J5.3 VARIABLE IMPACTS AND DIFFERENTIAL RESPONSE TO FLASH FLOODING IN THE *PASO DEL NORTE* METROPLEX (EL PASO, TEXAS, USA / CIUDAD JUÁREZ, CHIHUAHUA, MEXICO)

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1. INTRODUCTION

The *Paso del Norte* metropolitan area (population > 2 million) (Figure 1) is comprised of two cities (El Paso, Texas, USA and Ciudad Juárez, Chihuahua, Mexico)- a single metropolis in two nations separated by a river (the Rio Grande / *Rio Bravo del Norte*). The two cities share the same meteorology, but a different socioeconomic status. Located in the Chihuahuan Desert, average annual precipitation is ~22 cm, most of which falls during the North American Monsoon in late summer, often in a short time, making the metropolitan area prone to flash flooding. Flash floods tend to occur at the start of the monsoon: of 48 flash flood events in the National Weather Service El Paso County Warning Area between 1972 and 2002, 22 occurred between 16 July and 15 August.

The cities are built around the Franklin Mountains (which almost completely bisect El Paso) and the *Sierra de Juárez* (which flanks Ciudad Juárez). The physical and socioeconomic (topographic and demographic) complexity of the area creates complexities in planning for, forecasting, and responding to these flood events.

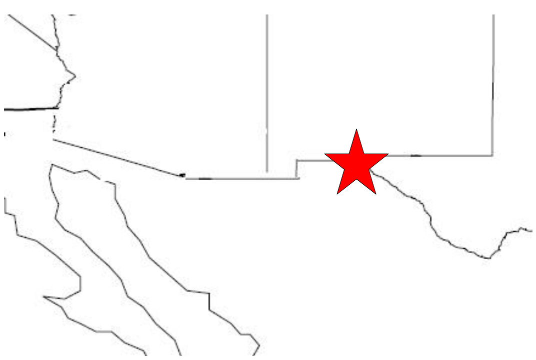

Figure 1. Location of the *Paso del Norte* metropolitan area in North America.

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The *risk* for a natural *disaster* is the combination of a population's exposure to a natural *hazard* and *vulnerability* to that hazard, *i.e.* the ability to anticipate, respond to, and recover from the hazard. A *natural hazard* becomes a *natural disaster* when it disrupts human socio-economic activity (Feng and Zhang, 2005). Extreme hydrometeorological events are especially prone to provoke disasters because they cover much larger scales of space and time than other geological hazards (Leroy, 2006).

Geographic factors- both physical and socioeconomic- are illustrated in the *Paso del Norte* with recent cases of catastrophic flash flooding, which have shown a much greater propensity for damage to Ciudad Juárez than to El Paso, even though they are part of the same urban area and experience the same meteorological events. The topographic and socioeconomic complexity of the area also creates complexities in the relative impacts of flooding.

2. PHYSICAL FACTORS

This relationship between hazard and disaster is illustrated in the *Paso del Norte* with the cases of the catastrophic flooding of early August 2006, and to a lesser extent with flash flooding associated with tropical cyclone Dolly's remnants in July 2008.

In what is locally known as "the Storm of 2006" (Figure 2), from 27 July to 4 August, 2006, El Paso International Airport (ELP) received 17.4 cm of rain, or about ¾ of its annual average precipitation in less than eight days: some neighborhoods in the West Side of El Paso received about 24 cm of rain in <8 hr on 1 August. Heavy rains continued through the summer monsoon: 3 of the top 16 heavy rain events over a 130- year period in El Paso happened within a five- week period in summer 2006, making July- September 2006 the wettest three-month period in El Paso since records began being kept in 1878 and the first time in the period that El Paso has received >7.5 cm of rain in three consecutive months (Gill and Novlan, 2007). Flash flooding and river flooding occurred numerous times during the period.

Figure 2. Street sign in El Paso documenting area of “Storm 2006” reconstruction.

More recently, on the morning of 26 July, 2008, decaying tropical cyclone Dolly passed directly over the Paso del Norte (Figure 3), producing 4.8 cm of rain at El Paso International Airport, 11.2 cm on the El Paso West Side, and 11.8 cm at the Ciudad Juárez airport.

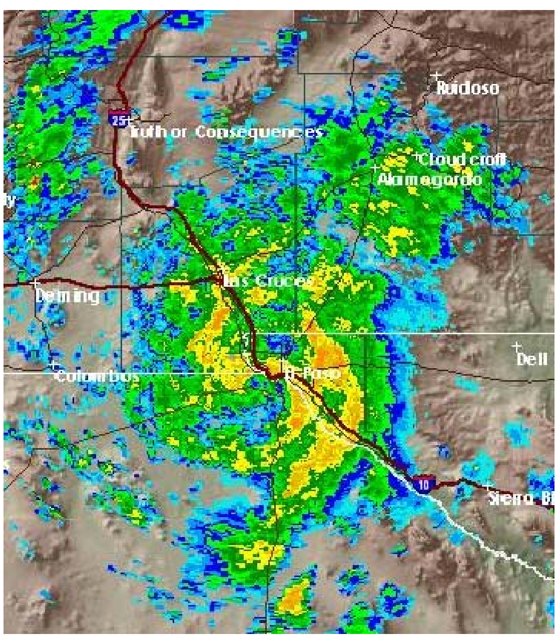

Figure 3. NEXRAD image of decaying tropical cyclone Dolly directly over the Paso del Norte, 8:21 AM local time July 26, 2008.

In both of these events, much higher rainfall totals in El Paso were reported from (the primarily residential) west slopes of the Franklin Mountains (as much as a 2x precipitation enhancement) due to orographic effects. Similar orographic enhancement of precipitation also likely was experienced by neighborhoods on the slopes of the *Sierra de Juárez*. Large arroyos in western El Paso (at the time, slated for housing development) began running with water for the first time in decades on 1 August, 2006. These flood waters quickly ran down to the more urbanized areas below and caused much damage.

During the peak of the 2006 event, the average return intervals (ARIs) for precipitation (as developed by the National Weather Service based on El Paso International Airport data, and used for planning purposes throughout El Paso) ranged from less than 1 year on time scales of ≤3 hr, 5 to 25 yr on time scales of 6 to 24 hr, and approximately 50 yr on time scales of 2 to 30 days (Gill and Novlan, 2007). However, if rainfall data from unofficial gauges on upper slopes of west El Paso (in the first author’s neighborhood and deemed credible) were applied to the ARIs developed from airport data (and used for the entire city), the “apparent” magnitude of the event would have been much higher. ARIs for the 2006 event based on these data would be ~50 to 200 yr on time scales of ≤2 hr, and >1000 years on time scales of 3 hr to 60 days (Gill and Novlan, 2007).

Short-term (≤24 hr) rainfall totals at the “official” rain gauge in both the 2006 and 2008 events would correspond to return periods of a few decades (2006) or a few years (2008), but in orographically- enhanced areas of the same city would correspond to return periods of a century or more. *Average recurrence interval curves based on airport data are not appropriate for flash flood hazard planning in neighborhoods <10 km away.* Orographic effects have not always been properly considered in the development of flood intensity/ duration/ frequency curves used for urban planning in El Paso and other mountain cities, causing an underassessment of flash flood risk in some neighborhoods and an exacerbation of monetary losses from flooding.

Recurrent heavy rain events (~30 to 40 cm / 9 days) during August and early

September 2006 led to river flooding in the *Paso del Norte:* the Rio Grande/ *Rio Bravo del Norte* flooded (Figure 4) five times during a five-week period (the first time since instrumental records started being kept that the river exceeded its banks in the *Paso del Norte* more than once in any single year), after not having flooded at all since 1958. Urban development in the floodplain has occurred in both cities in recent decades, putting the very low-lying areas (as well as the highlands) at a higher flood risk.

Figure 4. River flooding on the Rio Grande/ *Rio Bravo del Norte* just upstream of El Paso, August 2006 (National Weather Service photo)

2. SOCIOECONOMIC FACTORS

The *Paso del Norte* is one metropolitan area, in two nations (one in the global North, one in the global South) with different abilities to cope with flood hazards. For the same storm, there will be much greater flood risks, impacts, and longer lasting effects in Ciudad Juárez than in El Paso, due to socioeconomic factors. During the 2006 floods, no fatalities or serious injuries were reported in El Paso, while there were reports of several persons killed and numerous injuries in Ciudad Juárez.

On the United States side in El Paso, at least 1500 homes, approximately 20 drainage facilities and 100 roadways were damaged by the 2006 floods, with damage estimates of approximately US $200 million (Collins, in press). A federal disaster declaration was made. But on the Mexican side in Ciudad Juárez, approximately 5000 homes were damaged or destroyed, approximately 20,000 residents left homeless, and monetary damage exceeded US$600 million, which is more than twice the city's annual budget (Paterson, 2006). The higher impacts in Ciudad Juárez appeared to be to poorer construction and maintenance of the urban infrastructure. Similarly, during the floods of 2008 associated with Dolly, storm impacts to the infrastructure and economy were much greater in Ciudad Juárez than in El Paso, for the same reasons.

While flood impacts in El Paso County during summer 2006 justified the federal disaster declaration, monetary damage estimates in relation to local economic productivity suggest that the severity of the disaster was an order of magnitude greater in Ciudad Juárez than in El Paso (Collins, in press). Within El Paso County, the impacts of flooding were most severe and prospects for recovery worst for residents of *colonias* (informal unincorporated settlements).

One can look at the interaction of physical and socioeconomic factors on flood risk in the *Paso del Norte* by considering the differential impacts of residents living on steep slopes experiencing orographically-enhanced precipitation in each city. The neighborhoods built into the west side of the Franklin Mountains are some of the most affluent (and thus less economically- vulnerable) districts of El Paso (Figure 5). However, the slopes of the *Sierra de Juárez* are home to some of the most economically- marginalized (and thus most economically- vulnerable) residents of Ciudad Juárez (Figure 6). Therefore, the residents of some of the most dramatically flood-impacted neighborhoods in Ciudad Juárez had the fewest assets to invest in hazard reduction, mitigation and recovery, and the highest risk of impact from flash floods, while the residents of the portion of El Paso that received the heaviest precipitation and the most monetary damage from the floods suffered a relatively smaller impact.

Almost all high-income households in El Paso (which tend to be located in the highlands) and most moderate-income households had flood insurance to compensate for their losses, while less than one in five low-income households in El Paso (predominantly in the lowlands) did (Collins, in press). Within El Paso, many very-low-income neighborhoods in the lowlands (especially *colonias,* lacking many aspects of infrastructure), were disproportionately impacted by the flood of 2006.

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Figure 5. Neighborhood on the west slopes of the Franklin Mountains, El Paso.

Figure 6. Neighborhood on the slopes of the *Sierra de Juárez*, Ciudad Juárez.

4. CONCLUSIONS & RECOMMENDATIONS

The twin cities of El Paso, Texas, USA and Ciudad Juárez, Chihuahua, Mexico, comprising the single *Paso del Norte* metropolitan area, and their differing response to flash floods, illustrate the effects of geography on urban weather and climate. These effects are both physical and economic ("orographic" and "demographic").

In regions of complex terrain in western North America- where precipitation often falls as localized convective storms, is influenced by complex topography, and the density of rain gauges is limited, the use of airport rain data may not be appropriate for flood recurrence and intensity planning across a metropolitan area. Areal/temporal averaging and integration of recurrence intervals would be more representative and useful. Reconsideration and updating of recurrence interval planning is underway for El Paso.

There is an insufficient density of rainfall reporting stations in the *Paso del Norte* and likely in other urban areas of the mountainous West, given the spotty nature of convective storms, even within the monsoon. Single-station-based climatologies (and flash flood planning derived from them) are thus likely to be unreliable, causing an underassessment of risk in some neighborhoods and an exacerbation of monetary losses from flooding.

The urban environmental impacts of floods are more severe in Mexico than in neighboring cities in the USA; the severity of damage in Mexico is amplified by a reduced capacity for social protection. In the *Paso del Norte*, the disaster risk from flash flooding is much greater in Ciudad Juárez, due to the greater economic vulnerability on the Mexican (literal and global South) side of the river.

Floods in the *Paso del Norte* illustrate how both socioeconomic and physical factors can create highly variable risks for, and capacities to respond to, severe weather hazards within a single metropolitan area. This example supports the development of impact-based, rather than purely hazard-based, severe weather forecasting and planning, which is the envisioned platform of the future for the National Weather Service. Such a methodology would be especially effective for urban areas with high spatial variabilities in meteorology and/or economic development. Assessment metrics incorporating GIS and spatially variable risks and impacts, now used to evaluate other natural hazards (tornadoes, earthquakes, winter storms), could be appropriate tools for management and mitigation of urban flooding.

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