CALL NUM: 7-(2006-)
LHR: Natural hazards review.
ISSN: 1527-6988
ART TI: "The Effects of urban Sprawl on the Vulnerability to a Significant Tornado Impact in Northeastern Illinois"
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Effects of Urban Sprawl on the Vulnerability to a Significant Tornado Impact in Northeastern Illinois

Soren G. Hall¹ and Walker S. Ashley²

Abstract: A sprawling U.S. population continues to spread into the fringes of urban development placing both populations and property in areas that were once largely unoccupied. Population tallies, housing unit totals, and housing values for 1990 and 2000 are examined to determine the extent to which this growth has affected the tornado hazard in northeastern Illinois. The growing town of Plainfield, Ill., located southwest of Chicago, is examined to determine how vulnerability to a tornado impact has changed in the town since an F5 tornado struck the community in 1990. The population and housing data indicate an increase of 8,629 persons and 3,058 housing units affected if the tornado were to have occurred in 2000 rather than 1990. Estimations of housing value affected by the Plainfield tornado indicate a 50% increase in 2000 compared with 1990 values. In addition to studying the impacts on Plainfield, four other scenarios are examined in suburban Chicago counties using the 1990 Plainfield tornado as a model for a potentially devastating strike. The large increase in total value of homes affected for each scenario highlights the overall increase in wealth throughout the study area, specifically along the urban fringe of development. The physical vulnerability throughout the study area has increased with the rise in population, but the most socially vulnerable areas appear to remain in the older urban centers.


CE Database subject headings: Natural disasters; Tornado; Suburbs; Chicago; Illinois; Meteorology; Climatology; Geographic information systems.

Introduction

Urban sprawl in the United States has become a significant issue of concern during the past several decades. This issue is not new; it has been relevant since the 1950s (Cavin 2003; Greene 2006), but the current rate of development has resulted in more attention to the problem. The urban fringes of large metropolitan areas have experienced the largest growth with the central city areas receiving less growth, or even decline (Greene 2006).

Urban sprawl has numerous implications for those concerned with land-use management, urban development, and social issues. One location where many of the important issues are highlighted is in the Chicago metropolitan area and the rapidly developing suburban area surrounding the city (e.g., see Auch et al. 2004). The favorable soil west of Chicago results in land that is well suited for agriculture purposes; land that is quickly being consumed by an ever-expanding suburban population. In the past, the value of this land was based on quality of the soil, but is now measured increasingly by the human lives and property that are becoming more common.

There have been many arguments against sprawl and its implications on modern society. Among these are: a growing dependence on vehicles resulting in increased levels of pollution, an unsustainable growth that needlessly exhausts limited natural resources, an increase in costs on infrastructure to accommodate growth, and a loss of community from the fragmented growth pattern (Greene 2006). The question posed by this research is: How has urban sprawl affected the vulnerability to tornadoes in northeastern Illinois and the Chicago metropolitan area? This is accomplished by examining changes in population, housing units, and the value of homes along the suburban fringe of Chicago. Social impacts on vulnerability to tornadoes are explored as well in an effort to determine the overall vulnerability to tornadoes in the study area. The Plainfield tornado, which occurred on August 28, 1990, serves as a model for a potentially devastating tornado strike. The path of the tornado is utilized in five hypothetical scenarios within the study region to illustrate the effect of a tornado in 1990 in comparison with 2000. Future estimates of how the population will continue to grow and what this means for urban development are also explored.

Background

With an ever-expanding U.S. population, social aspects of hazard and risk management have become a relevant and important topic of concern (Changnon et al. 2000; Sarewitz and Pielke 2001; Cutter et al. 2003). The manner in which the population grows, not just the growth itself, can play a significant role in the evolution of hazards for a given region.

Urban Sprawl

Urban growth is a normal and inevitable fact; urban sprawl is not. Urban sprawl represents a specific type of growth distinct from
traditional development. One of the most widely attributed features used to describe sprawl is the presence of low-density developments where individual structures and groups of developments are widely spaced (Duany et al. 2000; Gilham 2002; Cavin 2003). The division of land uses is another defining characteristic of sprawl. There is a lack of commingled zoning types, particularly commercial and residential, that is common among more established towns. Residential areas are developed in pods that are connected by feeder roads that lead to the main thoroughfares. This type of growth results in the dependence on vehicles to get to the other zones for shopping, working, and recreation. This division is in contrast to the traditional model for development where housing, businesses, recreational areas, and government facilities are commingled and do not require the use of vehicles to get from one place to another.

Mitigation of potential hazards requires careful land-use management practices. This has to be done with communities with proper hazard mitigation practices. There is a need to mitigate policies in order to protect against the characteristics of urban sprawl. These include: efficient use of land by utilizing high density development, use of open space, parks and trees, redevelopment of underutilized urban land, higher use of public transportation, mixed use development to promote pedestrian traffic, and energy conservation and utilization of efficient technologies (Miletic 1999). A higher density of development is favored and underdeveloped land is used before taking open land on the periphery of development, resulting in less dependence on vehicles for transportation. The contrasts between urban sprawl and sustainable development leads to the conclusion that urban sprawl could represent a potentially hazardous form of development. Evidence for this argument is supported by a study that examined the “Tri-state Hailstorm” of April 10, 2001 (Changnon 2003). This storm traveled 585 km from eastern Kansas to southern Illinois and led to substantial losses in the suburban areas of St. Louis and Kansas City, Mo. The combined insured losses for the individual hail events over the 2-day period totaled $2.1 billion (2005 dollars), ranking it as the ninth costliest weather-related catastrophic event during 1949–2001. According to Changnon (2003), these losses occurred in areas that were rural farm lands 25 years ago but are now suburban areas on the fringe of St. Louis and Kansas City, Mo. This case exemplifies the reality that social factors are playing an increasing role in the characteristics and landscapes of hazards. By choosing to continually broaden the boundaries of urban (primarily residential) development, a larger population spread spatially over an area becomes increasingly vulnerable to a potential hazard.

**Tornado Climatology**

Tornado hazards and their climatology are difficult to quantify. The total number of tornadoes has increased steadily over time, but this is due to the large increase in “weak” tornadoes being reported (Angel 2002; Boruff et al. 2003; Brooks et al. 2003). Other factors influencing the tornado climatology include: errors reporting or recording the time and location information, spatial and temporal variability in the collection of severe-weather reports for warning verification programs, deployment of Doppler radar and the National Weather Service modernization in the 1990s, changes in the nature of detailed damage surveys, increased population, improved public awareness, and the proliferation of storm chasers and video cameras (Brooks et al. 2003). The 1990s experienced 12,138 tornadoes, contrasted with only 4,796 reported tornadoes in the 1950s (Boruff et al. 2003). During 1953–1996, the increase in the annual number of tornadoes is contrasted by a steady or relatively small increase in the number of tornado days (Kunkel et al. 1999; Brooks et al. 2003). This suggests that there may not be an actual increase in the number of tornadoes, rather merely an increase in the number of tornadoes being reported.

The tornado that served as the basis for this analysis was the devastating Plainfield, Ill. tornado that occurred on August 28, 1990. The tornado resulted in 29 deaths, 300 injuries, and over $238 million in damages (2005 dollars). The Plainfield tornado reached the highest category on the Fujita scale (F5) and struck the town of Plainfield as an F4 (Fujita 1993). The Fujita scale (cf. McDonald 2001, Table 1) does not measure the strength of the tornado directly, but instead estimates tornado wind speed intensity based on damage.

The topic of risk and vulnerability assessment was brought to the forefront after the large tornado outbreak that struck the Oklahoma City, Okla. and Wichita, Kan. metropolitan areas on May 3, 1999. The effect of the tornado was 20 killed and underdeveloped land is used before taking open land on the periphery of development, resulting in less dependence on vehicles for transportation. The contrasts between urban sprawl and sustainable development leads to the conclusion that urban sprawl could represent a potentially hazardous form of development. Evidence for this argument is supported by a study that examined the “Tri-state Hailstorm” of April 10, 2001 (Changnon 2003). This storm traveled 585 km from eastern Kansas to southern Illinois and led to substantial losses in the suburban areas of St. Louis and Kansas City, Mo. The combined insured losses for the individual hail events over the 2-day period totaled $2.1 billion (2005 dollars), ranking it as the ninth costliest weather-related catastrophic event during 1949–2001. According to Changnon (2003), these losses occurred in areas that were rural farm lands 25 years ago but are now suburban areas on the fringe of St. Louis and Kansas City, Mo. This case exemplifies the reality that social factors are playing an increasing role in the characteristics and landscapes of hazards. By choosing to continually broaden the boundaries of urban (primarily residential) development, a larger population spread spatially over an area becomes increasingly vulnerable to a potential hazard.

**Research Design and Methods**

The research area for this study covers a six county region in Illinois (i.e., DuPage, Kane, Kendall, Lake, McHenry, and Will) surrounding the Chicago urban core (Fig. 1). The recent sprawling growth has occurred principally in this “ring” of counties (Table 1). The growth in the study area during the period from 1990 to 2000 accounts for 58% of the total growth for all 102 counties in Illinois. Over the same span, these counties have grown at nearly twice the pace percentage-wise of the United States as a whole.

The attributes for the 1990 and 2000 data were acquired from the U.S. Census Bureau (2005). The attribute data at the block level include total population as well as housing units. These data are used to determine how the total number of housing units has changed over time as well as how many more people would be affected by a potential tornado. The tract level data include information on housing values and will be used as a general guide to note how wealth has changed over time throughout the census tracts. The value of housing units is provided as a median value for each tract, not exact values for individual properties. These median values were adjusted for inflation to 2005 dollars in order to compare the values and determine changes from 1990 to 2000 (Friedman 2000).

The Plainfield tornado represents an event of catastrophic potential if it were to strike a highly vulnerable area. The path of the Plainfield tornado was mapped in a previous study (Fujita 1993)
total area of the selected block. The population affected could then be adjusted based on the proportion of the block that was actually affected. Again, there is error in this method as well because it assumes an equal distribution of the population throughout the area of each block. As both methods would be estimations, and the alternative method made further assumptions about the distribution of developments, the first method was chosen as the primary method of analysis in this investigation. Nevertheless, the second, or alternative, method was also utilized for the Plainfield scenario to approximate the overestimation in the primary method.

The size of block units change from one census to the next. This is an important factor to consider when selecting block units affected by the path of the tornado. Any 2000 block unit that falls within a 1990 block unit is selected for analysis. This step maintains a very close agreement of spatial area covered for both time periods. When these steps are completed, the population and housing unit totals are calculated for the selected features.

The initial analysis focuses on how the changes in population and housing units have affected the vulnerability to a potential tornado in the growing suburban town of Plainfield. In addition to the analysis of effects for the Plainfield area, four other scenarios in counties surrounding Chicago are examined as well. The path of the Plainfield tornado was placed over locations in each of the counties to determine the change in impacts from 1990 to 2000. The placement of the tornado paths in each of the scenarios was not random. Instead, the paths were placed intentionally over areas that had experienced a considerable increase in development due to urban sprawl. The path placement in these four settings was intended to be a "worst case scenario" (Clarke 2005) for sprawl population affected, not necessarily total persons affected.

### Analysis and Results

A growing U.S. population is moving from the urban centers to the suburban fringes and building communities where none were present a short time ago. This increase in development is visible along the urban fringe when comparing U.S. Census defined urban areas for 1990 and 2000 (Fig. 1). It is apparent that the spatial extent of urban development has increased around the periphery of development over this time period, sometimes leaping over undeveloped areas to urban clusters further out.


<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DuPage</td>
<td>781,666</td>
<td>904,161</td>
<td>928,718</td>
<td>122,495</td>
<td>15.6</td>
<td>24,557</td>
<td>2.7</td>
<td>865</td>
</tr>
<tr>
<td>Kane</td>
<td>317,471</td>
<td>404,119</td>
<td>472,482</td>
<td>66,648</td>
<td>27.3</td>
<td>8,004</td>
<td>16.9</td>
<td>1,347</td>
</tr>
<tr>
<td>Kendall</td>
<td>39,413</td>
<td>54,544</td>
<td>72,548</td>
<td>15,131</td>
<td>38.4</td>
<td>18,004</td>
<td>33.0</td>
<td>831</td>
</tr>
<tr>
<td>Lake</td>
<td>516,418</td>
<td>644,356</td>
<td>692,803</td>
<td>127,393</td>
<td>24.8</td>
<td>48,539</td>
<td>7.5</td>
<td>1,150</td>
</tr>
<tr>
<td>McHenry</td>
<td>183,241</td>
<td>260,077</td>
<td>296,389</td>
<td>76,836</td>
<td>41.9</td>
<td>36,310</td>
<td>14.0</td>
<td>1,564</td>
</tr>
<tr>
<td>Will</td>
<td>357,313</td>
<td>502,266</td>
<td>613,849</td>
<td>144,953</td>
<td>40.6</td>
<td>111,583</td>
<td>22.2</td>
<td>2,168</td>
</tr>
<tr>
<td>Total</td>
<td>2,195,522</td>
<td>2,769,523</td>
<td>3,076,881</td>
<td>574,001</td>
<td>26.1</td>
<td>307,358</td>
<td>11.0</td>
<td>7,936</td>
</tr>
<tr>
<td>Illinois</td>
<td>11,430,002</td>
<td>12,419,293</td>
<td>12,712,016</td>
<td>292,014</td>
<td>8.6</td>
<td>292,723</td>
<td>2.3</td>
<td>143,963</td>
</tr>
<tr>
<td>United States</td>
<td>248,709,873</td>
<td>281,421,906</td>
<td>293,656,842</td>
<td>32,712,033</td>
<td>13.2</td>
<td>12,254,936</td>
<td>4.3</td>
<td>9,161,964</td>
</tr>
</tbody>
</table>

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**Fig. 1.** Map of Chicago region illustrating urban growth and the five specific areas and tornado (northwest-to-southeast oriented black lines) scenarios examined in this investigation.
Analysis of Impacts on Population and Housing Units

The tornado path and block data for 1990 and 2000 were overlain in a GIS to determine the resultant impacts on the number of persons affected by a tornado in each year (Fig. 2). The path of the tornado is shown passing over U.S. Census designated urban areas near Plainfield, Ill. Much of the new development was spared from the strike, with the greatest development lying to the northeast of the tornado track. The tornado touched down near Oswego and passed through an area of Kendall County with a relatively low population. The tornado reached its peak intensity just east of the urban areas around Plainfield before finally diminishing in intensity prior to reaching Joliet. The majority of the urban areas affected by the tornado were in Will County, which accounts for a much larger population. The overall increase in affected population for both counties combined was 8,629 persons, representing an increase of 75.8% (Table 2). This total shows that there has been considerable change in the population affected by the tornado since 1990.

With the increase in population, there was a corresponding increase in housing units (Table 3). Once again, considerably more structures were affected in Will County due to a larger extent of development. The total increase in housing units affected over the period of study was 3,058. These population and housing values demonstrate a pronounced change due to a growing population. Despite a large undeveloped area included in the data, the change in the effects of the Plainfield tornado between years is substantial.

As described in the methodology section, an alternative method of calculating the number of persons and housing units impacted was also utilized for the Plainfield scenario in order to assess the amount of possible overestimation in our original method. This second method calculates the portion of the block area affected in relationship with the total area of the selected block, providing adjusted values based on the proportion of the actual block affected. The alternative methodology suggests an increase of 1,793 persons and 563 housing units affected by the tornado scenario in Plainfield if it were to have occurred in 2000. This is a 79.2% reduction in the number of persons and an 81.6% decrease in the number of housing units impacted when compared with the original method. However, these values obtained from the alternative method may be underestimates as superimposing historical damage tracks from largely rural areas (e.g., 1990 Plainfield area) onto more suburban or urban areas (e.g., 2000 Plainfield area) likely underestimates the full damage potential of the tornado (e.g., see Wurman et al. 2007). Nevertheless, these values from the alternative method still represent an increase of 44.9 and 39.3% in the number of persons and housing units impacted over the period of record, respectively. These values suggest that the

<table>
<thead>
<tr>
<th>Location</th>
<th>1990</th>
<th>2000</th>
<th>Increase in</th>
<th>Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kendall</td>
<td>1,066</td>
<td>1,306</td>
<td>240</td>
<td>22.5</td>
</tr>
<tr>
<td>Will</td>
<td>10,463</td>
<td>18,852</td>
<td>8,389</td>
<td>80.2</td>
</tr>
<tr>
<td>Total</td>
<td>11,529</td>
<td>20,158</td>
<td>8,629</td>
<td>75.8</td>
</tr>
</tbody>
</table>

Table 2. Change in Population Impacted by Plainfield Tornado 1990–2000

<table>
<thead>
<tr>
<th>Location</th>
<th>1990</th>
<th>2000</th>
<th>Increase in</th>
<th>Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kendall</td>
<td>376</td>
<td>448</td>
<td>72</td>
<td>19.1</td>
</tr>
<tr>
<td>Will</td>
<td>4,279</td>
<td>7,275</td>
<td>2,996</td>
<td>70</td>
</tr>
<tr>
<td>Total</td>
<td>4,655</td>
<td>7,723</td>
<td>3,068</td>
<td>65.9</td>
</tr>
</tbody>
</table>

Table 3. Change in Housing Units Impacted by Plainfield Tornado 1990–2000
number of fatalities would increase from the realized 29 in 1990 to a potential 78 in the 2000 Plainfield scenario.

In addition to analyzing the population and housing unit impacts of the tornado for Plainfield, the path of the tornado was also placed over vulnerable locations in the other counties surrounding the Chicago area (Fig. 3). Fig. 3 displays areas with population densities greater than 77 persons/km² for both 1990 and 2000. This value was chosen to remove the extremely low-density rural populations, but keep both high- and low-density urban populations.

Population and housing unit totals were calculated for each scenario (Tables 4 and 5). Both DuPage and Lake Counties have total population densities of over 500 persons per km², with values of 1,045 and 555, respectively. This higher density of development is evidenced in the high population values for 1990 and 2000 for the counties of DuPage, and to a lesser extent, Lake. Although the DuPage scenario showed high values of population change, it was relatively small based on the initial values (35% increase by percentage). The path of the tornado in DuPage County [Fig. 3(a)] passed through areas that were largely urbanized in 1990, only affecting a small portion of the new urban area in the northwest portion of the area. The relatively small percentage change of affected population between 1990 and 2000 for the DuPage scenario is expected when the map is considered, although the total number of people affected is large relative to the other scenarios. Lake county experienced less growth than the other three counties (9,285 persons), but this resulted in a doubling of persons affected with an increase of 103.1%. These changes are also evident in Fig. 3 displaying the path of the tornado. Lake County [Fig. 3(b)] has a large portion of its area urbanized in 1990, but there is substantial growth in urban areas for 2000 as well. The tornado affected newly urbanized areas near Third Lake and Wildwood in the northern portion of the map before continuing southeastward into areas that were urbanized prior to 1990.

The Kane scenario [Fig. 3(c)] experienced the greatest in-

Table 4. Change in Population Impacted by Hypothetical Event for Various County Scenarios

<table>
<thead>
<tr>
<th>Location</th>
<th>1990</th>
<th>2000</th>
<th>Increase in</th>
<th>Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DuPage</td>
<td>35,118</td>
<td>47,416</td>
<td>12,298</td>
<td>35</td>
</tr>
<tr>
<td>Kane</td>
<td>4,830</td>
<td>18,667</td>
<td>13,837</td>
<td>286.5</td>
</tr>
<tr>
<td>Lake</td>
<td>9,003</td>
<td>18,288</td>
<td>9,285</td>
<td>103.1</td>
</tr>
<tr>
<td>McHenry</td>
<td>5,056</td>
<td>18,857</td>
<td>13,801</td>
<td>273</td>
</tr>
</tbody>
</table>

Table 5. As in Table 6, except Change in Housing Units Impacted

<table>
<thead>
<tr>
<th>Location</th>
<th>1990</th>
<th>2000</th>
<th>Increase in</th>
<th>Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DuPage</td>
<td>13,369</td>
<td>16,928</td>
<td>3,559</td>
<td>26.6</td>
</tr>
<tr>
<td>Kane</td>
<td>1,627</td>
<td>6,487</td>
<td>4,860</td>
<td>298.7</td>
</tr>
<tr>
<td>Lake</td>
<td>3,127</td>
<td>6,355</td>
<td>3,228</td>
<td>100</td>
</tr>
<tr>
<td>McHenry</td>
<td>1,632</td>
<td>5,954</td>
<td>4,322</td>
<td>260.4</td>
</tr>
<tr>
<td>Total</td>
<td>19,775</td>
<td>35,396</td>
<td>15,621</td>
<td>80.1</td>
</tr>
</tbody>
</table>
crease by both actual total change (13,837 persons) as well as percentage (286.5%). The McHenry scenario [Fig. 3(b)] also had substantial increases in population affected by percentage (273.0%) with a total change in population of 13,801 persons. These changes represent an increase in affected population by nearly threefold in only a ten-year period. Referring back to Table 1, the population change by percentage for the study area, Illinois, and the United States were 26.1, 8.6, and 13.2%, respectively. When these values are compared with those in Table 4, the growth in these areas can be considered unique.

In the Kane scenario, the tornado affected new urban areas southeast of Pingree Grove and continued southeastward into new urban areas south of Elgin. The large change in population and housing units affected is confirmed by the urban growth in Fig. 3(c). Although much of the tornado path in the McHenry scenario traveled through rural areas, the southern portion that affected the areas of Lakewood and Lake in the Hills saw enough new growth to affect the results. There is also a large area of growth north and east of Huntley that was not affected by the tornado scenario. As anticipated, the changes in housing units affected followed the same pattern as the population numbers. Kane was the only scenario to see a greater increase by percentage in housing units than persons. This indicates that the average number of persons per housing unit decreased in Kane County.

**Analysis of Median Home Values**

The changes in the median value of homes throughout the study period were examined to determine how the wealth has changed throughout the region (Fig. 4). Overall, there does appear to be a general progression of higher valued homes spreading outward from the highly urbanized areas of the central city, as well as an overall increase in value throughout the study area. The southeastern portion of McHenry County, the northern half of Kane County, and the northern border of Will County saw the most striking changes.

The total value of the housing units affected by each hypothetical tornado scenario was calculated for 1990 and 2000 to determine how the potential for monetary losses had changed between years (Table 6). It is worth noting again that the popula-

### Table 6. Total Value of All Homes Affected and Average Value per Home for 1990 and 2000, Adjusted to 2005 Dollars

<table>
<thead>
<tr>
<th>Location</th>
<th>Value of affected homes 1990 (millions)</th>
<th>Value of affected homes 2000 (millions)</th>
<th>Increase in thousands</th>
<th>Average value per housing unit 1990</th>
<th>Average value per housing unit 2000</th>
<th>Difference in average value per housing unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>DuPage</td>
<td>$2,874</td>
<td>$3,777</td>
<td>$903</td>
<td>$214,975</td>
<td>$223,121</td>
<td>$8,146</td>
</tr>
<tr>
<td>Kane</td>
<td>$329</td>
<td>$1,222</td>
<td>$893</td>
<td>$202,213</td>
<td>$188,377</td>
<td>($13,836)</td>
</tr>
<tr>
<td>Lake</td>
<td>$835</td>
<td>$1,657</td>
<td>$832</td>
<td>$267,029</td>
<td>$267,791</td>
<td>$762</td>
</tr>
<tr>
<td>McHenry</td>
<td>$305</td>
<td>$1,201</td>
<td>$896</td>
<td>$184,625</td>
<td>$201,713</td>
<td>$17,088</td>
</tr>
<tr>
<td>Plainfield</td>
<td>$639</td>
<td>$1,242</td>
<td>$603</td>
<td>$137,272</td>
<td>$160,818</td>
<td>$23,546</td>
</tr>
</tbody>
</table>

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Table 7. Median Value of Homes by County for 1990 and 2000, Adjusted to 2005 Dollars

<table>
<thead>
<tr>
<th>Location</th>
<th>1990</th>
<th>2000</th>
<th>Difference</th>
<th>Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DuPage</td>
<td>$203,914</td>
<td>$216,554</td>
<td>$12,640</td>
<td>6.2</td>
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<td>Kane</td>
<td>$152,452</td>
<td>$178,130</td>
<td>$25,678</td>
<td>16.8</td>
</tr>
<tr>
<td>Lake</td>
<td>$213,319</td>
<td>$229,308</td>
<td>$16,899</td>
<td>8.3</td>
</tr>
<tr>
<td>McHenry</td>
<td>$115,995</td>
<td>$121,681</td>
<td>$5,686</td>
<td>13.1</td>
</tr>
<tr>
<td>Will</td>
<td>$113,712</td>
<td>$117,356</td>
<td>$3,644</td>
<td>28.2</td>
</tr>
<tr>
<td>Kendall</td>
<td>$118,268</td>
<td>$122,022</td>
<td>$3,754</td>
<td>16</td>
</tr>
</tbody>
</table>

ion and housing unit calculations are overestimates. The total number of homes affected would likely be smaller and all homes would not be destroyed completely. The total values for these impacts would be extraordinarily large; greater than $1 billion in total value for all scenarios for 2000. Regardless, these values illustrate the large changes in total value of homes affected by a potential tornado strike.

DuPage had the most homes impacted, and correspondingly, saw the largest total in value of impacted homes as well. All events, with the exception of Plainfield, saw increases in value of over $800 million, although the area did see the largest change (increase of over $23,000) in median house price between years. Comparing the average value per housing unit for 1990 and 2000 is useful in interpreting the relative impacts on total change from the effects of both housing units and increases in wealth. The only event that did not show an increase in average value was Kane County. Despite the substantial increase in total homes impacted, there was a decrease of nearly $14,000 in average value between years. Further inspection proved that many of the new homes built in the southeastern portion of the tornado tract were of lower value, thereby decreasing the median value of homes in this area. The value of the homes impacted in 1990 were relatively low (mean value of $137,272 per home) when compared with the other areas examined. Therefore, the new homes in the Plainfield area could actually be of comparable value to the new homes built elsewhere in the study area.

The median home values for each tornado event can be compared with the median value for the entire county with which they are associated (Table 7). This was performed to determine how representative the tornado events were of the overall county values. There are some large differences between the impact areas and the county as a whole. For example, the tornado event in Kane County had a decrease in median value of nearly $14,000, but the median value for the county as a whole increased by over $23,000. Clearly, this path was not representative of the change in median values throughout the county, despite the large increase in median housing units. Lake and McHenry, the two most highly developed counties, experienced smaller increases for the county as a whole as well as for the tornado events. The changes in median value on the county-level are generally greater for counties experiencing large growth (Kane, McHenry, Will, and Kendall) and smaller for the more established counties (Lake and DuPage).

Social and Physical Vulnerability

Social factors have a significant influence on the ability of populations to respond to disasters (Changnon et al. 2006; Sarewitz and Pielke 2001; Cutter et al. 2003). Certain factors are thought to positively or negatively affect the vulnerability of a location, but the relative magnitude of each factor is not well understood. Although a detailed assessment of social factors influencing hazards is beyond the scope of this research, three major factors (density, race, and wealth) are examined.

Race can become an influence due to language and cultural factors that make communication and cooperation between groups difficult (Cutter et al. 2003). To examine areas that may be more vulnerable because of social factors, areas of high minority population density and low median home values were compared (Fig. 5). Census blocks with greater than 25% minority populations and census tracts with median home values of less than $150,000 were overlaid for 2000. There are several areas that show a high concentration of minorities with low home values. In Lake County, there is an area of high minority populations along Lake Michigan that correspond with low home values. There are two noticeable areas in the eastern portion of Kane County that exhibit the same relationship as well as a cluster in northern Will County. These are areas that could be potentially more vulnerable to a tornado impact as a result of language and cultural barriers. It is worth noting that these clusters tend to be areas that are well established with older developments and generally do not represent sprawling growth.

Population density has been found to be a determinant in the number of fatalities and injuries caused by a tornado event (Simmons and Sutter 2005a). When comparing high-density blocks with low median home value tracts, a similar relationship to what
in population of roughly 150,000 persons per 10-year interval. The population per square kilometer was also determined to get an overall picture of the density of growth for the county as a whole. Based on current estimates, the data show that the population per square kilometer will more than double from 1990 to 2020.

However, the latest population estimates from July 5, 2005 for Will County indicate a current population of 642,813 (U.S. Census Bureau 2005). Table 8 places the population of Will County at less than 20,000 persons from the target value for 2010. Fig. 8 indicates that population growth since 1990 has approached 85% in 2005; a near doubling over a 15-year period, rather than 20 years as planned. The faster growth is placing a larger population at risk for an increased impact. With current projections for Will County already exceeded, further growth will only increase the risk of a tornado impact.

Discussion

The goal of this study was to analyze the extent to which the vulnerability to a tornado impact has changed due to increased population growth and a spreading development pattern in the suburban areas surrounding Chicago. There were several key findings from the analysis that illustrate this increased vulnerability, including:

- The data confirm the predicted increases in number of persons and housing units impacted over the period of study.
- There is an overall increase in median housing value throughout the study area that is generally concentrated along the urban fringe of development. This rise in home value will result in potential increased losses in the event of a tornado.
- New housing developments primarily consisted of non-minorities and minorities tended to be in the older, higher density areas. High concentrations of minorities as well as high density developments are negatively correlated with ability to respond in a disaster. As a result, these areas will have the greatest vulnerability.
- The new developments were generally low density and sprawling in nature and displayed higher median home values. These areas will be at a greater risk of a tornado impact due to the increase in spatial extent of development. If a disaster were to occur, this population is better equipped to respond.

Population and Housing Units

The growth in the six-county study area accounted for 58% of the total growth in all of Illinois during the time period studied. Large changes in population and housing unit totals were found for the area impacted by the Plainfield tornado on August 28, 1990. There was an increase of 8,629 in affected population and 3,068 in housing units impacted had the tornado occurred in 2000. The

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**Table 8. Growth of Population and Housing Units in Will County**

<table>
<thead>
<tr>
<th>Will County</th>
<th>1990</th>
<th>2000</th>
<th>% increase since 1990</th>
<th>2010</th>
<th>% increase since 1990</th>
<th>2020</th>
<th>% increase since 1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>357,313</td>
<td>502,266</td>
<td>41</td>
<td>662,492</td>
<td>85</td>
<td>822,743</td>
<td>130</td>
</tr>
<tr>
<td>Population/km²</td>
<td>1,105</td>
<td>1,554</td>
<td>41</td>
<td>2,050</td>
<td>85</td>
<td>2,546</td>
<td>130</td>
</tr>
<tr>
<td>Housing units</td>
<td>122,870</td>
<td>175,434</td>
<td>43</td>
<td>228,445</td>
<td>86</td>
<td>283,704</td>
<td>131</td>
</tr>
<tr>
<td>Housing units/km²</td>
<td>380</td>
<td>543</td>
<td>43</td>
<td>707</td>
<td>86</td>
<td>878</td>
<td>131</td>
</tr>
</tbody>
</table>
hypothetical tornado scenarios in Kane and McHenry Counties were particularly effective in emphasizing the results due to sprawl. Changes in population and housing units impacted for the events in these counties approached 300%. The tornadoes also affected large populations in Lake and DuPage Counties, but the changes between years were smaller. The majority of the new growth in these counties was along the edges further from the urban centers. Overall, there was a considerable increase in the total number of persons and housing units impacted by each tornado scenario.

Median Home Values

The median home values generally increased throughout the study region, particularly in areas toward the urban fringe. Will, Kendall, Kane, and McHenry Counties all had increases in median home values of over $20,000. DuPage and Lake, the two counties closer to the central city that were largely urbanized prior to 2000, had smaller increases, but still had overall median values larger than the other four. The most expensive homes are still closer to the city, but the largest changes in home price are along the urban fringe. This was in line with findings in Changnon (2003) in the study of a hail outbreak affecting the suburbs on the fringe of St. Louis and Kansas City, MO. The developments along the urban fringe generally contained higher valued homes, resulting in greater losses from the hailstorm as a consequence of the new development. These findings, along with the results of this study, lead to the assertion that sprawl growth can have a considerable impact on the cost due to hazards.

The total value for the homes impacted by the tornadoes in each county fluctuated, with DuPage County experiencing the greatest value total. This highlights the fact that denser developments will likely lead to more costly tornado impacts. The sprawling developments will likely result in fewer homes and people being impacted by a given event due to the large spacing of developments. Conversely, with a larger spatial extent at risk, the probability that persons or property will be impacted will increase. The largest disasters will likely occur in developments that have a denser development pattern (e.g., see Wurman et al. 2007). However, the probability of a dense area being impacted is less due to the small spatial extent and wide spacing. The return frequency of tornadoes for a given point is small; therefore, it is unlikely that a tornado will strike the same dense population more than once over a short period of time. With this interesting relationship between density and strike probability, it remains to be seen how the density of development will impact damage and fatality totals in years to come. Despite the fact that denser developments will generally result in greater losses, large increases were found in the total value of homes impacted by each tornado event. Each tornado event resulted in greater than a $1 billion in estimated damages for 2000. The increases were not only due to more homes being impacted, but also a higher average value of homes since 1990. These values indicate that urban sprawl has impacted the potential for damage in the study area.

Vulnerability to Tornado Hazard

The greatest change in vulnerability to the area is simply that there are more people over a larger area in harms way. The analysis of the five tornado paths throughout the study region emphasized how these changes in population are resulting in vastly larger populations impacted. Population density has been correlated with an increase in fatalities (Simmons and Sutter 2005a), so the higher density areas will likely create the largest disasters (Wurman et al. 2007). These areas are susceptible due to social vulnerabilities as well. This analysis indicated that there are higher proportions of minorities in the higher density areas. These populations are at an increased risk because of cultural and language differences that make reacting to disasters more difficult.

The higher density areas were also found to have lower home values. The general wisdom is that wealthier persons will have more money for safer housing and other preventative measures for potential hazards. This is confirmed in Simmons and Sutter (2005a) in an examination of F5 tornado casualties. Income was found to be a statistically significant determinant in fatalities and injuries to F5 tornadoes, indicating that wealthier communities are better able to protect themselves. The opposite result was found in an examination of all tornadoes from 1982 to 2002 (Simmons and Sutter 2005b). In fact, Simmons and Sutter (2005b) showed that with every $1,000 increase in median income, the expected fatalities increase by 3.6%. These seemingly straightforward relationships of social vulnerability and hazards may be more complex than imagined.

The new growth areas were found to be generally low density, sprawling developments. The majority of these communities consisted of primarily nonminorities of higher economic status (e.g., higher median home values as a proxy). These communities are usually more adept at reacting to hazards both in prior mitigation and access to resources for rebounding after losses (Cutter et al. 2003). In spite of the fact that these communities are not highly vulnerable socially, the sheer volume of new development creates a greater spatial extent of physically vulnerable areas. There are simply more people with more wealth creating a greater potential for large economic losses. These data are in line with results found in previous studies (Rae and Stefkovich 2000; Changnon 2003; Changnon and Burroughs 2003; Wurman et al. 2007) and verify that societal shifts in population are responsible for increases in losses due to hazards.

Many believe that mitigation against tornado hazards is not possible; if a tornado is going to strike an area, there is nothing that can be done. Tornado mitigation, as with most preventative measures, is a combination of scientific, economic, psychological, and political issues (Doswell 2005). Political leaders, as well as local communities, must be aware of the potential tornado hazard in their region. A comparison of two F5 tornado impacts highlights the importance of mitigation. The first is the small town of Heston, Kan., located within tornado alley, which experienced a tornado impact on March 13, 1990. The other tornado was the one examined in this research. The Plainfield tornado resulted in 29 fatalities, whereas the Heston tornado resulted in none. Prior mitigation is thought to be the difference between the two results (Doswell 2005). In this instance, the prior mitigation is largely in the form of public awareness. Residents and community leaders are aware of the potential tornado threat and know what to do if a tornado were to strike. This case also highlights the importance of “worst-case” thinking. The government as well as the public must prepare for the possible, not just the probable.

Summary and Conclusion

The study of hazards is an increasingly import topic of research. Populations continue to spread into the fringes of urban develop-
ment, putting them at increased risk to hazards. Important changes on how we choose to grow must be made in order to limit the potential for future loss of life and property. Knowledge of these dangers, which has increased substantially in recent decades, is an important first step, but mitigation must not stop there.

An examination of the change in vulnerability to tornado hazards in northeastern Illinois was accomplished by: (1) examining changes in population, housing units, and (2) examining social impacts on vulnerability to tornadoes. The changes in population and housing units, as well as overall wealth, show an increased vulnerability to hazards in the study area. This increase in vulnerability is most evident along the urban fringe of development, which saw the largest population changes. There was an overall increase in wealth throughout the study area, particularly along the urban fringe. The dense urban areas continue to be vulnerable due to large populations, lower value of homes, and larger relative minority populations.

Future research could be conducted by staying within the local area of the current study. A complete analysis of all possible hazards affecting the area (floods, damaging winds, earthquakes, severe heat and cold, among others) should be considered. For example, a study by Fujita and Wakimoto (1981) examined a 50 km wide zone of damage from Chicago to Detroit. Initially, a large cluster of 10-20 tornadoes were thought to be the cause of the damage, but further study indicated that downbursts and microbursts associated with a derecho windstorm (Ashley and Mote 2005) were the cause of the damage. Wind speeds for this event were estimated at 63 ± 10 m s⁻¹. The estimated damage total from this windstorm was $1.3 billion (2005 dollars), highlighting the potential for non-tornadic, severe storm-related losses in the region. The width of this damage swath was much larger than that of the Plainfield tornado. The overestimations in total persons and housing units impacted in this study would likely be underestimations for a large-scale derecho windstorm. In addition, this study only examined the impacts of sprawl on the tornado hazard in northeastern Illinois. Similar work would also be of interest in areas that have seen similar growth and also have a greater tornado frequency.

This research largely focused only on the physical vulnerability of shifting populations. Studies by Cutter et al. (2003) and Changnon (2003) have emphasized the importance of social vulnerability to hazards. Factors such as age, economic status, and race, as well as a better understanding of why development occurs in a given area, are necessary in order to properly plan and mitigate future impacts. If social vulnerability were examined in more detail in context with the most physically vulnerable areas, a full tornado hazard map could be created that would highlight the areas with the greatest overall susceptibility.

This research is an initial effort in understanding the effects of urban sprawl on the tornado hazard in the Chicago region. How this will translate into the future depends on the nature of urban development and how communities choose to grow. Growth in these areas during the past decade has posed numerous questions regarding economic and social implications due to sprawl. The question of how this growth has affected the potential tornado hazard is an important issue for both economic and social reasons as well. Data from this research would be relevant to planners, as well as the insurance industry, due to potential increases in losses. It is important to understand the risk and vulnerability related with tornado hazards in order to properly mitigate where possible and otherwise plan for the impacts of such an event.

Acknowledgments

The writers wish to thank Dr. Dave Changnon, Dr. Rich Greene, and Dr. Mace Bentley for providing comments on a prior version of this work. They also appreciate the comments and suggestions provided by three anonymous referees.

References


