The EXPANDING BULL'S-EYE EFFECT

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FEMA/JOCELYN AUGUSTINO

Aerial image of the Moore, Oklahoma, 2013 EF5 tornado path damage.

Weather hazards such as tornadoes and hurricanes affect thousands of people annually, often resulting in casualties and billions of dollars in damage. These extreme weather events can lead to disasters, which are a product of both hazard risk and societal exposure. Hazard risk describes the frequency and magnitude of a weather hazard, while societal exposure is defined as who and what is affected by an event. The NOAA reports that there have been nearly 180 weather and climate disasters in the United States since 1980 that have cost a $1 billion or more, with the total cost of these events exceeding $1 trillion! The number of billion dollar events has been increasing over time, begging the question: Is this trend due to more extreme events, or are changes in society to blame for the alarming increase? In this article, we will assess the latter factor by exploring population increase, intensifying development, and the extensive history of rural-to-urban migration, placing these demographic shifts in the context of increasing disasters in the United States. Since 1940, developed land represented only 2.5% of the total land area in the United States, but, by the end of the 21st century, urban and suburban development could make up as much as 18% of the conterminous land area. Could future growth in the number of people and their assets exposed to these hazards lead to increased disaster frequency and magnitude? How many people could potentially be affected if a violent tornado struck Atlanta, Georgia; Chicago, Illinois; or Dallas, Texas, in the future? What if a potentially catastrophic hurricane made a direct hit on Houston, Texas; Miami, Florida; or New York, New York?

Weather Hazards

Tornadoes and tropical cyclones are some of nature's most powerful and impressive phenomena. While a majority of thunderstorms do not produce severe weather, when atmospheric conditions are favorable, massive hail, damaging winds, and even long-lived tornadoes can occur. Throughout the United States, roughly 5% of all storms result in severe weather with less than 1% of storms producing a tornado. Approximately 1,200 tornadoes occur across the conterminous United States each year, with roughly 20% rated as significant (EF2+ on the Enhanced Fujita Scale) and 1% recorded as violent (EF4+). Historically, long-track (≥ 5 miles in length) significant tornadoes have caused 85% of all fatalities and 75% of the recorded damage. Although relatively infrequent, violent tornado events have been responsible for over two-thirds of tornado deaths since 1950.

In the last few years, tornadoes such as the EF5 that hit Joplin, Missouri, on May 22, 2011, and the EF5 that struck Moore, Oklahoma, on May 20, 2013, have resulted in large numbers of fatalities and economic loss. Specifically, the 2013

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The 2013 Moore, Oklahoma, tornado moves through a neighborhood that was recently undeveloped farmland.

Moore tornado killed 24 people and caused an estimated $2 billion in damage. The Joplin tornado resulted in 158 total deaths, making it the single deadliest tornado in the United States since modern tornado recordkeeping began in 1950. In addition, the Joplin tornado is the costliest tornado on record, with nearly $3 billion in damage reported. These recent two events highlight the devastating consequences that can result when a violent tornado moves across a developed landscape. Imagine, for a second, if the infamous 2013 El Reno, Oklahoma, EF3 tornado—an unbelievably wide, erratic, and terrifying multiple-vortex tornado that traversed largely undeveloped land—had formed just 25 miles further east? This horrific hypothetical would have placed the tornado across the heart of densely populated Oklahoma City during Friday evening rush hour!

While tornadoes do their share of damage, tropical cyclones are the most destructive weather hazards on Earth. Many developed landscapes around the world are affected by these events, sometimes resulting in significant injury, death, and economic loss. When these swirling storms make landfall, they may produce strong winds that can destroy personal property and infrastructure; historically storm surge and inland flooding have been responsible for a large majority of deaths associated with these cyclones. Since 1851, 290 hurricanes have made landfall on either the United States Gulf or Atlantic Coasts. Of these 290 storms, 97 of them have been rated as major hurricanes (Category 3+ on the Saffir-Simpson Scale). Greater than 85% of all major hurricanes to strike the United States have done so on the shores of just three states—Texas, Louisiana, and Florida. Florida alone has been hit by 40% of all landfalling United States hurricanes in the past 160 years. Overall, historical records indicate that the Gulf and Atlantic Coasts are subject to approximately two landfalling hurricanes per year, with a major hurricane making landfall approximately once every other year.

Recent tropical cyclone events such as Hurricanes Katrina and Sandy have created billions of dollars in damage and killed thousands of people. Hurricane Katrina, which killed over 1,800 people, is the costliest tropical storm disaster in United States history, with an estimated $125 billion in damage reported. Over 1 million people were displaced by Katrina, leaving hundreds of thousands of New Orleans, Louisiana, and central Gulf Coast residents unemployed and homeless. Apart from the monetary and human consequences, Katrina also had a profound impact on the environment. The extreme storm surge resulted in significant beach erosion that stretched hundreds of square miles. Much of the media attention associated with Katrina focused on political and governmental response, with the effects of mismanagement and poor relief efforts well documented.

Hurricane Sandy was the second-costliest United States hurricane on record, with greater than $68 billion in damage and 148 confirmed deaths. Lower Manhattan experienced a storm surge of 14 feet that led to the flooding of seven subway tunnels under the East River. As a result, the New York City Metropolitan Transportation Authority commented that the flooding associated with Hurricane Sandy was the worst disaster in the 108-year history of the city's extensive subway system.

Given these recent tornado and tropical storm disasters, one begins to ask, "Is this the new normal? Will tornado and tropical storm disasters become more frequent in the future?" These are questions that emergency managers, policy makers, researchers, media, and, of course, the public are asking. Global climate change and its possible "weirding" of weather are often suggested as a potential driver in the amplification of economic losses and impacts from weather disasters over the last half century. However, disaster frequency and magnitude increases may be, at least in part, attributable to the surge in people and their assets exposed to hazards, not necessarily due to changes in the climatology of hazard events themselves. That is, growing population, developed landscapes, and wealth are likely important factors in the increasing trends in disaster counts and impacts.

The Expanding Bull's-Eye Effect

The expanding bull's-eye helps to explain the amplification in disaster frequency and magnitude throughout time. As seen in Figure 1, the expanding bull's-eye can be thought of as an archery target, where inner rings are made up of people and their possessions, and arrows symbolize hazard events. Unlike real archery, the expanding bull's-eye target rings enlarge over time. This amplification results in a greater likelihood of arrows hitting an inner ring on the target. Accordingly, as population continues to grow and expand, the chance that a hazard impacts developed land, resulting in a disaster, increases. When combined with a hazard landscape that is possibly being reshaped by climate change, the expanding bull's-eye effect suggests the potential for more and greater disasters in our future.

The expanding bull's-eye effect is best demonstrated when examining two regions of the conterminous United States—the area east of the Continental Divide, where most tornadoes occur, and the Atlantic and Gulf Coasts, where

LAND USE SOURCE DATA IN PANEL B PROVIDED BY DR. DAVID THEOBALD AND U.S. EPA

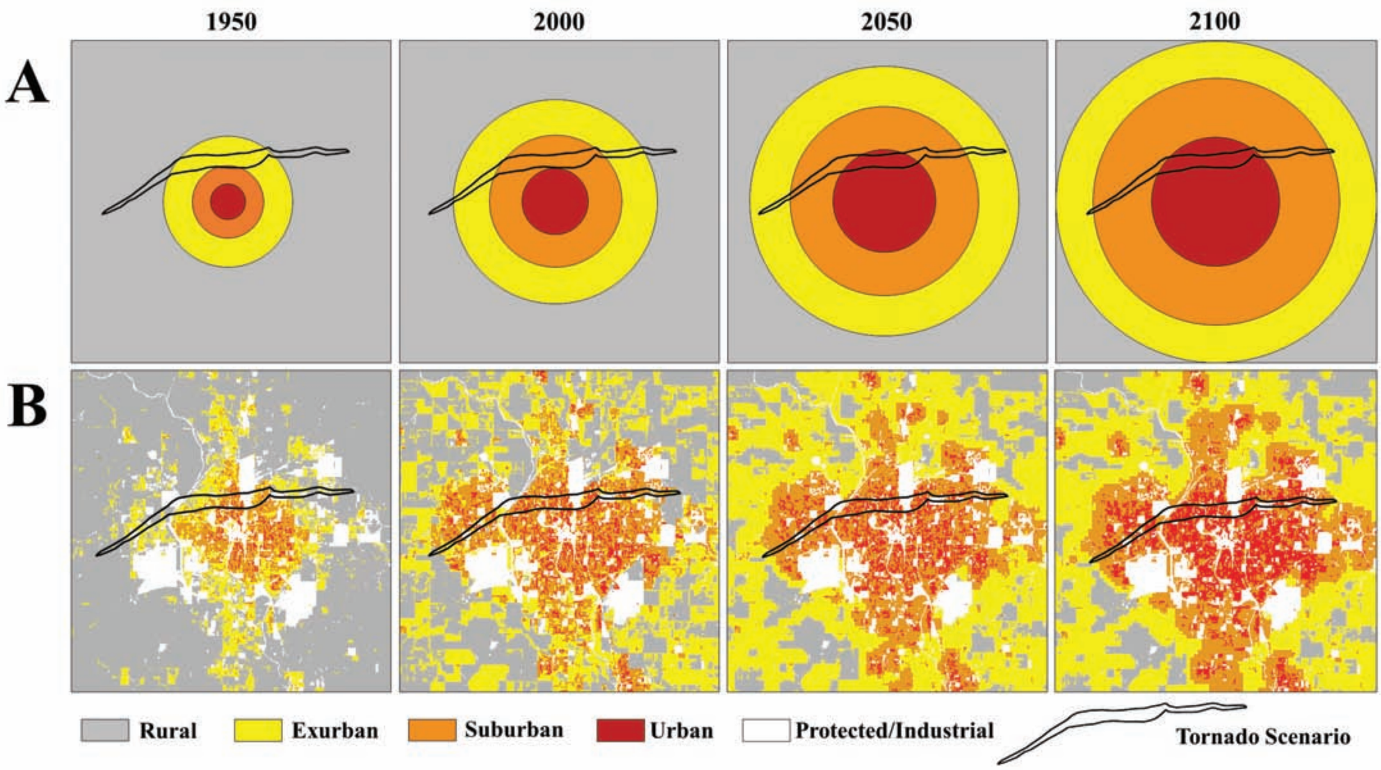

Figure 1. The expanding bull's-eye effect illustrated with the 2013 Moore, Oklahoma EF5 tornado footprint overlaid atop A) a theoretical metropolitan region and B) Wichita, Kansas, for the years of 1950 through 2100.

United States hurricanes landfall. Many major United States cities and urban areas subject to the expanding bull's-eye effect are located within these regions. For example, cities such as Atlanta, Georgia; Chicago, Illinois; Dallas, Texas; Houston, Texas; Miami, Florida; and New York, New York, exemplify an expanding bull's-eye given that they have developed rapidly over the last century and are forecast to continue this extreme growth over the next century. Figure 2A illustrates the amplification of developed land area and total number of homes east of the Continental Divide from 1940 to 2100. The uncertainty in future population and housing growth is captured in Figure 2 by including the Intergovernmental Panel on Climate Change's (IPCC) projections of potential climate and societal changes. In 1940, a large majority of land east of the Continental Divide was considered rural or sparsely populated. By 2010, rural land had decreased by 20%, transitioning to urban, suburban, and exurban development types. Specifically, total urbanized land area east of the Continental Divide has increased 540% over the past 75 years. The total number of homes in this region of the United States could increase as much as 94 million, or 92%, over the next 85 years.

Figure 2B shows the same concept, except for those counties that border the Atlantic and Gulf Coasts. These coastal locations are more densely

LAND USE AND HOUSING SOURCE DATA PROVIDED BY DR. DAVID THEOBALD AND U.S. EPA

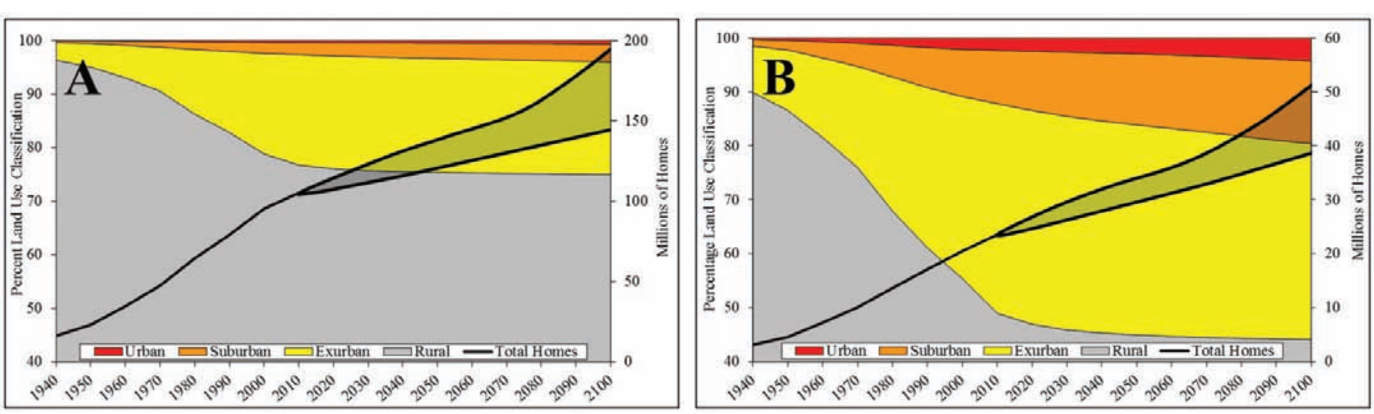

Figure 2. The percentage of urban, suburban, exurban, and rural land use A) east of the Continental Divide and B) Atlantic and Gulf Coast counties from 1940-2100. The black line indicates the total number of homes within the region in millions. The shaded area represents the potential number of homes in the region throughout the 21st century based on various climate and societal scenarios.

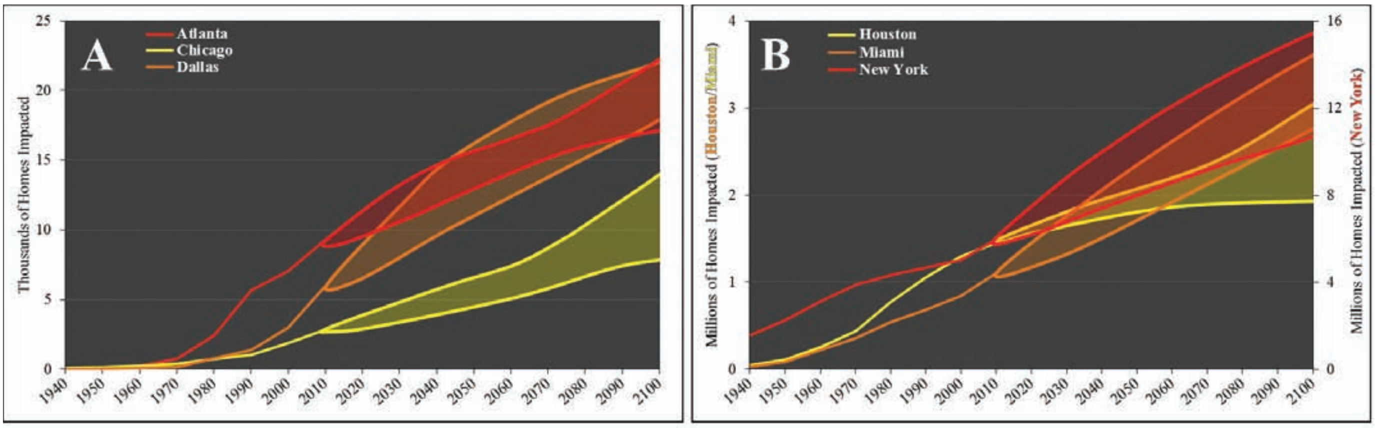

Figure 3. The total number of homes impacted by sample A) tornado and B) hurricane event scenarios. The shaded area represents the potential number of homes impacted throughout the 21st century based on various climate and societal scenarios.

populated compared to development east of the Continental Divide. In 1940, 90% of the land bordering the Atlantic and Gulf Coast was considered rural. By 2100, as much as 60% of this land could be considered developed. The United States Census Bureau found, that in 2010, approximately 39% of the United States population resided in coastal counties, yet these counties only account for 10% of the conterminous United States land area. In addition, more than 16 million people were living within the coastal floodplain in 2010. Since 1970, coastal shoreline county population has increased 40%, indicating that approximately 35 million more people and their homes are in the direct path of potentially devastating storm surges. As of 2010, the coastal shoreline county population density is approximately four times greater than that of the average United States county population density.

How many more homes in Houston, Texas; Miami, Florida; New York, New York; or your favorite coastal community would be affected in 2100 by a Category 5 hurricane compared to one that occurred in 1940? How will the expanding bull's-eye alter tornado disaster potential in Chicago, Illinois; Wichita, Kansas; Kansas City, Missouri; Dallas, Texas; or any number of cities at high risk to severe thunderstorm hazards over the next 85 years? These questions can be answered by taking historical weather events and overlaying them on locations of interest. For example, a model representing Hurricane Andrew's extreme winds and intensity can be placed over New York City to examine potential hazard impacts on The Big Apple in 1940, 2000, 2050, and 2100. This "what if" scenario method can be used to illustrate how the expanding bull's-eye effect is changing the disaster landscape across both space and time. To provide examples of this method, the 2013 Moore EF5 tornado damage survey path and 1992 Hurricane Andrew wind swath path have been placed near or over major cities (Figure 3).

Figure 3 highlights the difference in the number of homes that would be potentially affected by the same tornado event from 1940 to 2100 for all path locations. Similar to Figure 2, the uncertainty in future total number of homes impacted is illustrated by the shaded areas from 2010 to 2100. The Atlanta tornado path scenario represents the greatest change in the number of homes impacted: In 1940, only 36 homes would have been struck by the tornado, but in 2100, as many as 22,500 homes would be affected by a similar event! This demonstrates how sprawling development, which characterizes Atlanta and many other American cities, can amplify potential disaster effects. Similar to the tornado path scenarios, the Hurricane Andrew path locations also demonstrate the expanding bull's-eye effect through the swelling number of people and homes affected throughout the 160-year period. Figure 3B suggests that if a Category 5 hurricane made landfall on the Houston, Miami, or New York coasts in 2100, greater than 1.9 million homes could be potentially affected in each case. The Big Apple region could have somewhere between 11 and 15 million homes affected in 2100. The Miami and Houston regions represent the greatest expanding bull's-eye effect from 1940 to 2100—the number of homes potentially hit by a Category 5 hurricane in these metropolitan areas is expected to increase as much as 9,000%! This represents a change of 3 million homes impacted by a Category 5 hurricane in 2100 as compared to 1940.

By examining the expanding bull's-eye effect, emergency managers, city planners, and policy makers will be able to appreciate how development and shifting demographics shape disaster potential. Understanding how the expanding bull's-eye effect influences disaster potential pro-

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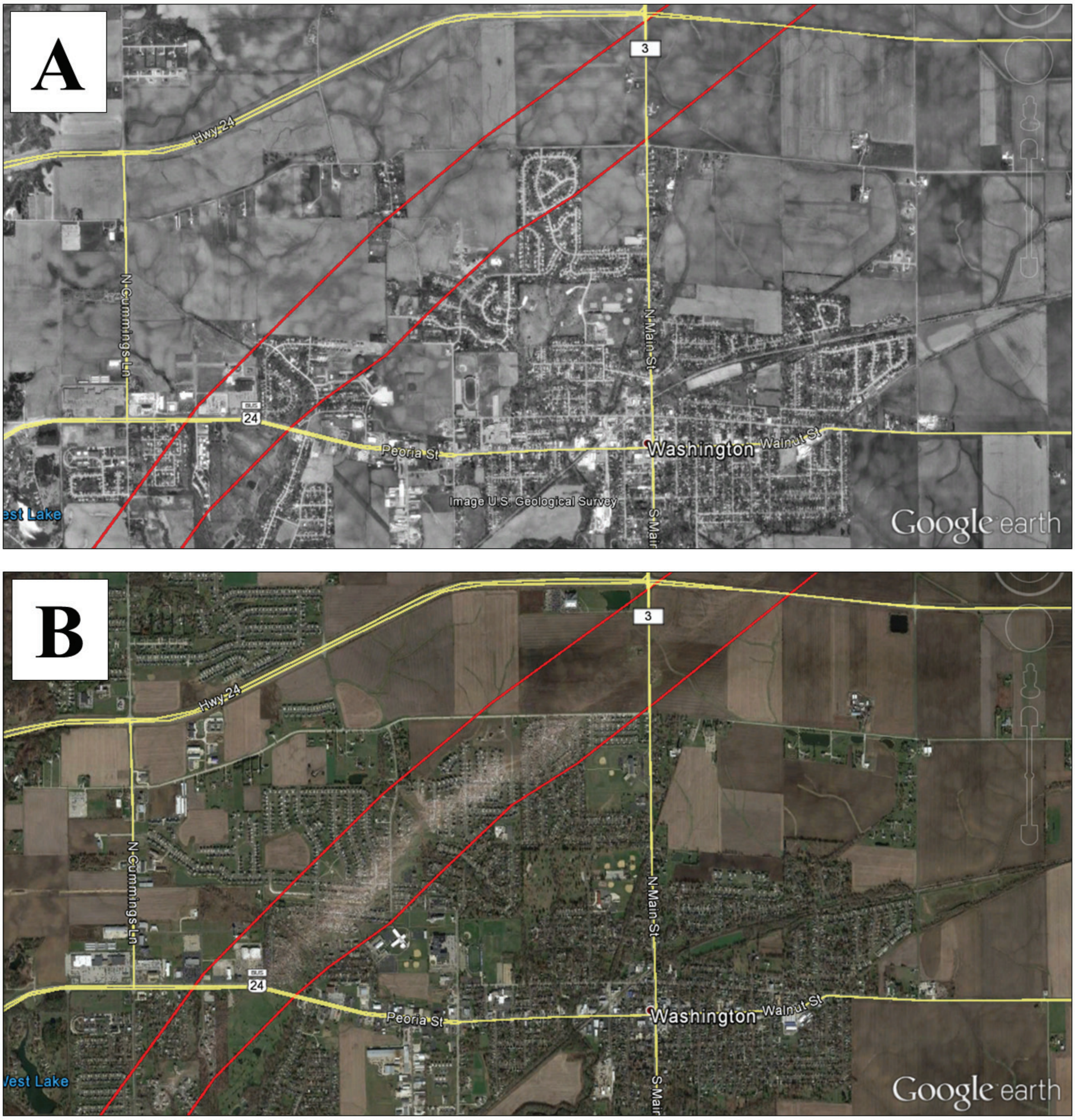

Washington, IL in A) April 6, 1994 and B) November 18, 2013 with the November 17, 2013 tornado footprint overlaid as an example of the expanding bull's-eye effect. A majority of the development struck by the tornado path was built within the last 10 years.

vides a perspective of disaster consequences that may be used to address policy through adapting zoning laws, refining state and local building codes, and improving infrastructure. For example, the implementation of safe rooms or the retrofitting of existing structures will help reduce fatalities and weather disaster effects. Such discussion has already taken place in Missouri and Oklahoma at the state and local government levels after recent devastating tornadoes. Through addressing development patterns, long-term strategies at the local level may begin to take disaster likelihood into account. Questions such as, "Where should a future community housing complex be built? What type of development (sprawling or compact) should a community undertake? Should this new housing complex mandate safe rooms?" can be answered by considering risk in the context of a community's expanding bull's-eye effect.

As global climate change continues to modify the weather hazard landscape, growth in population and developed land also persists; therefore, both risk and societal exposure should be evaluated when examining future disaster potential. Disasters only occur where there are people and possessions to be affected. Imagine if the strongest and widest tornado on record occurs in the middle of a largely undeveloped landscape—there will be no billion dollar disaster or people affected. However, if that same tornado were to occur over a city, thousands of people could be injured or killed and billions of dollars in damage could result! The chance of the latter is increasing as populations swell and more land is converted from undeveloped to developed.

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