POPULATION DENSITY, URBANIZAION, and CATASTROPHIC WEATHER PHENOMINAE: A Statistical Exploration of the Relationships Affecting Weather Related Fatalities and the Economic Costs of Selected Violent Weather Categories Utilizing 1950 – 2000 NOAA Data

By

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ABSTRACT:

The United States suffers from more instances of severe weather than any other country. This is due to many variables including the countries size, climate, physical features, and available oceanic moisture. Due to improved detection, early warning, media, and public education, the number of severe weather related fatalities has largely decreased over the past century. Irrespective to the potential and largely unknown effects of global climate change, the economic and human costs associated with a relatively random, probable, and constant amount of annual severe weather should increase at some critical threshold value associated with increased percent of land use characterized as urban.

INTRODUCTION:

In 2005 a strong and spatially large Category 3 hurricane struck the central Louisiana coast. Clichés like 'unexpected' and 'freak occurrence' were used to describe the storm. Overdo were may have been a more scientific word to use, however history will remember it as Katrina. Over 1800 people lost their lives in 7 states and the United States had received its costliest, deadliest, and largest natural disaster in over a century. A year later, the city of New Orleans has come nowhere near making a full recovery and many neighborhoods still lie in ruins.

In 1999, a large super cell thunderstorm spawned a series of tornados up to F5 that hit Oklahoma City, Oklahoma. While not an uncommon occurrence, the tornados were especially powerful part of the large outbreak and tracked across a major American metropolitan area.

When it was all over, 40 people were dead, 675 injured, and the financial burdon exceeded 1 billion dollars (NOAA These events while painting a picture of nature at its most violent and destructive, are in now way unusual. In a average year, over 1000 tornados strike the United States. This is only one of nature's hazards. Floods, Blizzards, Heat waves, Hail, wind, etc all are events that occur on an annual basis. Each year approximately 1200 tornados strike the US causing about 1500 injuries. Less than one percent of tornados are F4 or stronger on the Fujita scale but that small minority accounts for over 70% of fatalities (livescience.com).

It would seem, excluding for global climate change, that given a relatively long-term predictable pattern of catastrophic weather related phenomena, that regardless of short term variability, human and economic cost associated with severe weather events would increase over time along with increased urbanization and population density. The footprints of tornados, floods, and hurricanes will be more likely to impact human development versus open land as population density increases. It is the purpose of this paper to try to discover and describe some of these relationships.

RESEARCH HYPOTHESIS:

The purpose of this research is to explore the relationship utilizing regression analysis between the increasing percent of the United States that is urbanized, the increasing United States Population, the annual severe weather fatalities, and the financial cost in constant dollars of severe weather damage in the United States. It is my hypothesis that there is a positive correlation between urbanized land area and the cost of severe weather disasters.

A REVIEW OF THE LITERATURE:

Brooks and Doswell III in a large study on the normalized economic damage of tornados from 1899 to 1990 ascertain that the cost of tornados will increase over time do largely to inflation, increased per capita wealth accumulation, and population increase. They were unable to study the direct relationship between population and tornado economic cost do to the difficulties in obtaining a sufficient amount of accurate information. They coined the term “temporal myopia” to describe the fact that recent data is overemphasized. While the economic analysis was interesting, it is weakened by not accounting for population in their study.

The North Texas Council of Governments (NTCOG) conducted a 2001 study superimposing various tornado tracts consistent with the 1999 Oklahoma outbreak over the DFW metro area to construct a Tornado Damage Risk Assessment. In one scenario 38,000 urban structures including 15,000 single family homes were in the path of the tornado. Additionally if this tornado occurred during rush hour, 84,000 vehicles would be in its path. I will not hazard a guess as to what the potential death toll of such a doomsday scenario would be but it would undoubtedly be biblical in proportions. The table below shows five potential random scenarios of the 1999 Oklahoma City Tornado Projected over the DFW metro area.

Total Damage Estimates for the Five Scenarios			
Scenario	**Structures Impacted***	**Property Value in Path**	**Potential Damages**
1	17,070	$1,630,613,000	$811,000,000
2	14,363	$1,652,263,000	$790,000,000
3	23,380	$4,188,993,000	$2,652,000,000
4	30,887	$5,013,443,000	$2,808,000,000
5	38,463	$5,064,222,000	$2,859,000,000

* Structures Impacted includes apartment units (NTCOG 2001)

Concannon in a 2000 article titled Climotological Risk of Strong and Violent Tornadoes in the United States found no evidence for a long term increase or decrease in the frequency of violent tornados. Concannon concludes however that due to the high variability in tornado frequency determining long term trends is difficult. She states that "rare events do occur" and points to a statistic that only 9 percent of tornado fatalities occur in areas classically defined as tornado alley where public awareness of the threat is high.

Konrad finds in his USGS fact sheet Effects of Urban Development on floods that increased urbanization increased the size and frequency of floods. Runoff effects peach discharge and this is correlates most closely with moderate storms. This is compounded by increasing vulnerability of ever increasing populations in flood prone areas (Konrad 2004)

De Souza discusses the complex relationship between population trends and environmental hazards with a focus on hurricanes. Underlining his article is the statistic that U.S. insurance companies have paid more for hurricane related storms from 2000 to 2004 than in the previous 30 years. This significantly exceeds inflation and frighteningly doesn't account for the then up and coming Katrina catastrophe in 2005. He finds that increasing numbers of people are choosing to live in high risk locations with respect to hurricanes. He sites that more people live in Dade and Broward county of Florida today than in the entire southeastern United States in 1930. (4)

The USDA's National Resource Inventory finds that the annual urbanization increased from 1992 to 1997 by over 1.5 times the previous 10 year average rate. Nearly 6.6% of the United States is urbanized. Aggressive coastal development and ever increasing sprawl are not only putting more people in harm's way, but are increasing the probability of occurrences hitting populated urbanized areas (NRCS 2000). Variability, lack of data, and enormous amounts of difficult to measure data make studies and correlations of tornados and other severe weather damage and population extremely challenging.

THE DATA:

The data for my research is derived from National Oceanic and Atmospheric Association (NOAA) and American Meteorological Association (AMS) data on severe weather damage data including lightning fatalities, tornado fatalities, flood fatalities, and hurricane fatalities. This data covers a period from 1940 to 2006. I have chosen to use only the data from 1953 to present as that is the year that the National Weather Service first issued watches and warnings, and there is a marked break in the fatality statistics at that point. Additionally WWII and the cold war pushed the envelope of radar technology and the 1960's through present continue to show the benefits of early warning manifested in decreasing fatality rates. I have chosen not to include data on heat and cold related fatality information in some analysis do to the briefer period of this data being recorded.

The economic cost of severe weather data gathered from NOAA only covers a period from 1988 to 2006 and does include heat and cold related damage in addition to tornado, hurricane, lightning, and flood damage. This category is called all hazard damage. Additionally I have included historical information on tornado damage in constant dollars.

I have also gathered historical population and population density data from the United States Department of Agriculture and the Census Bureow. The population density data is in the format of average persons per square mile for the United States. While the data does go back to the time of the first census in 1790, I have chosen to analyze only data from 1950 to 2000. It is the intention of this study to discover possible relationships between urbanization and storm damage, fatalities, etc. Unfortunately, I had difficulty in obtaining decisive 50 year information on percent of land use characterized as urban. Though I was able to obtain percent values, there is the issue of what characterizes urban land versus developed land, etc. Therefore as a measure of density I settled upon average population per square mile of the United Sates. This is in no way a perfect statistic, but It nevertheless is an indicator of density. In some ways it may be too conservative in determining relationships in the scope of this report as many regions of the United States ie death value, desert southwest, are not at high risks of catastrophic tornados etc and are sparsely populated.

The Mean Geographic Center of Population of the Conterminous United States has drifted from Illinois to Missouri in the last 50 years. By all indications, this lies well within Tornado alley and flood prone regions.

THE ANALYSIS:

The independent variables for my research are average number of people per square mile for the United States (PopDence), and number of annual reported tornados (AnnualTornado), and total annual number of hurricanes that strike the United States (AnnualHuricane). Since the population density is derived from decennial census data, I utilized 2nd order polynomial equations to derived trend lines utilizing excel to determine estimated yearly values. These lines were excellent fits for the data. I coded the years from 1950 to 2020 as 1 to 70 simplify the formulae and to determine average population per square mile. Pearson's R in this case merely shows the robustness of the polynomial formulae in terms of its ability to accurately estimate yearly PopDense and PopTotal values. This made comparisons between the population data and the annual severe weather data simpler and helped to compensate for the extreme variability of severe weather events had I only used decennial weather data.

PopDense $y = 0.201x^2 - 1.574x + 7.959$, $R^2 = 0.997$

PopTotal $y = 0.669x^2 - 2.497x + 7.948$, $R^2 = 0.998$

The dependant variables in my research are a dollar value for all hazard's damage n the United States (AllHazardCost), annual tornado fatalities (TornadoFatal), annual United States flood fatalities (FloodFatal), and annual hurricane related fatalaties (HurrFatal), heat related fatalities (HeatFatal), cold related fatalities (ColdFatal), and winter related fatalities (WintFatal). I chose to exclude lightning related fatalities simply because they are among the most arguably preventable of severe weather fatalities (stat inside during lighting) and with the exception of forest fires (not the subject of the research), don't generally have the potential for catastrophic social and economic cost.

I have utilized regression analysis to seek interesting and meaningful correlations between the data that support my hypothesis that increased population density will at some point achieve a threshold that causes the human and economic cost of severe weather events to start to increase significantly. Additionally I have used a Poisson distribution upon constant dollar Tornadic Events and Category 3 - 5 hurricanes over the past 100 years to determine a yearly and decade probability (addition rule of probability) of a those two types of events occurring in the near future. The following are the correlation formulas that I used to determine the R values for my multivariate analysis and additionally the formulae for the correlation of determination or Pearson's R. To determine the significance of my results I have utilized Cohen's (1988) table for interpreting the meaningfulness of r values. The table is a bit liberal in my opinion in terms of what it considers a strong correlation, however do to the extreme variability of severe weather events and phenomena, I feel his values are appropriate for exploratory research such as this.

The final analysis I performed on the data was to utilize the Poisson Discrete Probability Distribution to determine the likelihood or probability of catastrophic tornados, hurricanes, floods, and the combination of these occurring in the United States on any given year.

Correlation

$$r_{xy} = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n\sum x_i^2 - (\sum x_i)^2}\ \sqrt{n\sum y_i^2 - (\sum y_i)^2}}.$$

where $\bar{x}$ and $\bar{y}$ are the sample means of X and Y , s_x and s_y are the sample standard deviations of X and Y and the sum is from i = 1 to n. As with the population correlation, we may rewrite this as

Pearson's R

$$r_{xy}^2 = 1 - \frac{\sigma_{y|x}^2}{\sigma_y^2},$$

where $\sigma_{y|x}^2$ is the square of the error of a linear regression of x_i on y_i by the equation $y = a + bx$:

Correlation	Negative	Positive
Small	−0.29 to −0.10	0.10 to 0.29
Medium	−0.49 to −0.30	0.30 to 0.49
Large	−1.00 to −0.50	0.50 to 1.00

Cohen's Table of r Value Significance

Poisson Discrete Probability Distribution

$$f(k, \lambda) = \frac{e^{-\lambda}\lambda^k}{k!}$$

Where:

- e is the base of the natural logarithm (e = 2.71828...),
- k is the number of occurrences of an event - the probability of which is given by the function,
- k! is the factorial of k,
- λ is a positive real number, equal to the expected number of occurrences that occur during the given interval. For instance, if the events occur on average every 4 minutes, and you are interested in the number of events occurring in a 10 minute interval, you would use as model a Poisson distribution with λ = 10/4 = 2.5.

Formulas and explanations courtesy of (Wikipidia 2007

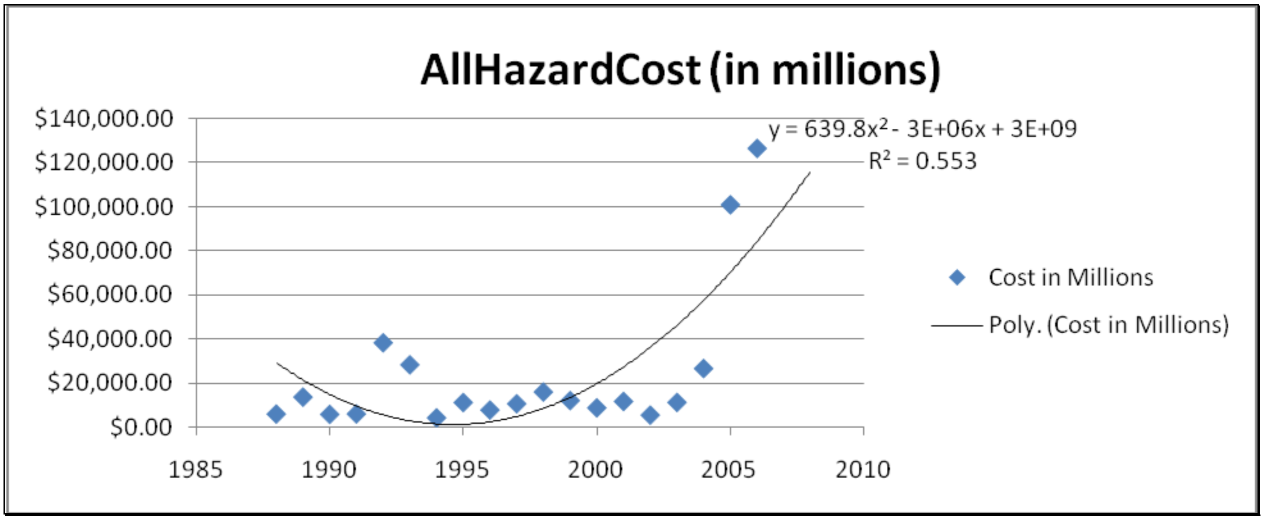

FIGURE 3: All Hazard Cost 1988 to 2006 in Millions of Dollars

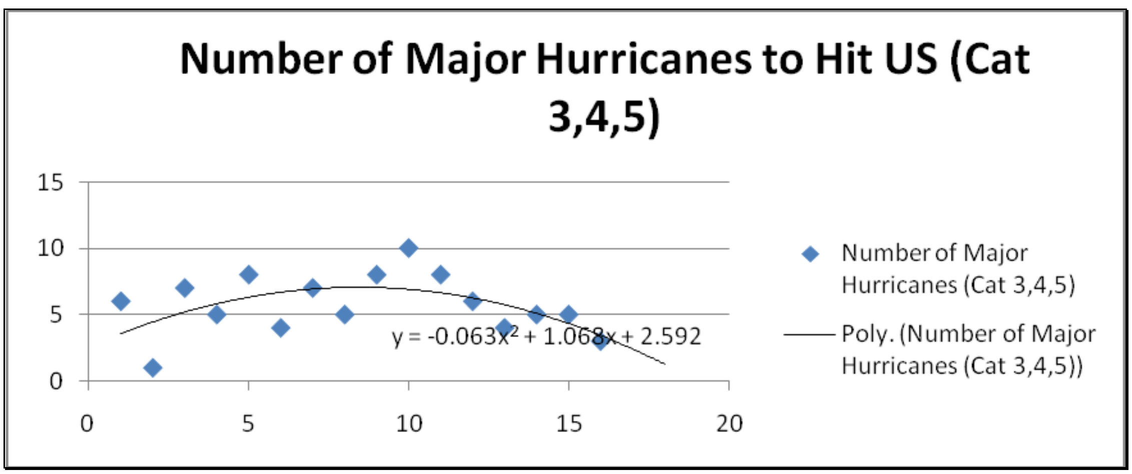

FIGURE 4: Number of Major Hurricanes to Strike U.S. 1950 to 2000 (Trend Line to 2020). Year 0 = 1950, 5 = 1960,…etc (for simplification of equation)

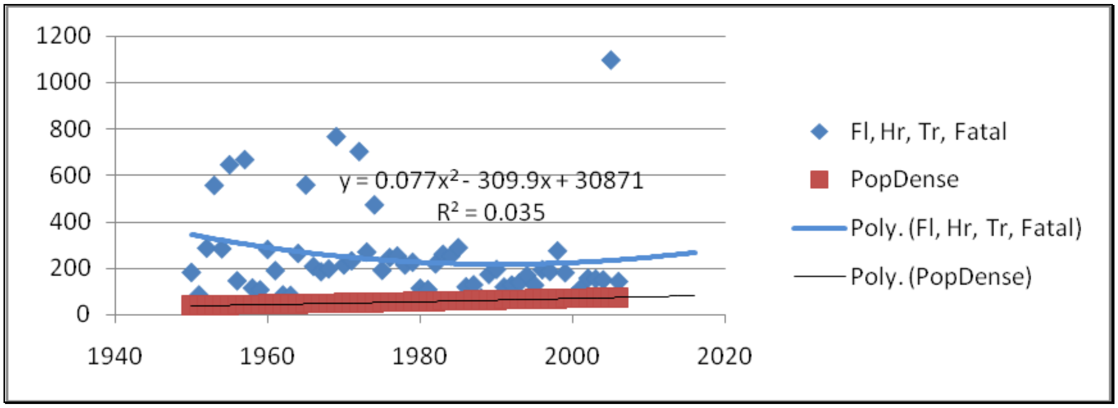

FIGURE 5: FloodFatal, HurrFatal, and TornadoFatal with PopDense (1950-2000) Trend lines to 2015

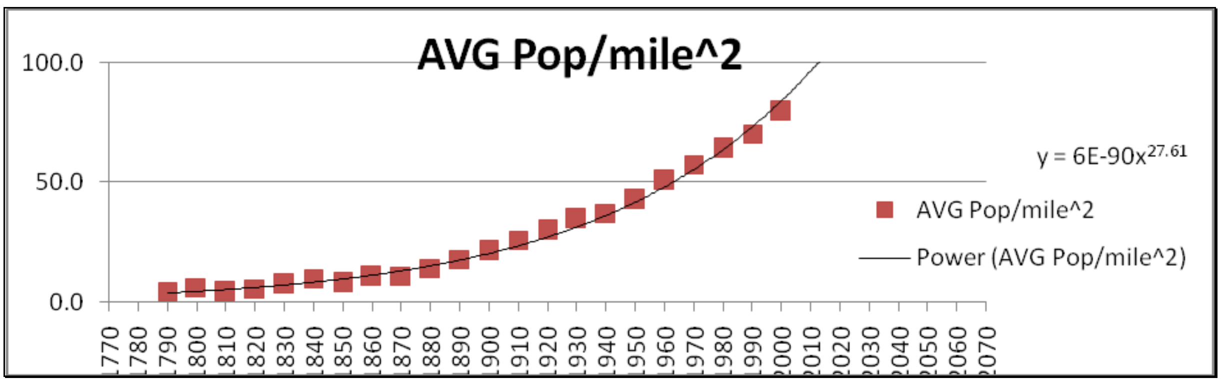

FIGURE 6: PopDense Illustrated from First Census until Current and Projected Forward

TWO SAMPLE T-TEST:

t-Test: Two-Sample Assuming Unequal Variances		
	Cost in Millions	*Cost in Millions*
Mean	963.8666667	641.6
Variance	466692.6952	115863.6857
Observations	15	15
Hypothesized Mean Difference	0	
df	21	
t Stat	1.635279659	
P(T<=t) one-tail	0.058446104	
t Critical one-tail	1.720742871	
P(T<=t) two-tail	0.116892209	
t Critical two-tail	2.079613837	

t-Test: Two-Sample Assuming Unequal Variances		
	Fatalaties	*Fatalaties*
Mean	74.92647059	23.39130435
Variance	7940.785558	539.4475703
Observations	68	69
Hypothesized Mean Difference	0	
df	76	
t Stat	4.616943142	
P(T<=t) one-tail	7.7747E-06	
t Critical one-tail	1.665151354	
P(T<=t) two-tail	1.55494E-05	
t Critical two-tail	1.991672579	

I sorted the top 30 costliest tornados by year ascending and then bisected the results. One sample is costliest events from 1896 to 1953 and the second is costliest events 1957 to 1999. While there are some obvious problems with this type of analysis, including small sample sizes, I wanted to see if worst case scenario events were becoming costlier or staying about the same. I failed to reject the critical value so the differences in these means could be explained by chance. I then compared the two samples for all tornado fatalities. The first sample consisted of 68 events from 1890 to 1950 and the second sample consisted of 69 events from 1953 to 1999. The results indicated there is a statistically significant difference in means of tornado event fatalities over these two periods. The mean for the first sample events is approximately 75. The second is approximately 23.

Top 30 Tornados by Economic Cost in constant 1997 dollars										
				Cost in Millions						Cost in Mi
1	1896	Louis, MO-E. St.	12	2916		15	1957	Ruskin Heights, MO	40	685
13	1890	Louisville, KY	3	836		22	1965	Branch County, MI	35	410
21	1898	Fort Smith, AR	2	440		30	1965	Toledo, OH	25	293
16	1913	Omaha , NE	5	589		7	1966	Topeka, KS	100	1126
24	1919	Fergus Falls, MN	4	354		26	1966	Polk County, FL	30	324
10	1924	Sandusky, OH	12	1023		29	1967	Oak Lawn, IL	30	301
3	1925	State (MO-IL-IN)	16	1392		9	1970	Lubbock, TX	135	1081
2	1927	St. Louis, MO	22	1797		19	1973	Conyers, GA	89	515
8	1936	Gainesville, GA	13	1111		20	1974	Xenia, OH	100	491
14	1944	Southwestern PA	15	697		6	1975	Omaha, NE	250	1127
5	1953	Worcester, MA	52	1140		28	1978	Bossier City, LA	100	314
12	1953	Waco, TX	41	899		4	1979	Wichita Falls, TX	400	1141
18	1953	Vicksburg, MS	25	548		17	1979	Windsor Locks, CT	200	570
23	1953	Flint, MI	19	400		25	1980	Grand Island, NE	140	337
27	1953	Warner-Robins, GA	15	316		11	1999	ma City, OK	1000	909

Data excerpted from (Brooks and Doswell 2000)

KEY FINDINGS:

The correlations between FloodFatal, HurrFatal, and TornadoFatal combined and individually with PopDense were all negative with the exception of HurrFatal which had .06 or almost no correlation at all. The correlations tended to be very weak in these categories with the exception of TornadoFatal which according to the chart was a moderate negative correlation. More telling than the actual values was that they combined and for the most part individually tended negative. The negative values on the 56 year dataset largely support the assumption that improvements in radar technology, early warning, and the dissemination of severe weather information to the public have made a detectable and positive difference in terms of annual lives saved.

Heat Fatality when compared to Cold Fatality had a small negative correlation or inverse relationship. This is the only possible indication that my research found that may be an indicator of climate change. The rise in heat fatalities is a disturbing trend and may have socioeconomic consequences in terms of our urban areas and accessibility of resources and energy related environmental controls ie air condition, etc.

The strongest correlation I discovered utilizing this method of correlation between one highly variable dataset (severe weather occurrences, fatalities, damage) and the fairly steady increase in PopDense was the correlation between AllHazardCost and PopDense which was a positive 0.53. Though it doesn't stand out in terms of being extremely strong or robust, it does differ significantly from the majority of my correlation findings which were very weak to moderate and negative.

The uniqueness of Hurricane Katrina in terms of 100 year statistics only time will tell. However it appears by analyzing the trend line of all fatalities extended into the 2010 that we maybe be at a critical threshold or nexus of PopDense; FloodFatal, HurrFatal, and TornadoFatal; and AllHazardCost. While a major factor, Hurriacane Katrina is not the sole cause for this upturn in the trend line. The data begins to level off and there are some slight increasing scores. A critical PopDense value of 100 people/square mile according to the regression line in table 6 should be achieved sometime around 2015 – 2020. Given current rates of increase the percent of land characterized by the USDA as urbanized should be well in excess of 10% at that point in time as well.

Next, utilizing Poisson Discrete Probability Distributions, I have created a yearly risk percent for tornado occurrences costing over 1 billion normalized dollars (1990 – 2000 data), floods costing over 10 billion dollars (1990-2000 data), and total number Cat 3 - 5 hurricanes that hit the United States (1990-2000 data). The probability of a catastrophic billion dollar weather related event in the categories described hitting the United States is over 100 percent for any three year period of time. As is evident from table, though there is a high degree of variability, these events happen consistently throughout the 1990 – 2000 period of time. The effects of ever increasing population density nationwide, not to mention tendencies toward higher density in high risk areas, combined with increasing personal wealth logically leads to the conclusion that a given amount of catastrophic weather events will lead towards ever increasing economic costs and human costs.

In terms of supporting my original hypothesis, quite a bit additional research is required as well as several decades of future information. If Katrina is any indication, I believe a significant shift in fatalities and economic damage will start to occur at a threshold of around 100 people/square mile and a percent total land urbanized of around 10%. Both these values given the trend lines in this paper should be achieved for the United States within the next ten years.

1950 to 2006 Data
Fl, Hr, Tr Fatal Correlation with PopDense
-0.16
Tornado Fatality Correlation with PopDense
-0.34
Flood Fatality Correlation with PopDense
-0.11
Hurricane Correlation with PopDense
0.06

1988 to 2006 Data
Heat Fatality to Cold Fatality Correlation
-0.24
All Hazard Cost Correlated with PopDense
0.53

FIGURE 7: Correlations Between Categories

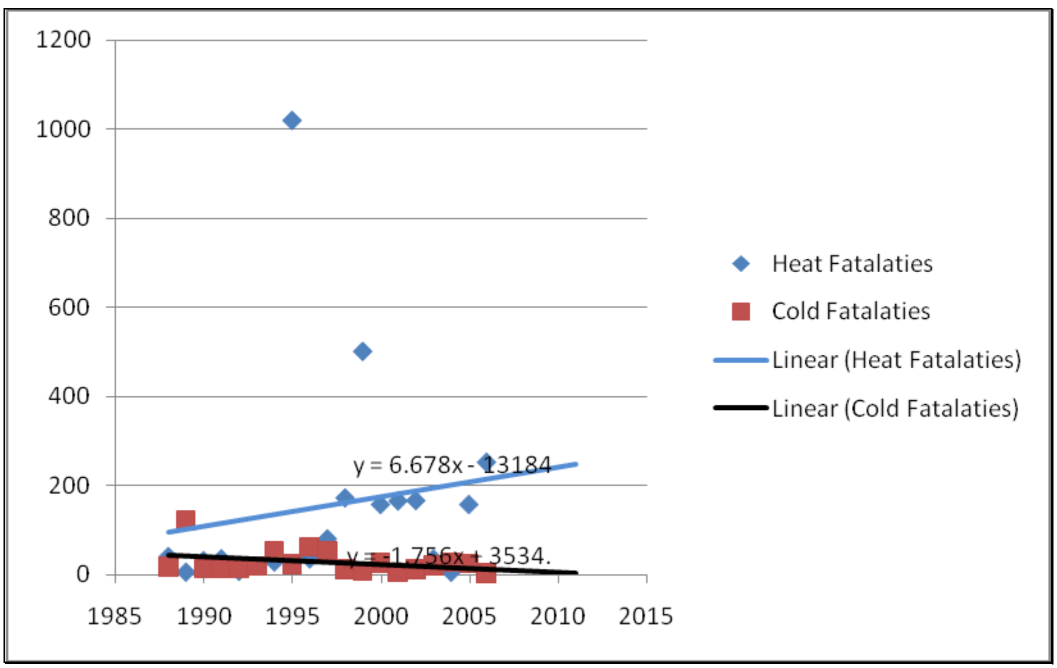

FIGURE 8: Heat Fatalities compared with Cold Fatalities (1988 to 2005)

Poisson Discrete Probability Distribution for Selected Catastrophic Weather Events 1900 - 2000 data; dollar amounts normalized in constant dollars		Floods over 10 billion dollars damage	Tornados over 1 billion dollars damage	Major Hurricanes (Cat 3,4,5) to hit mainland U.S.	Total Catastrophic Weather Events in U.S. 1900 to 2000
	#/Year	6	9	62	77
Probability of Given number of x number of catastrophic weather events happening in one year	1	5.65%	8.23%	33.35%	35.65%
	2	0.17%	0.37%	10.34%	13.73%
	3	0.00%	0.01%	2.14%	3.52%

Figure 9: Poisson Discrete Probability Distribution for # of Categorical Occurences

CONCLUSION:

The research supports my initial hypothesis that there is a positive correlation between increasing population density and the economic cost of severe weather phenomenon. While there is a myriad of factors leading to the increasing cost of these probable and fairly typical events. In terms of supporting my hypothesis that increasing density would eventually override the benefits of early warning and detection of catastrophic weather in terms of increasing fatalities, the data was inconclusive.

However, the data does not necessarily contradict my theory that at a critical threshold of approximately 100 people per square mile and 10 percent urbanization, average yearly catastrophic weather fatalities would start to rise significantly. Katrina is such a massive event in terms of human casualties and so recent, that it skews the data to the point that trend line analysis can be misleading. Katrina's uniqueness aside, more research is recommended over the next 25 years comparing the effects of population density in high risk areas with catastrophic (not freak) weather occurrences to determine what the future impacts of these natural events will be.

If increased risk is detected, hope is not lost. There are many innovative and sometimes simple building materials and techniques that can “weather proof” average structures such as single resident homes and office buildings. Alternative construction techniques are not cheap, but will the cost of preparedness be less than the cost of inaction? Additionally, at some point in the future, the use of urban growth boundaries could be used to limit sprawl into high risk areas ie lowlands and shoreline environments. Some of these preventative measures may have ancillary and positive environmental Sid effects. Nature is very robust towards natural disasters; cities at this time are not. Only time and continued research will tell with certainty what the effects of increasing urbanization, population density, and severe weather events will have on the socioeconomic fiber of the United States.

SELECTED TABLES WITH URL's:

Table 2. Population, Housing Units, Area Measurements, and Density: 1790 to 2000

[For information concerning historical counts, see "User Notes." Density computed using land area. For information on nonsampling error and definitions, see text]

United States	Population			Housing units			Area measurements in square miles		Average per square mile	
		Change from preceding census			Change from preceding census					
	Total	Number	Percent	Total	Number	Percent	Total area	Land area	Population	Housing units
2000 (Apr. 1)	281 421 906	32 703 604	13.1	115 904 641	13 642 440	13.3	3 794 083	3 537 438	79.6	32.8
1990 (Apr. 1)	r 248 718 302	22 176 103	9.8	r 102 262 201	13 851 574	15.7	3 787 319	3 536 278	70.3	28.9
1980 (Apr. 1)	226 542 199	23 240 168	11.4	88 410 627	19 706 312	28.7	3 618 770	3 539 289	64.0	25.0
1970 (Apr. 1)	203 302 031	23 978 856	13.4	68 704 315	10 377 958	17.8	3 618 770	3 536 855	57.5	19.4
1960 (Apr. 1)	179 323 175	27 997 377	18.5	58 326 357	12 189 281	26.4	3 618 770	3 540 911	50.6	16.5
1950 (Apr. 1)	151 325 798	19 161 229	14.5	46 137 076	8 698 362	23.2	3 618 770	3 552 206	42.6	13.0
1940 (Apr. 1)	132 164 569	8 961 945	7.3	37 438 714	(X)	(X)	3 618 770	3 554 608	37.2	10.5
1930 (Apr. 1)	123 202 624	17 181 087	16.2	(X)	(X)	(X)	3 618 770	3 551 608	34.7	(X)
1920 (Jan. 1)	106 021 537	13 793 041	15.0	(X)	(X)	(X)	3 618 770	3 546 931	29.9	(X)
1910 (Apr. 15)	92 228 496	16 016 328	21.0	(X)	(X)	(X)	3 618 770	3 547 045	26.0	(X)
1900 (June 1)	76 212 168	13 232 402	21.0	(X)	(X)	(X)	3 618 770	3 547 314	21.5	(X)
1890 (June 1)	62 979 766	12 790 557	25.5	(X)	(X)	(X)	3 612 299	3 540 705	17.8	(X)
1880 (June 1)	50 189 209	11 630 838	30.2	(X)	(X)	(X)	3 612 299	3 540 705	14.2	(X)
1870 (June 1)	38 558 371	7 115 050	22.6	(X)	(X)	(X)	3 612 299	3 540 705	10.9	(X)
1860 (June 1)	31 443 321	8 251 445	35.6	(X)	(X)	(X)	3 021 295	2 969 640	10.6	(X)
1850 (June 1)	23 191 876	6 122 423	35.9	(X)	(X)	(X)	2 991 655	2 940 042	7.9	(X)
1840 (June 1)	17 069 453	4 203 433	32.7	(X)	(X)	(X)	1 792 552	1 749 462	9.8	(X)
1830 (June 1)	12 866 020	3 227 567	33.5	(X)	(X)	(X)	1 792 552	1 749 462	7.4	(X)
1820 (Aug. 7)	9 638 453	2 398 572	33.1	(X)	(X)	(X)	1 792 552	1 749 462	5.5	(X)
1810 (Aug. 6)	7 239 881	1 931 398	36.4	(X)	(X)	(X)	1 722 685	1 681 828	4.3	(X)
1800 (Aug. 4)	5 308 483	1 379 269	35.1	(X)	(X)	(X)	891 364	864 746	6.1	(X)
1790 (Aug. 2)	3 929 214	(X)	(X)	(X)	(X)	(X)	891 364	864 746	4.5	(X)

http://www.census.gov/prod/cen2000/phc3-us-pt1.pdf#page=44

Table A. **Mean Center of Population of the United States: 1790 to 2000**

Census year	North latitude	West longitude	Approximate location[1]
United States:			
2000	37° 41' 49"	91° 48' 34"	In Phelps County, MO, 2.8 miles east of Edgar Springs, MO.
1990	37° 52' 20"	91° 12' 55"	In Crawford County, MO, 10 miles southeast of Steelville, MO.
1980	38° 08' 13"	90° 34' 26"	In Jefferson County, MO, 1/4 mile west of DeSoto, MO.
1970	38° 27' 47"	89° 42' 22"	In St. Clair County, IL, 5 miles east-southeast of Mascoutah, IL.
1960	38° 35' 58"	89° 12' 35"	In Clinton County, IL, 6-1/2 miles northwest of Centralia, IL.
1950	38° 48' 15"	88° 22' 08"	In Clay County, IL, 3 miles northeast of Louisville, IL.
Conterminous United States:[2]			
1950	38° 50' 21"	88° 09' 33"	In Richland County, IL, 8 miles north-northwest of Olney, IL.
1940	38° 56' 54"	87° 22' 35"	In Sullivan County, IN, 2 miles southeast by east of Carlisle, IN.
1930	39° 03' 45"	87° 08' 06"	In Green County, IN, 3 miles northeast of Linton, IN.
1920	39° 10' 21"	86° 43' 15"	In Owen County, IN, 8 miles south-southeast of Spencer, IN.
1910	39° 10' 12"	86° 32' 20"	In Monroe County, IN, in the city of Bloomington, IN.
1900	39° 09' 36"	85° 48' 54"	In Bartholomew County, IN, 6 miles southeast of Columbus, IN.
1890	39° 11' 56"	85 °32' 53"	In Decatur County, IN, 20 miles east of Columbus, IN.
1880	39° 04' 08"	84° 39' 40"	In Boone County, KY, 8 miles west by south of Cincinnati, OH.
1870	39° 12' 00"	83° 35' 42"	In Highland County, OH, 48 miles east by north of Cincinnati, OH.
1860	39° 00' 24"	82° 48' 48"	In Pike County, OH, 20 miles south by east of Chillicothe, OH.
1850	38° 59' 00"	81° 19' 00"	In Wirt County, WV, 23 miles southeast of Parkersburg, WV.[3]
1840	39° 02' 00"	80° 18' 00"	In Upshur County, WV, 16 miles south of Clarksburg, WV. Upshur County was formed from parts of Barbour, Lewis, and Randolph Counties in 1851.[3]
1830	38° 57' 54"	79° 16' 54"	In Grant County, WV, 19 miles west-southwest of Moorefield, WV. Grant County was formed from part of Hardy County in 1866.[3]
1820	39° 05' 42"	78° 33' 00"	In Hardy County, WV, 16 miles east of Moorefield, WV.[3]
1810	39° 11' 30"	77° 37' 12"	In Loudoun County, VA, 40 miles northwest by west of Washington, DC.
1800	39° 16' 06"	76° 56' 30"	In Howard County, MD, 18 miles west of Baltimore, MD. Howard County was formed from part of Anne Arundel County in 1851.
1790	39° 16' 30"	76° 11' 12"	In Kent County, MD, 23 miles east of Baltimore, MD.

[1]Place names are in terms of 2000 and may not have existed at time of the recorded census.
[2]Conterminous United States excludes Alaska and Hawaii.
[3]West Virginia was set off from Virginia, Dec. 31, 1862, and admitted as a state June 20, 1863.

Scale	Wind	Typical damage
F0	< 73 mph	**Light damage**. Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
F1	73-112	**Moderate damage**. Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off roads.
F2	113-157	**Considerable damage**. Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
F3	158-206	**Severe damage**. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.
F4	207-260	**Devastating damage**. Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated.
F5	261-318	**Incredible damage**. Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air in excess of 100 yards; trees debarked; incredible phenomena will occur.

LiveScience / SOURCE: NOAA

<http://ams.allenpress.com/perlserv/?request=getabstract&doi=10.1175%2F1520-0434(2001)016%3C0168%3ANDFMTI%3E2.0.CO%3B2>

by assuming that all wealth changes before 1925 and after 1997 can be modeled just with inflation.

Rank	Date	Location	Raw	Adjusted
1	*27 May 1896*	*St. Louis, MO–E. St. Louis, IL*	*12*	*2916 (2167)*
2	29 Sep 1927	St. Louis, MO	22	1797
3	18 Mar 1925	Tri-State (MO–IL–IN)	16	1392
4	10 Apr 1979	Wichita Falls, TX	400	1141
5	9 Jun 1953	Worcester, MA	52	1140
6	6 May 1975	Omaha, NE	250	1127
7	8 Jun 1966	Topeka, KS	100	1126
8	6 Apr 1936	Gainesville, GA	13	1111
9	11 May 1970	Lubbock, TX	135	1081
10	*28 Jun 1924*	*Lorain–Sandusky, OH*	*12*	*1023 (1071)*
11	*3 May 1999*	*Oklahoma City, OK*	*1000*	*909 (963)*
12	11 May 1953	Waco, TX	41	899
13	*27 Mar 1890*	*Louisville, KY*	*3*	*836 (586)*
14	23 Jun 1944	Southwestern PA	15	697
15	20 May 1957	Ruskin Heights, MO	40	685
16	*23 Mar 1913*	*Omaha, NE*	*5*	*589 (769)*
17	3 Oct 1979	Windsor Locks, CT	200	570
18	5 Dec 1953	Vicksburg, MS	25	548
19	31 Mar 1973	Conyers, GA	89	515
20	3 Apr 1974	Xenia, OH	100	491
21	*11 Jan 1898*	*Fort Smith, AR*	*2*	*440 (349)*
22	11 Apr 1965	Branch County, MI	35	410
23	8 Jun 1953	Flint, MI	19	400
24	*22 Jun 1919*	*Fergus Falls, MN*	*4*	*354 (296)*
25	3 Jun 1980	Grand Island, NE	140	337
26	4 Apr 1966	Polk County, FL	30	324
27	30 Apr 1953	Warner Robins, GA	15	316
28	3 Dec 1978	Bossier City, LA	100	314
29	21 Apr 1967	Oak Lawn, IL	30	301
30	11 Apr 1965	Toledo, OH	25	293

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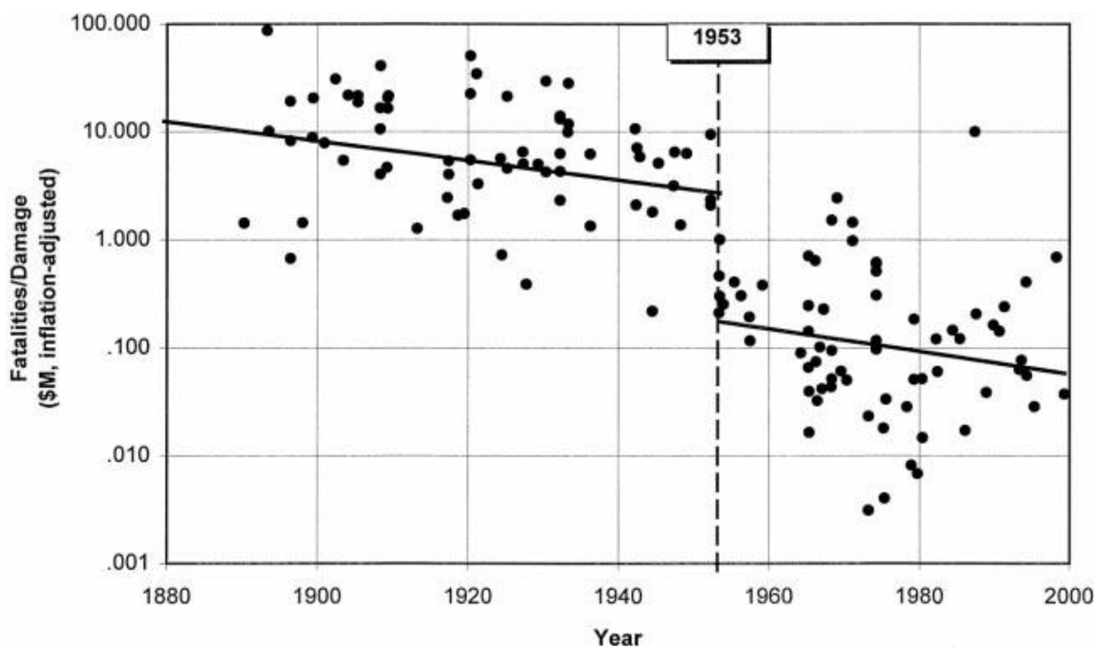
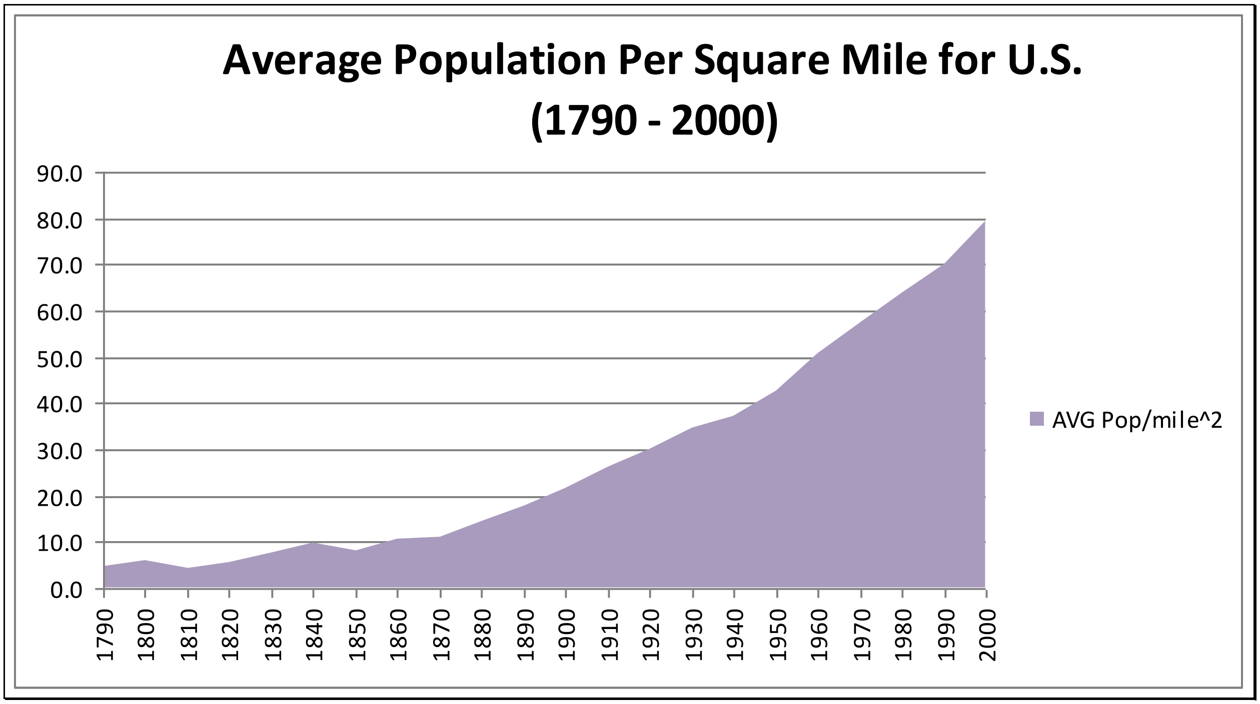


http://ams.allenpress.com/perlserv/?request=getabstract&doi=10.1175%2F1520-0434(2001)016%3C0168%3ANDFMTI%3E2.0.CO%3B2


Average Population Per Square Mile for U.S.
(1790 - 2000)
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1790
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
AVG Pop/mile^2

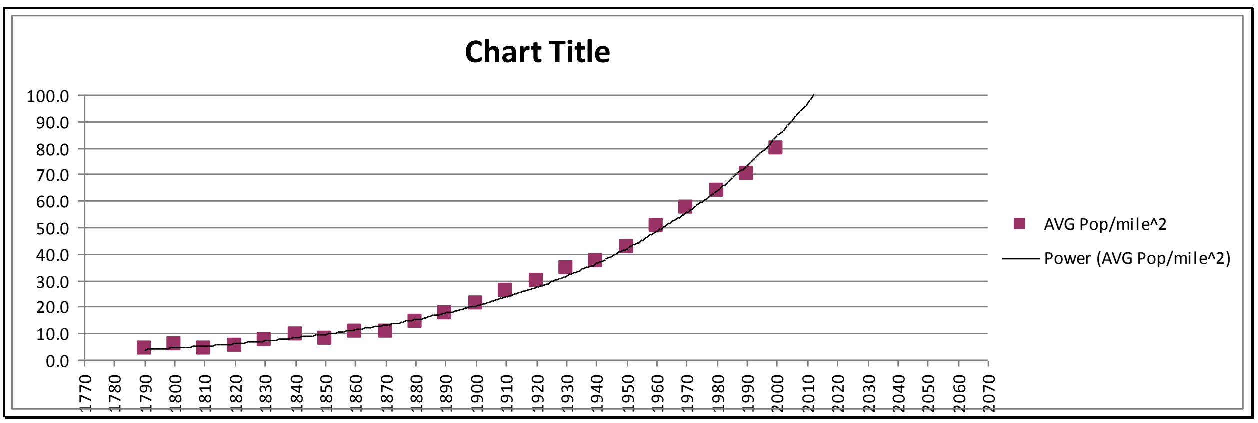


Chart Title
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1770
1780
1790
1800
1810
1820
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1870
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1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
AVG Pop/mile^2
Power (AVG Pop/mile^2)

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