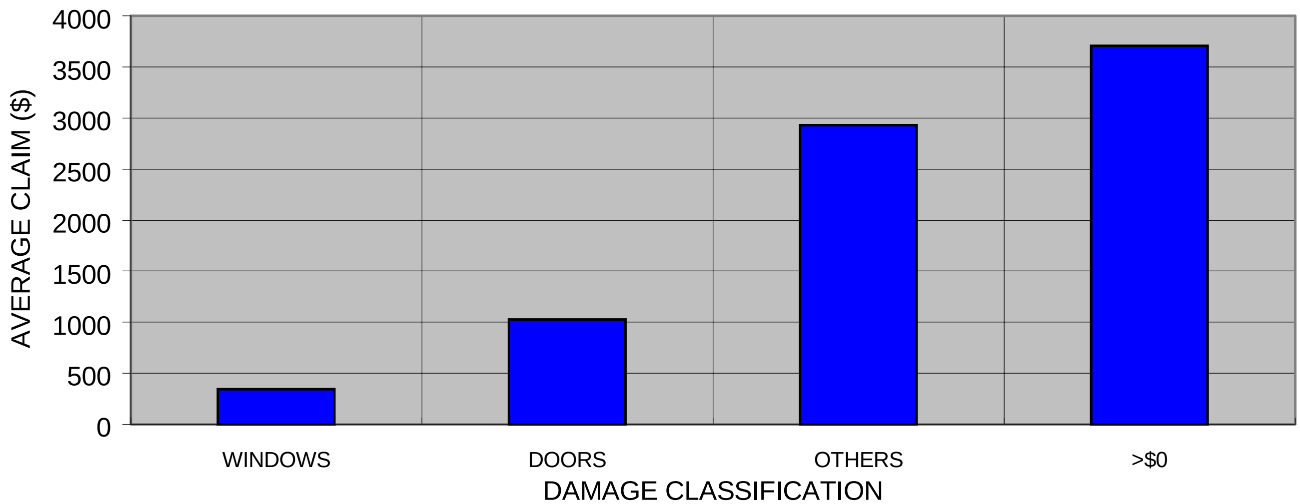
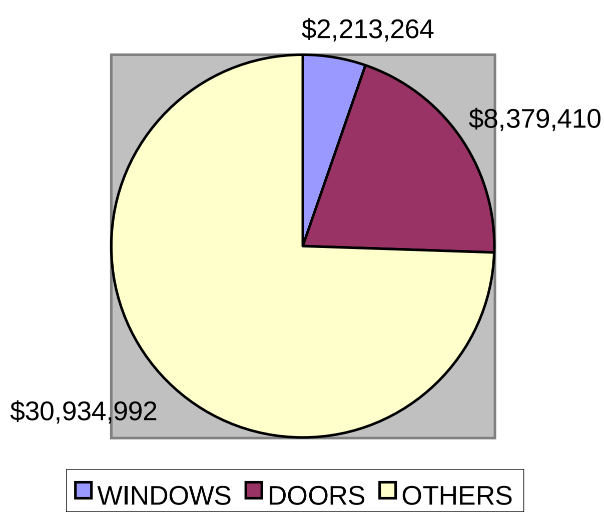


Figure 8. Claims dollars apportionment
Single-family residences



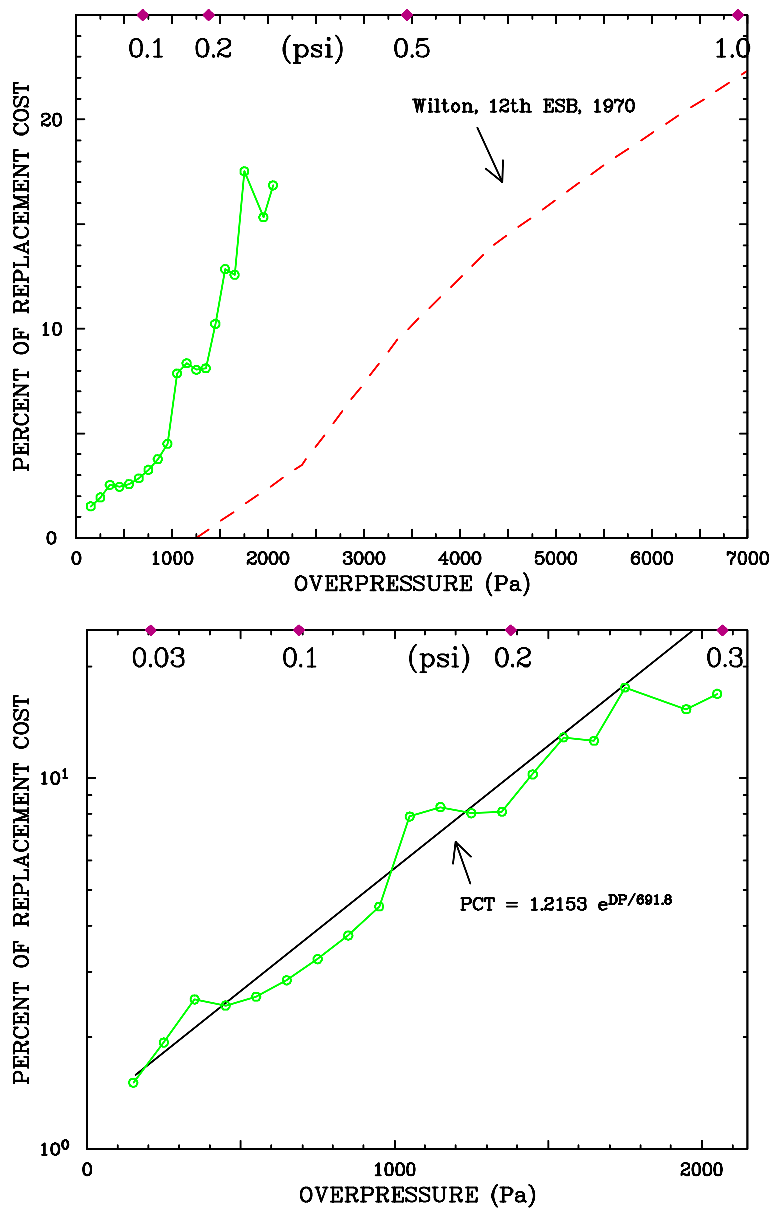


Figure 9. Total SFR damage percent of replacement cost
Top. Linear Cost Scale Bottom. Exponential Cost Scale

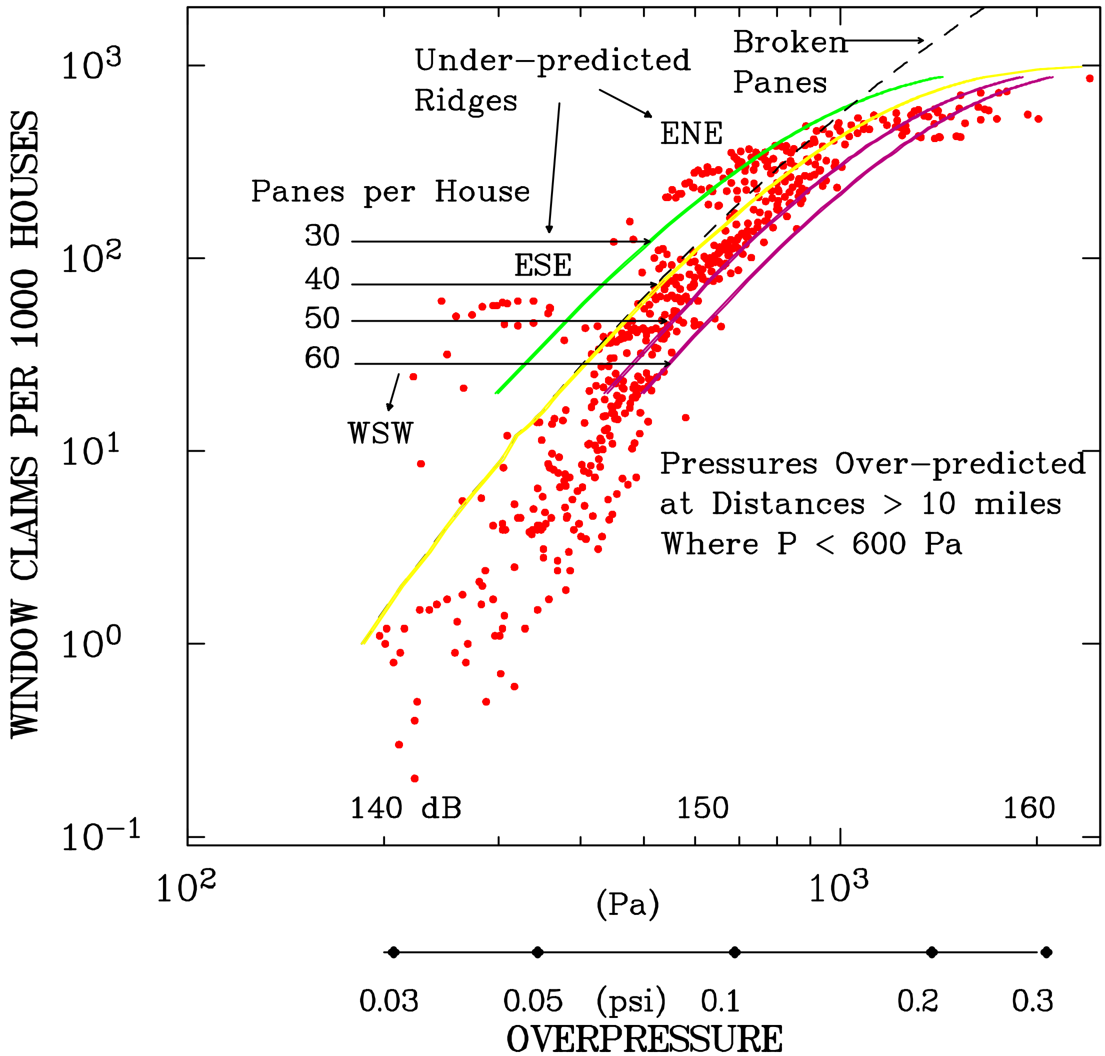


Figure 10. Correlation of overpressure with damage intensity smoothed over 21 grid squares. (3.4 km^2)

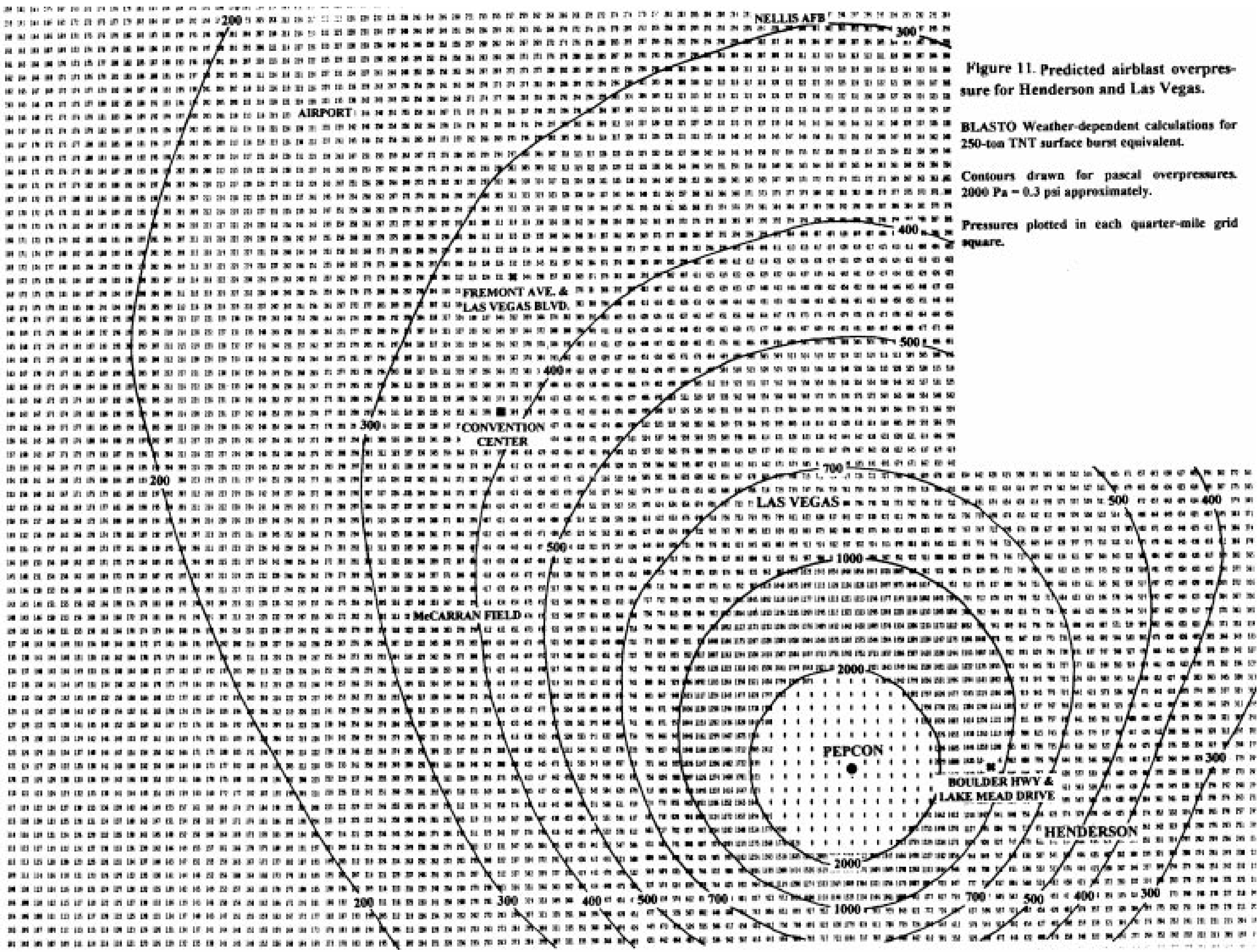


Figure 11. Predicted airblast overpressure for Henderson and Las Vegas.

BLASTO Weather-dependent calculations for 250-ton TNT surface burst equivalent.

Contours drawn for pascal overpressures. 2000 Pa = 0.3 psi approximately.

Pressures plotted in each quarter-mile grid square.

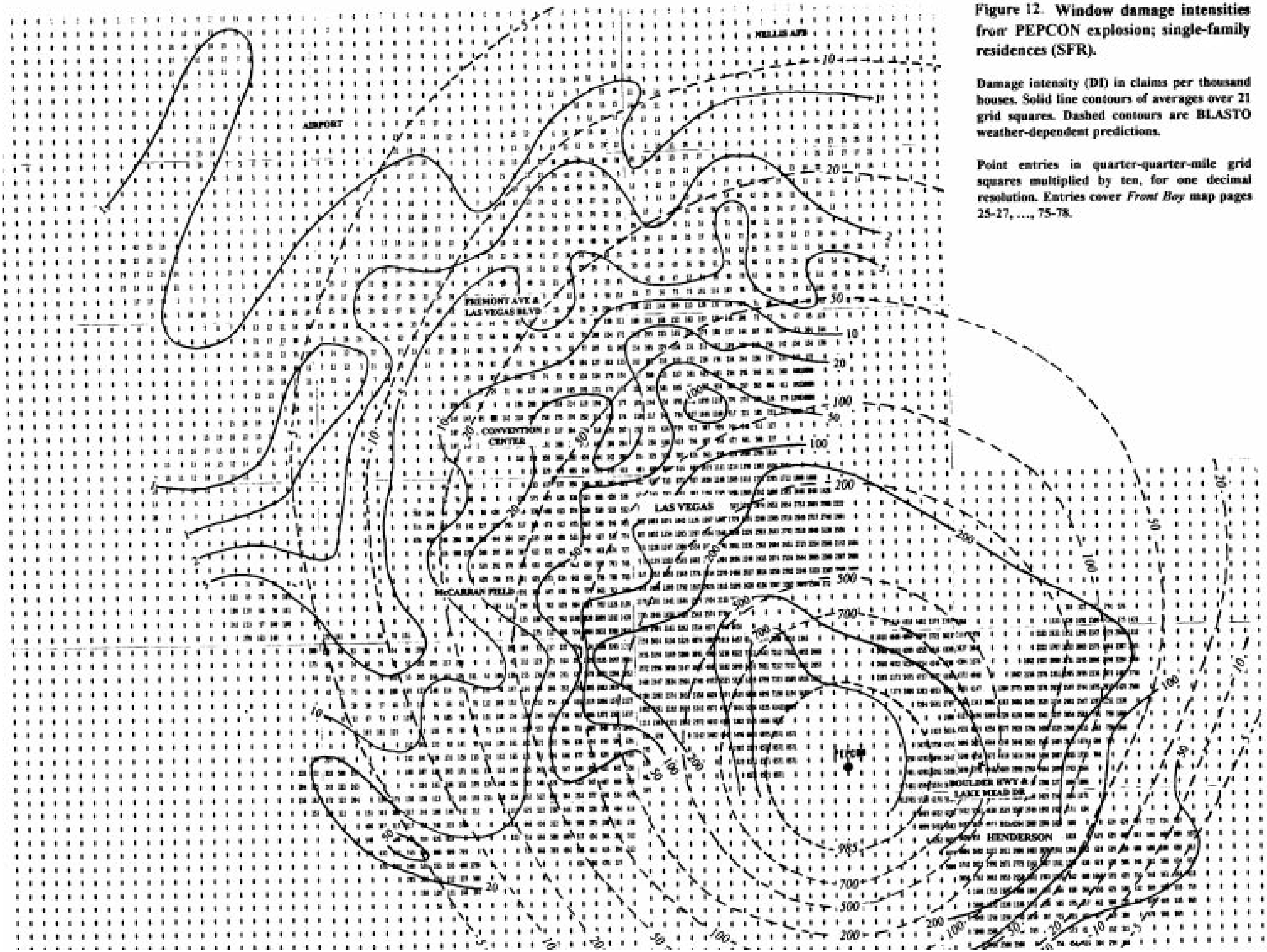


Figure 12. Window damage intensities from PEPCON explosion; single-family residences (SFR).

Damage intensity (DI) in claims per thousand houses. Solid line contours of averages over 21 grid squares. Dashed contours are BLASTO weather-dependent predictions.

Point entries in quarter-quarter-mile grid squares multiplied by ten, for one decimal resolution. Entries cover *Front Boy* map pages 25-27, ..., 75-78.

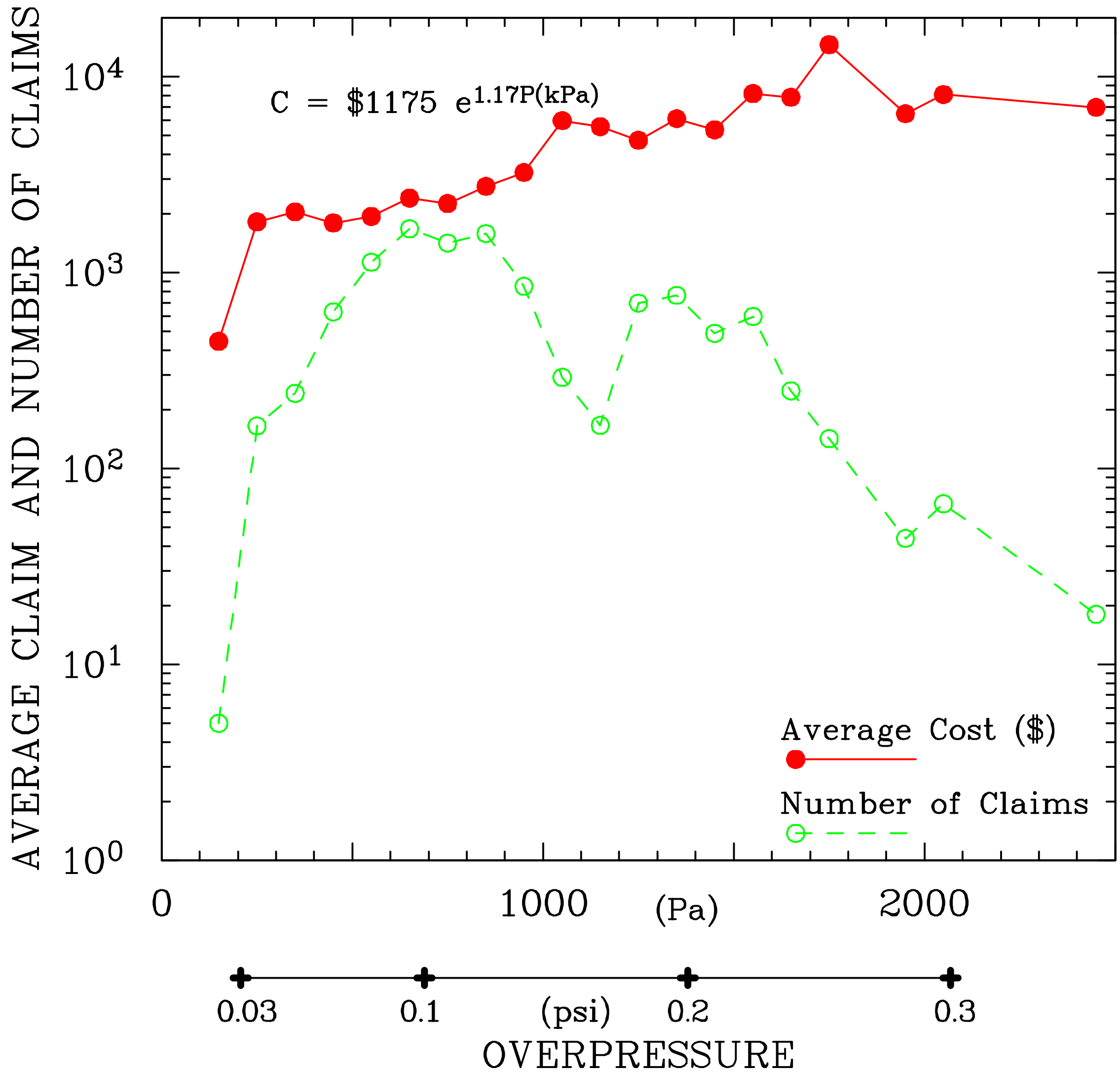


Figure 13. Total SFR damage claims versus overpressure; points for 100 Pa increments.

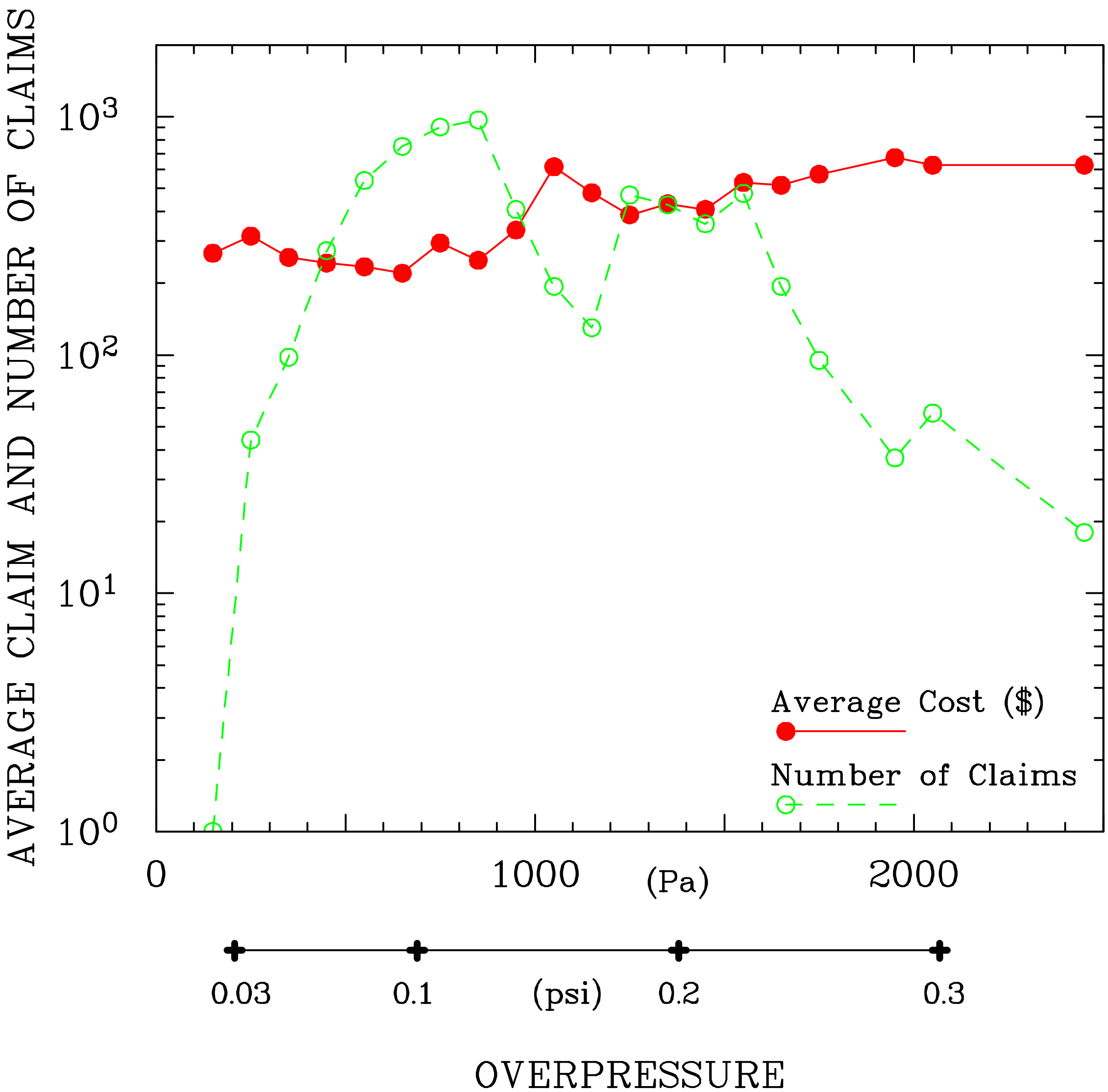


Figure 14. Window damage claims versus overpressure; points for 100 Pa increments.

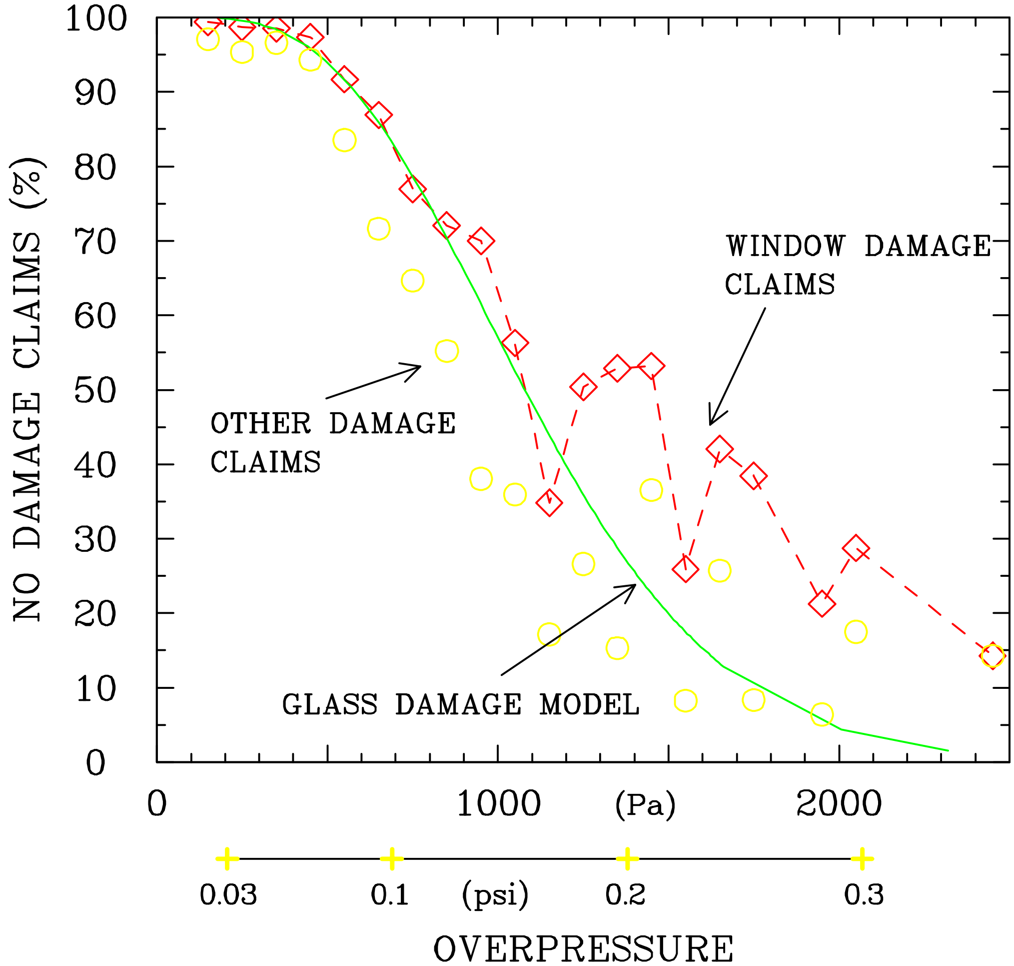


Figure 15. Percent of SFRs with no damages claimed.

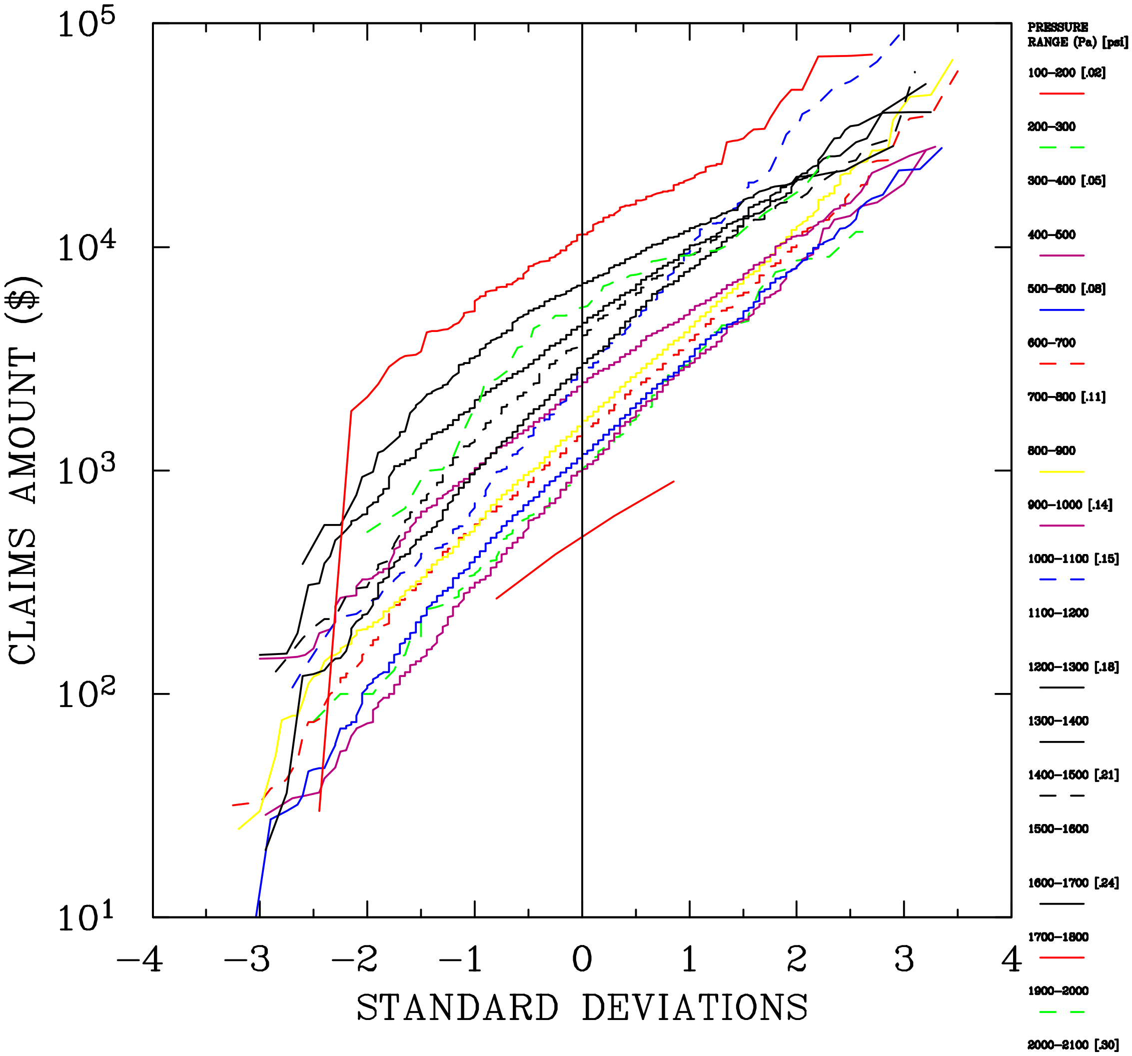


Figure 16. Distribution of SFR total claims amounts.

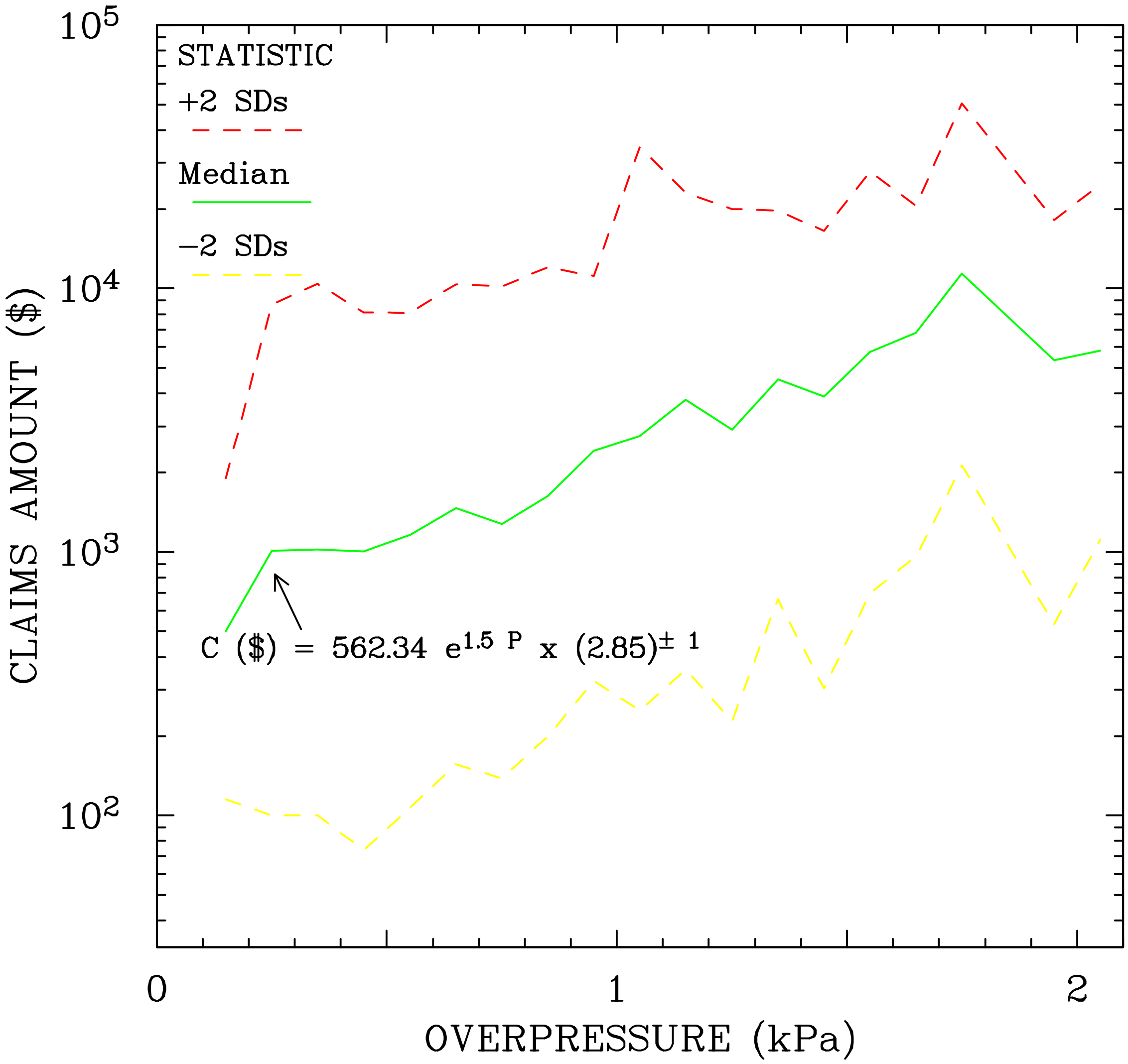


Figure 17. Distribution parameters, total SFR claims amounts.

Figure 18. Total claims dollars
mobile homes & multi-family residences.

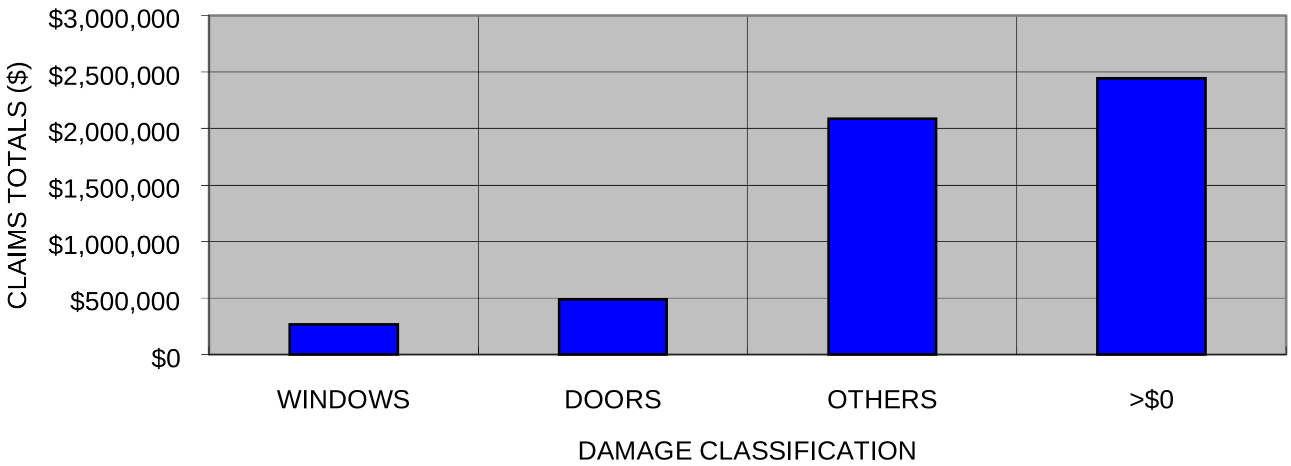


Figure 19. Number of claims
non-residential properties.

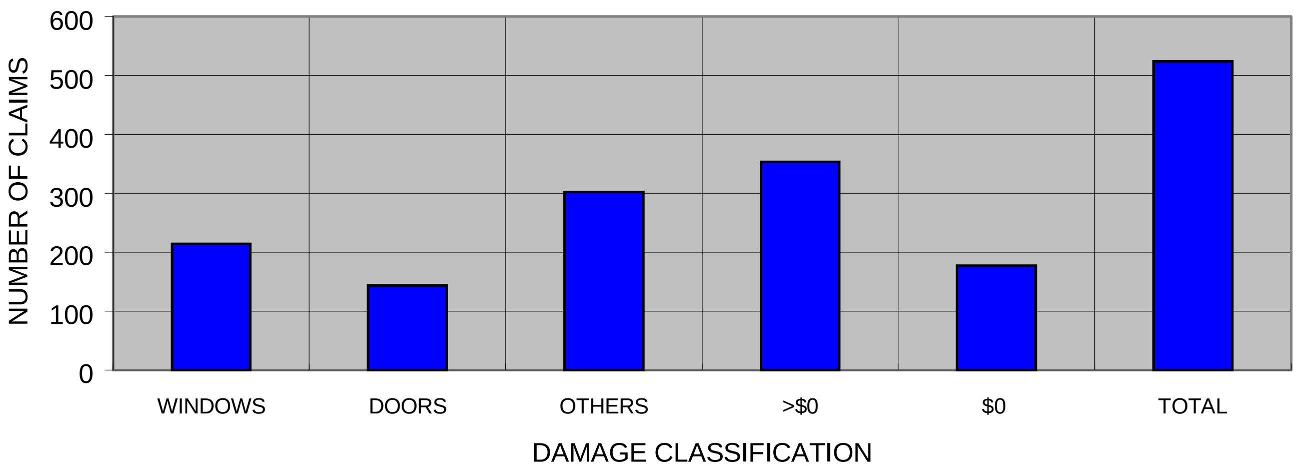


Figure 20. Total claims dollars
non-residential properties.

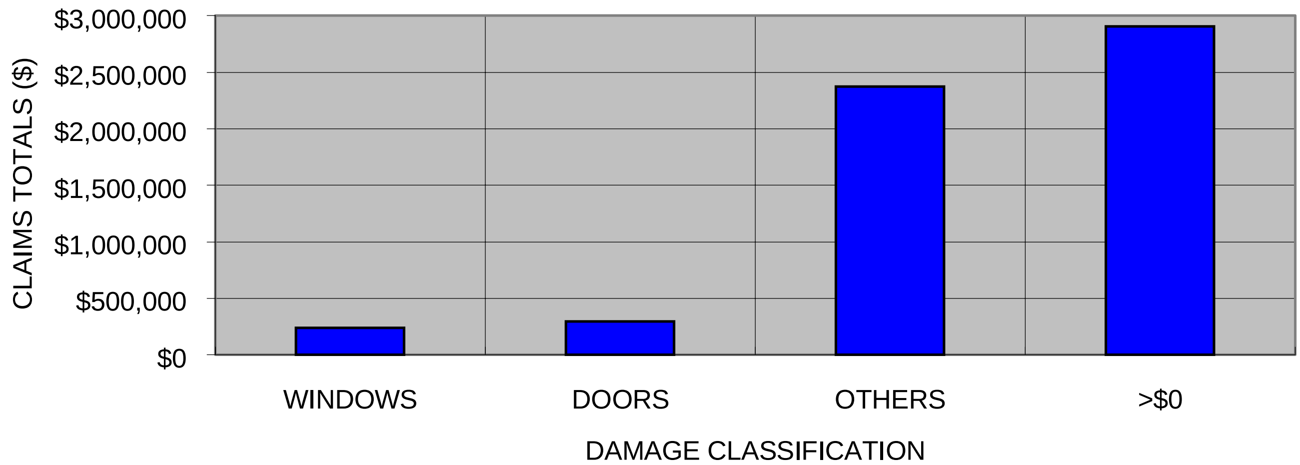


Figure 21. Claims Dollars
Non-Residential Properties