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When Engineering Solutions to Coastal Surge and Flooding Are Not Sufficient to Meet the Threat

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This study examines the threat and damage that coastal surge brings to Houston Metroplex and points out the importance of well-planned evacuation. In particular, the evacuation of several million people from a highly-populated area requires careful planning, coordination of resources, and precise direction from the leadership. Given widespread damages caused by severe weather over the past few decades to Houston Metroplex, the related authorities should work together to develop the orderly and coordinated evacuation plans so as to reduce loss of life and property.

Keywords: evacuation, coastal surge, flooding, disaster, Houston Metroplex.

Introduction

Throughout recorded weather history, the Houston Metroplex has experienced its share of severe weather in the form of hurricanes, tornadoes, and tropical storms.[1] When disaster strikes, there are priorities to consider. Foremost among those priorities is the safety and protection of human life; followed by preservation of infrastructure and industry. Infrastructure and industry are different from human life because they must be protected in place. Humans can remain in

[1] For the purposes of this document the Houston Metroplex is equal to the "Greater Houston Area" or the Houston Metropolitan Statistical Area (MSA). It is comprised of the following nine counties (numbers in the parentheses show population):

- Harris County (4,092,459).
- Fort Bend County (585,375).
- Montgomery County (455,746).
- Brazoria County (313,166).
- Galveston County (291,309).
- Liberty County (75,643).
- Waller County (43,205).
- Chambers County (35,096).
- Austin County (28,417).

And includes the following Metropolitan Areas:

- Houston (2,242,193).
- The Woodlands (109,679).
- Sugar Land (80,704).
- Baytown (70,330).
- Conroe (71,592).

place, or they can be moved out of harm's way as necessary. Likewise, a solution that protects infrastructure and industry may not be the best solution for humans.

Houston and the Metroplex

Demographics

- The Greater Houston Metroplex is the fifth largest metropolitan area in the United States with a population in excess of 6,500,000.
- The gross metropolitan product (GMP) in 2012 of the Metroplex MSM was $449 billion, fourth largest in the United States, making it a major industrial player.
- About 25% of the petroleum products consumed in the United States are processed within the Metroplex.
- Home to three major seaports, the ports of Houston, Texas City and Galveston, makes the Metroplex one of the most important shipping hubs in the world.
- The Texas Medical Center is the largest medical center in the world.
- Galveston is home to one of the two biocontainment labs in the United States.

Thus, the Houston Metroplex ranks high in all three areas of strategic concern - population, infrastructure, and industry.

Houston Metroplex – Severe Weather History

Since 1980, more than 70 hurricanes and tropical storms have impacted Texas. Thirteen major storms have directly impacted the Houston Metroplex; 3 storms resulted in significant storm surge.
In any type of coastal cyclonic event, the principal threats involved include coastal surge, rainfall flooding, and wind.

Hurricane Alicia in August, 1983, came ashore 25 mi. south of Galveston as a Category 3 hurricane. Alicia had a broad front extending out 125 mi. from the center, with maximum winds of 115 mph. The highest recorded tides occurred in Baytown, Texas at 10-12 feet, not particularly significant for tidal surge. Most of the surge damage occurred in areas not protected by the Galveston seawall. The storm worked its way north up the I-45 corridor into downtown Houston, and north from there. Twenty-three tornadoes were spawned by the storm in the Galveston and Houston areas, all in the F2 category. Rainfall in the Metroplex averaged 8-11 inches. Away from the immediate coastal area, most of the damage was caused by strong winds and rain.

Despite early hurricane warnings being issued for the area from Corpus Christi, Texas to Morgan Point, Louisiana, and an early evacuation order for the low-lying areas, most residents did not take the threat seriously and only about 10% evacuated. As the storm became more intense, Galveston's mayor ordered a full-scale evacuation, but by then the bridges to the mainland were impassible making evacuation impossible. Twenty-one people died and the area suffered $2.6 billion in damage.

Hurricane Ike in 2008, made landfall as a Category 2 hurricane. Storm surge of 20 feet above normal tide occurred the coast from Galveston along the Bolivar Peninsula. Approximately 113 fatalities occurred in the UNITED STATES Property damage exceeded $24.9 billion.

Coastal Surge

History shows that coastal surge is a matter of concern and a force that is not entirely understood or respected. In the case of the Houston Metroplex, several efforts are currently underway with the purpose of mitigating the effects of storm surge in the coastal area.

SSpeed

Rice University's Severe Storm Prediction, Education & Evacuation from Disasters (SSpeed) Center, formed in 2007, has proposed a moveable gate structure system across the lower San Jacinto River to, "...prevent the upstream propagation of a storm surge from Galveston Bay."

Ike Dike

Texas A&M University at Galveston has proposed the Ike Dike, a coastal barrier system extending across Galveston Island and the Bolivar Peninsula, theoretically protecting the Metroplex from coastal surge.

Both projects stress the national security implications, preservation of the Houston Ship Channel and its commerce, which would be addressed by their implementation. They are in the developmental stage, seeking support and funding. There is no question but that these are potentially worthwhile projects in terms of lessening the effects of coastal surge. That said, not all storm events that occur in the Texas Gulf area, come from offshore or create tidal surge.

Severe Weather – Meeting and Managing the Threat

In June, 2001, the Houston area experienced Tropical Storm (TS) Allison, one of the "brown ocean effect" storms that linger over land for protracted periods of time dumping large amounts of rain in a given area. TS Allison remained over the southeast Texas area more than 14 days dropping over 40" of rain. Flooding over 70,000 homes, $9 billion in damage, and resulting in 23 deaths before it moved on to the Northeastern U.S. Along the Texas coast, the preponderance of the damage was caused by flash flooding. As the storm formed, a voluntary evacuation was issued for the western end of Galveston Island. As the storm progressed, local evacuation operations took place in the areas affected by tributary flooding. Allison is ranked as the costliest tropical storm on record in the United States, and the second deadliest tropical storm in history.

Photo: Wikimedia

According to the Harris County Flood Control District website:

> FLOODING IS OUR NATURAL DISASTER
> Harris County doesn't have earthquakes... doesn't have blizzards... doesn't have avalanches. We have flooding. A major flood still occurs somewhere in Harris County about every two years. Most of the flooding is in areas developed prior to the current understanding of flood potential and prior to regulations restricting construction in flood-prone areas. Fortunately, since the 1970's, there has been flood insurance to ease the financial impact of flooding. Despite tremendous flood damage reduction projects that have indeed reduced the risk of flooding, more flood insurance funds have been paid here than in any other National Flood Insurance Program-participating community.

The Question – To evacuate or not evacuate

As well-intentioned as the efforts to control and dissipate storm surge are, events sometimes occur that are beyond their influence. Concentrated rainfall, flooding, flash flooding, wind, fire, and the after effects of those events are the phenomena that present the greatest threat to humans. There are times when circumstances dictate that the prudent action to avoid serious injury or even death is flight – Evacuation.

In disaster response & evacuation, a proactive response is better than a reactive response (saves more lives, more easily accomplished, more cost effective)

Mass evacuation requires detailed planning, constant training, as well as close coordination and precise execution.

Hurricane Rita

During the day on Tuesday, September 20, 2005, experienced Texas hurricane watchers and interested parties began to take note of Hurricane Rita as it entered the Gulf of Mexico (GOM) on a generally westerly course. Rita had formed as a hurricane in the Bahamas on Sunday, September 18. It had drifted on a westerly course, passing through the Florida Straits, and entering the GOM.

Just three weeks prior, on August 29, Hurricane Katrina made landfall as a Category 3 hurricane, southeast of New Orleans causing 1245 deaths and property damage in excess of $108 Billion. More than 1 million people were displaced and fled to other areas – over 375,000 to Texas alone. Local, state, and federal authorities were struggling with housing and caring for the evacuees, no small task.

In the case of Rita, there were differences of opinion and different predictions as to what course the storm would take and the potential severity – threat- of the storm itself. As a matter of caution, Gov. Perry declared Texas a disaster area. The State Emergency Operations Center 'stood up' on 24-hour watch status. A request for a declaration was made to the White House, but was not immediately acted on. FEMA Region VI was still overwhelmed by the aftermath of Katrina.

As it reached the warmer waters, Rita increased in intensity to 180 MPH. At that point it began to cool and act erratically, making a slow turn to the northwest. The predictions were erratic. On Wednesday, September 21, NWS/NHC forecast track did not look good for Houston. The Wednesday 10:00 PM forecast projected a near direct hit on Houston predicted to occur early on Saturday morning. The predicted storm track from Houston, was north, running essentially parallel to the I-45 corridor.

On that same day, a mandatory evacuation by 6:00 PM was ordered for citizens of Galveston County involving a population of 267,000. Arrangements were made to evacuate citizens without transportation in a bus convoy of approximately 80 buses and take them to shelters in the Huntsville area. At the same time, officials in Houston had decided against a mandatory evacuation but encouraged people living as far inland from the coast as 35 miles to voluntarily evacuate. Simultaneously, residents of other nearby areas, with the memories of the New Orleans Katrina experience fresh in their mind, made the decision to evacuate on their own. Unfortunately, but not surprisingly, different entities reacted on their own initiative, without consultation or coordination with adjoining entities.

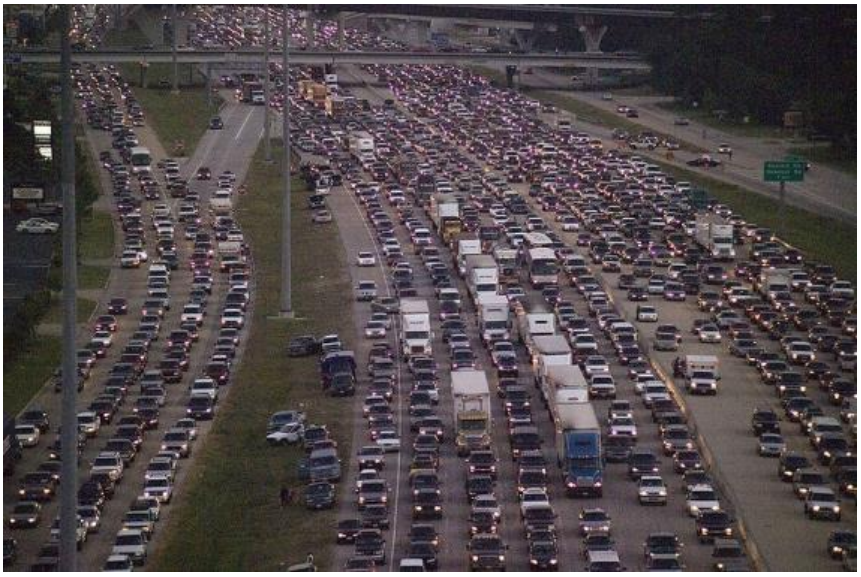
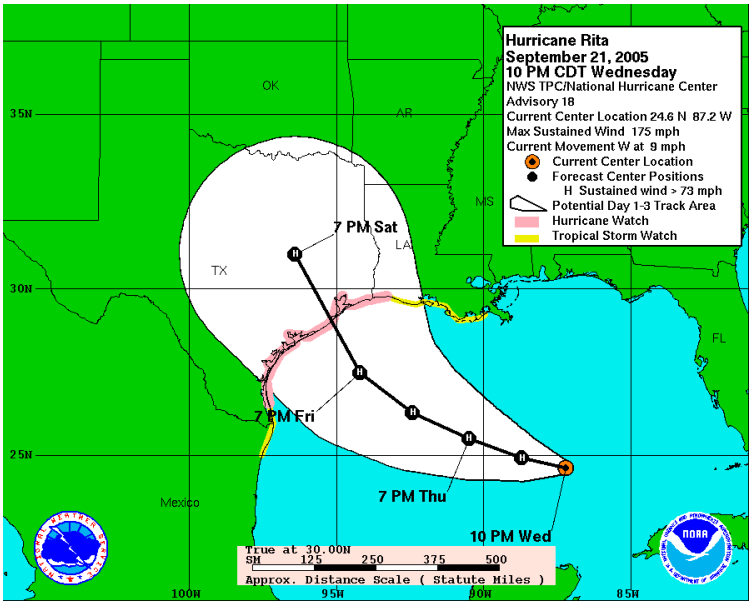


Photo: Population Reference Bureau

By early afternoon on Wednesday, September 21, traffic on I-45 to Dallas, U.S. 59 to Northeast Texas, U.S. 290 to Austin, and I-10 to San Antonio were at, or close to, maximum capacity outbound from Houston. Science writer Eric Berger had the following to say retrospectively in the Houston Chronicle:

> *"Some people may think Houston overreacted to Hurricane Rita, but I don't. That storm scared the bejesus out of me. I still remember seeing the latest forecasts roll in on Wednesday night, September 21st. The graphic below came from* ***the National Hurricane Center*** *that night, showing a "perfect storm" for Houston. At the time Rita had maximum sustained winds of an astonishing 175 MPH*

Forecast for Hurricane Rita at 10 PM CT, Wednesday, September 21. (NOAA)



> *This track represented a worst-case scenario for Houston, with the stronger northeast quadrant of the storm pushing a massive wall of water into Galveston Bay and up the Houston Ship Channel into the heart of the region's chemical industrial complex. The strongest winds would travel directly up the densely-populated Interstate 45 corridor. That night I was suitably (and uncharacteristically)* ***freaked out****: The* ***current track*** *for Rita is just about as bad as you could imagine for the Houston-Galveston area. Unless the storm turns south or north in the next 24 to 48 hours we are set up for a truly horrific event. I am not going to sugar-coat this, my friends. If the storm comes ashore as forecast, it would essentially be the worst-case scenario described* ***here****. As a Houston resident and property owner, I am truly mortified right now. If you are under a mandatory evacuation order, you should heed it. What ensued next, of course, was mayhem."*

As KXII Fox 12 pointed out, "The Houston area's geography makes evacuation particularly tricky. Unlike other hurricane-prone cities where the big city is on the coast, Houston is 60 miles inland. So, a coastal suburban area of 2 million people has to evacuate through a metropolitan area of nearly 4 million."

In the Rita situation, the primary evacuation route from Houston was I-45-N to north Texas. The secondary routes were US-59 N to northeast Texas, US-290 to Austin, and I-10 W to San Antonio. I-10 E to New Orleans was not considered to be an attractive option in the aftermath of Hurricane Katrina except by some people who had evacuated to Houston from Louisiana in the aftermath of Hurricane Katrina. That, exactly, was the crux of the situation and a problem of mammoth proportions.

Making the situation even more complicated, there was a lack of adequate communication between Galveston County officials and agencies in Harris, Montgomery and Waller Counties which left the transient (pass through) counties unaware and unprepared for the onslaught of motorists. By mid-afternoon, Wednesday, September. 21, I-45 was essentially a parking lot stretching from Galveston, north to Huntsville and further north toward Dallas. As time went on, the situation worsened as traffic increased, cars became disabled or ran out of gas, accidents occurred, people became ill and unable to continue their trips. Services along the primary evacuation route ran out of supplies and could no longer serve the public. Re-supply was out of the question. The first responder community, including police, fire and EMS personnel were overwhelmed. Secondary services diminished and then failed completely.

The overall scene stretching from Galveston to, and through, Houston to the northeast, north, northwest, and west along the four major and numerous secondary evacuation routes became so chaotic and confused that any meaningful sense of situational awareness was lost except in a few select locations where the authorities had planned and prepared for this type of eventuality.

This was the situation at midnight, Friday night, as Hurricane Rita approached the Texas coast with Houston dead in its sights. As typically happens in such situations, when the storm front impacted with the coast, the storm slowed down and nearly stalled. Eventually, it weakened slightly due to shore effect and started acting erratically. In one sweep of the weather radar, Rita deviated about 3 degrees to the right and made landfall in the area of Sabine Pass shortly after midnight on Saturday morning. It then proceeded on a northerly course roughly parallel to the Texas-Louisiana border.

It was later estimated that had Rita not shifted course at the last minute, that approximately 85,000 people along the I-45 corridor would have been its victims. All things considered, the Hurricane Rita evacuation was not done well.

Lesson #1 – *The evacuation of several million people from a highly-populated area requires careful planning, coordination of resources, and precise direction from the leadership*.

Evacuation - The Ultimate People Solution

While engineering solutions are important in consideration of all strategic concerns, ultimately the safety of human life trumps all other considerations. History has shown time and time again that some events in life are so threatening to the health and safety of human beings, they must leave their domiciles, either on their own initiative or under direction from government officials, and move to safe haven – evacuation.

Sometimes, evacuation is a matter of moving people away from a localized threat, such as a flooding stream, to near-by high ground. Other occasions, such as oncoming hurricanes, forest fires, etc., require a more complex evacuation process. Regardless of whether an evacuation is a local evacuation or one of higher magnitude, there is no such thing as a simple evacuation.

Photo: Alison Nissen

Evacuation, even under the best of circumstances, is a complicated process fraught with problems and complications. People under stress do not like to leave their homes and possessions. They often do not have a place of sanctuary or means of support. Frequently, they do not have transportation. The fear of the unknown prevails. Evacuation, particularly those that involve rescue, can be a very scary experience. Statistically, one out of five evacuees suffers from medical issues requiring medication and/or professional medical attention, a major complication.

Photo: Reuters/ Tim Johnson

Local History of Evacuation

The first recorded evacuation in Texas occurred in 1900 during the Great Galveston Hurricane when virtually all of Galveston Island was evacuated. There have been 19 recorded evacuations of some level in the Houston Metroplex since the 1900 Galveston storm. The Houston Metroplex experience with large scale evacuations is not unlike other similar areas in the United States. The most notable examples are the Hurricane Rita evacuation in 2005 and the Hurricane Ike evacuation in 2008.

Hurricane Rita Evacuation

The Hurricane Rita evacuation suffered serious problems. Pre-planning by the responsible parties proved to be insufficient and ineffective. Communication and coordination between the principal stakeholders (City of Galveston, Galveston County, City of Houston, and Harris County) did not occur as it should have. Communication between the players in the Metroplex and Texas Division of Emergency Management (TDEM) was sparse.

Photo: AP

2016 Spring Storms

During the months of April, May, and June 2016, the Houston Metroplex experienced a number of prolonged inland storms that dumped as much as 20 inches of rain on the Metroplex area resulting in extensive flooding in areas adjacent to major and minor tributaries that flow through the area. Sub-divisions in those areas suffered moderate to severe flooding, necessitating local evacuations and swift water rescue operations. During April alone, more than 1800 high water rescues were conducted in Harris County. To the extent possible, inhabitants of the affected subdivisions has been evacuated before the flooding occurred.

The Dynamics of Evacuation

Evacuation, regardless of size, is a component of Incident Command, and it is usually early in any disaster. It may, or may not, involve rescue operations. Time is of the essence – Human lives are at risk.

- Serious pre-planning and training are essential to success.
- Coordination.
- Situational Awareness.
- Communications.

A Houston Metroplex Solution

Geographically, the Metroplex covers an area totaling 10,062 sq. mi., a large area with a heavily distributed population. Currently, within the Metroplex, the level of coordination between the various counties involved is not as robust as it should be. Some coordination exists, but not at an optimum level to achieve an ideal solution. This is an organizational issue that can be solved by the government leaders and emergency managers involved agreeing to build a consensus organization.

The disaster evacuation command and control (C^2) function across the nine member counties in the Metroplex is bifurcated to the point that it impacts negatively on the mission. The evacuation protocols in the Houston Metroplex require a careful re-examination in the form of a requirements study. Houston and East Texas have equally as much, if not more, experience with storm evacuations as any other U.S. entity. The potential exists for the Metroplex to build a model evacuation system.

In a normal C^2 situation, this situation would call for a conveniently-located central command center from which the evacuation function would be directed. In this instance, that arrangement would be impractical. In times of turmoil, county and municipal leaders rightfully want to operate from their respective emergency operations center, their home turf.

Sometimes the event itself makes travel to a central location impossible as Houston's mayor discovered during the 2016 spring storms when he was unable to travel from City Hall to TranStar in West Houston for a press conference. The other disaster recovery functions are best controlled in a county-by-county environment.

In the envisioned scenario, a Central Coordination Center (CCC) would serve an intelligence function to gather, analyze, and disseminate storm information to all interested parties; in order to establish and maintain situation awareness; but not operate as a command center, that function being left in place in each county.

A recent survey of the Metroplex stakeholders by the Hobby School showed that there is an abundance of communications infrastructure dedicated to the disaster recovery mission. However, as is the case with coordination, the communications structure is primarily vertical

(stove piped) within agencies and entities, and lacks horizontal connectivity with other entities and agencies. What would a regional disaster coordination center look like?

Model - Southeast Texas Regional Disaster Coordination Center

- Considerations
  - Facility Features
    - Survivability
    - Security
    - Sustainability
    - Interoperability
    - Flexibility
    - Co-locate with TranStar?

- Located as geographically-central as possible
  - In a low flood-risk area
  - Hardened Facility (address storm, man-made threat)
  - Easy access to Class 1 road system
  - Robust communication hub
    - Radio
    - Intranet
    - Internet
    - Traffic Cameras
    - Video Teleconferencing
  - A robust enterprise network (voice, data, Internet, video teleconferencing) linking the individual county Emergency Operations Centers (EOC) as well as other involved parties and entities (TRANSTAR, NOAA, DPS, Medical Center, etc.).
  - Expansion of the highway camera system to completely cover the major highways in all nine Metroplex counties.
  - Project participation by weather services (Weather Underground, the Weather Channel, AccuWeather).
  - Control remains at the city/ county/ state level.
  - Center serves as coordinator of intelligence information (collect, analyze, disseminate); operational coordination between entities link to media and the public, resource locator.

- Connectivity:
  - Law Enforcement, Fire, EMS, OEM
  - TranStar
  - Public utilities
  - NOAA / NHC / SPC
  - Medical Facilities
  - TX DPS / DEM
  - TXDOT
  - Transportation Hubs (Airport, seaport, surface transportation)
  - Vehicle towing & maintenance
  - FBI

- DHS
- Coast Guard
- FAA
- Fuel Supply
- Media

Other Input

If properly supported, all of the improvements discussed in this document are candidate for federal grant funding.