"Weathering the Storm: Improving Hurricane Resiliency Through Research"
Hearing before the Subcommittee on the Environment of the House Committee on Science, Space and Technology
Testimony of Jim Blackburn, SSPEED Center, Rice University
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1. Overview of the Interdisciplinary work we do at SSPEED Center

The Severe Storm Prediction, Education and Evacuation from Disaster (SSPEED) Center is an interdisciplinary research entity formed at Rice University in 2007 that is dedicated to researching hurricanes and severe rainfall events. Our focus has been on hurricane surge and large rain events; we are not focused on wind damage at this time. The SSPEED Center brings in researchers not only from around the Rice campus but from several other universities, including the University of Houston, the University of Texas, Louisiana State University and Texas A&M University, as well as private consultants as needed. The Center includes engineers, architects, environmental scientists, economists and legal and political science researchers. Most of the funding for the SSPEED Center's research has come from private sources, such as the Houston Endowment; thus, our research has been primarily focused on flooding issues in the Houston area. We have been working on addressing urban flooding problems in Houston, especially since Hurricane Harvey (2017), and have been working on coastal resilience issues since Hurricane Ike (2008). We have published over 50 peer-reviewed papers since 2010 regarding various aspects of our research, and the SSPEED Center has hosted conferences, workshops and

seminars to bring in experts from around the world to collaborate and help provide a better understanding of the issues and potential solutions.

2. How We Can Build Resilience to Storm Impacts

Building resilience to adverse impacts from surge and rain events is a very difficult issue. First, one has to define resilience, which I consider to be the ability to withstand impacts, being not only to absorb but also recover, to "spring back into shape". In SSPEED Center's initial work after Hurricane Ike, we were all struck by the difference between the impact of Ike's surge on human development near Galveston on the Bolivar Peninsula , which was devastated, as compared to the adjacent natural marsh and prairie ecosystems, which were inundated up to twenty miles inland and recovered relatively quickly.

These natural systems are resilient because they have evolved to survive and rebound from inundation. We made an early decision that from a non-structural flood damage reduction standpoint, we needed to encourage economic solutions that recognized the value of our coastal marshes and prairies because on the Texas coast, regulation to protect these areas is not likely to happen. We believed that if we could create monetary benefits from maintaining, enhancing or creating such resilient land uses, then we would be heading in the right direction. These economic solutions will be discussed further in Sections 3 and 4 below.

Second, a point of resilience relating to "living with water" evolved from Hurricane Harvey as well as many earlier large rain events

in the Houston region. I doubt that any city in the world can "control" the flooding generated by a Harvey-like storm that dumped 40 to 50 inches of rain in 4 days. We can, however, minimize the damage from such storms by making more room for water in our communities. In Houston, we have tried to limit the expanse of our channels and bayou flood plains to maximize development immediately adjacent to them. Over time, this has proven to be unwise; we will need to move back development from the water's edge, providing more room for the water and letting the bayous flood along their physical floodplains. The Dutch, who many consider to be the best flood protection thinkers in the world, have made a similar decision to "make room for the river" in their more recent projects. Flood water must be treated differently than in the past. We cannot banish it. We simply must expand the area "dedicated to water". That will generate land use consequences that are discussed in Section 4 below.

Third, for us here in Houston to become resilient, we must address coastal surge flooding in the Houston-Galveston area, which threatens the largest refining and chemical complex in the United States. The 2.2 million barrels of refining capacity and 200+ chemical plants on the west side of Galveston Bay are very much at risk from the large storms we are starting to see. This infrastructure represents 13% of U.S. refining capacity and almost 27% of the jet fuel capacity of the United States. This is a bona fide national security issue not adequately addressed by current methodologies (see Section 4), and this critical infrastructure is not going to be able to just move from harm's way. The industrial complex along the Houston Ship Channel and Galveston Bay has to be protected with structural solutions if it is going to survive the next several decades. Just as important is the need to protect the

approximate 800,000 people living adjacent to the western shoreline of Galveston Bay, many of whom work at these plants. The western bay area potentially inundated by storm surge from a weak Category 4 hurricane (also known as FEMA Storm 36) is shown in Figure 1.

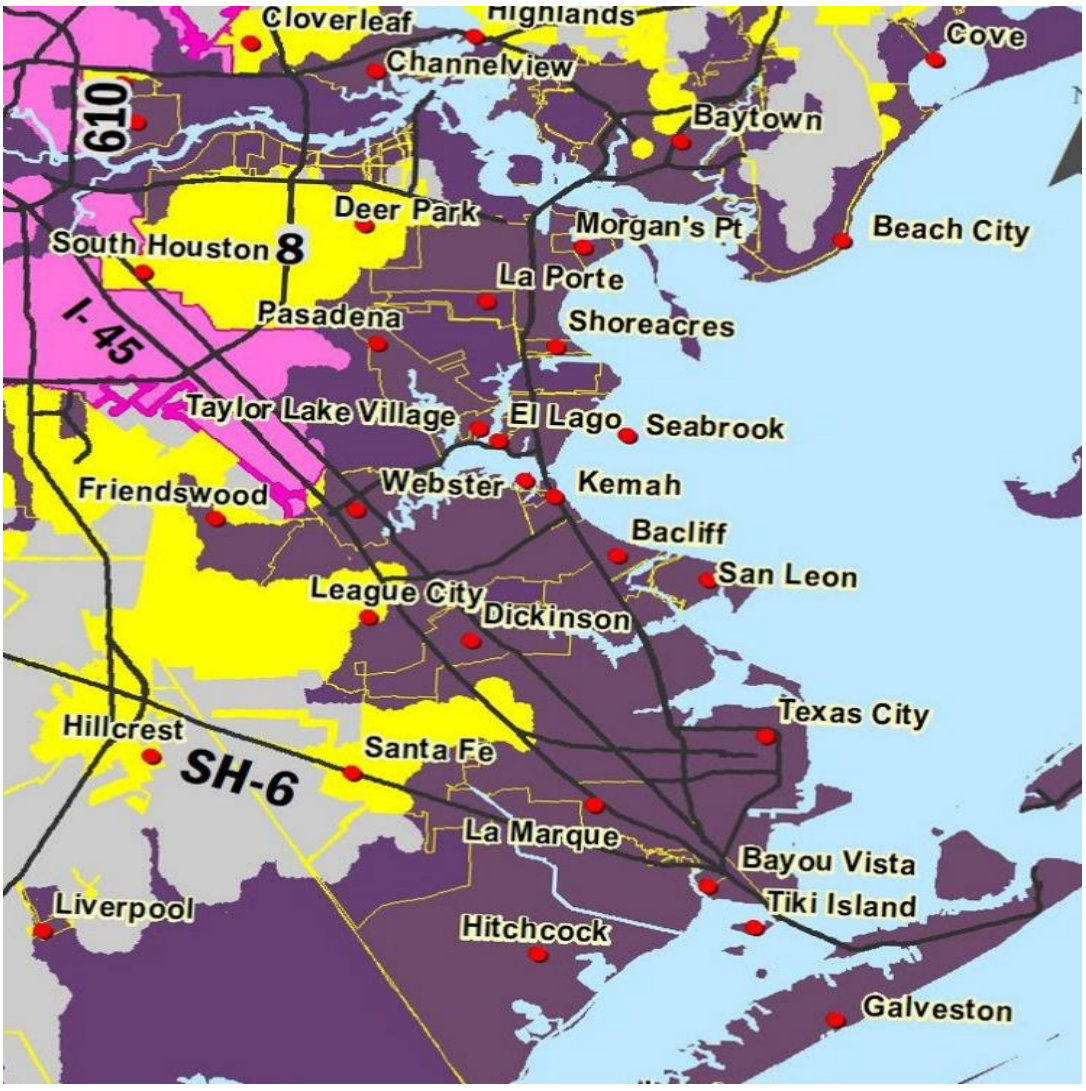

Figure 1. The projected inundated area (in purple) from a weak Cat 4 (FEMA Storm 36) coming ashore at the worst location for Houston. (Computer modeling from SSPEED Center; graphic by Christina Walsh for the author.)

Such a hurricane's storm surge would inundate the area shown in purple , including the western bay cities that are identified and the refining and chemical complexes up the Houston Ship Channel (top center), the Bayport complex (north of Taylor Lake Village and El Lago) and the Texas City industrial complex. Areas shown in yellow are the portions of incorporated cities not flooded by this surge, the pink area is that part of the City of Houston also not flooded by this surge and the light grey is unincorporated areas not flooded by this surge.

In the case of the Houston Ship Channel (a federal navigation project), non-federal action may generate surge protection to a greater level than federal action will provide, an important piece of the resilience puzzle that is related to both the characterization of the risk and the flexibility of our evaluation tools. To this end, the SSPEED Center has proposed the Galveston Bay Park Plan, an in-bay surge protection system that is compatible with and supplemental to the Coastal Spine barrier recently proposed by the U.S. Army Corps of Engineers. Further discussion of this issue is set out in Sections 3 and 4 of this presentation.

Fourth, for humans to be resilient, we need vision, information and action. Vision includes mimicking nature where possible, "living with water" and protecting critical infrastructure and people from the big storms of the future. Good information is imperative to making sound decisions, yet it is lacking, if not absent, at least in the Houston region regarding issues such as the size of rain events and hurricanes in the future, flood detection and warning and public awareness and education. We often seem to skip this step of good information and go directly to "action", and that is a major resilience-related mistake from my perspective.

3. How to Mitigate these Storm Impacts

In order to mitigate the potential impacts from storm surge and heavy rains, a community should first develop a realistic vision for the future, then create and disseminate high quality information about those risks and solutions, and finally take specific action as quickly as possible given that some of these solutions may take a decade or more to implement.

Vision is important. We need to "see" a pathway forward. That pathway has to include an image of what it means to "live with water", particularly in our coastal areas and in major cities adjacent to river systems. But a realistic vision needs realistic information in order for us to understand how much water we need to plan for. Our lack of vision is only compounded by our failure to recognize that rainfall events are getting larger and more frequent, as evidenced by the chart below compiled by the Harris County Flood Control District (see Figure 2). The maximum rainfalls for various durations of time from four recent storms affecting the Houston area reveal our lack of understanding of our risks when they are compared to what meteorologists call the 100-year and 500-year rainfall amounts in Houston for these same durations. The 100-year and 500-year rainfall events (typically based on a 24-hour storm duration) are those utilized in the current 100-year floodplain maps from the Federal Emergency Management Agency (FEMA), including those we have here for the Houston area.

Likewise, Hurricanes Harvey, Irma and Maria, all from 2017, are among the most severe that we have experienced. We need to foresee these extreme events in the future and have an approach to our

development patterns that can accommodate these storms in areas such as the undeveloped land adjacent to the coast and in our floodplains, and an approach that can repel these waters for areas around our existing critical infrastructure and communities, perhaps creating a metaphor of the yin and yang of flood protection in the future.

Duration	Harvey August 2017	Allison June 2001	Tax Day April 2016	October 1994	100 Year Rain	500 Year Rain
1-hr	6.8	5.7	4.7	3.7	4.3 Inches	5.5 Inches
2-hr	11.9	9.9	7.3	4.7	5.7 inches	7.6 inches
3-hr	14.8	13.5	8.3	5.3	6.7 inches	9.2 inches
6-hr	18.9	21.2	13.9	7.2	8.9 inches	12.8 inches
12-hr	20.9	28.3	16.7	12.0	10.8 inches	15.5 inches
24-hr	25.6	28.4	17.4	20.9	13.2 inches	18.9 inches
2 days	35.2	28.5	17.5	23.1	14.5 inches	20.0 inches
4 days	47.7	38.5	N/A	28.9	15.9 inches	21.1 inches

Figure 2. Maximum Rainfall Amounts from Recent Storms affecting the Houston area compared to the FEMA 100-year and 500-year storm events. (Rainfall reports are from Jeff Lindner, Harris County Flood Control District.)

Information is the second key component to flood damage mitigation. We need the best possible understanding of the size and severity of our future storms. We cannot depend on the statistics of the past when we are seeing storm characteristics changing before us. When Tropical Storm Allison hit in 2001 with extraordinary rainfall amounts, our flood control district captioned their report “Off The Charts”, with some considering Allison to be a 10,000-year event. And then came the 2015 and 2016 Memorial Day, Tax Day and Halloween flood events, also very large rainfalls, followed by Harvey in 2017 which

went even further off the rainfall charts. Similarly, Hurricane Ike in 2008 had an unusually large wind field for "Category 2" level wind speeds, and thus exceeded projected storm surges for such a hurricane, causing the National Weather Service to add a surge estimate to the longstanding use of wind speed-based categories that is also based on wind field size. Unfortunately, future prediction of increasing hurricane statistics does not currently exist and will be further discussed in Section 4.

Action is needed in several areas. We must protect the critical infrastructure of the Houston Ship Channel, the Bayport Industrial complex and Texas City. The Coastal Spine that has been proposed by the U.S. Army Corps of Engineers is part of a coastal defense system for the Galveston Bay area, but that system, while certainly helpful, does not adequately protect these three refining and chemical centers and the nearby local communities from the larger storm events of the future and the surge generated within Galveston Bay behind the Coastal Spine. To address this situation, the SSPEED Center has developed an in-bay barrier system called the Galveston Bay Park Plan, a concept that combines the future widening of the Houston Ship Channel with additional flood protection by converting the dredged material into the building material for the in-bay barrier. That concept is shown in Figure 3.

Figure 3. The proposed Galveston Bay Park Plan (shown in the center of the image of Galveston Bay). Image from SSPEED Center by Rogers Partners.

This structural flood protection project will be constructed to a height of 25 feet above sea level and will utilize dredge material generated by the future widening of the Houston Ship Channel. Small craft navigation and water circulation gates are indicated by the five red lines and the red circle indicates the location of the deep-water navigation gate for tankers and container vessels. The green area is

beneficial use upland and marshland construction, and the created land mass is proposed for various human recreational activities.

In order to construct this project, a permit application is proposed to be submitted to the Corps of Engineers on behalf of one or more governmental entities. At this time, ongoing discussions are occurring with stakeholders such as the Port of Houston to determine their willingness to participate in this permit application to construct this project which has been determined by the Corps of Engineers to be compatible with their Coastal Spine proposal. This 25-foot in-bay barrier will require construction of various components, such as a levee, several gate structures including a major navigation gate, and raising the Texas City flood protection levee to 25 feet. It is anticipated that elements of the Coastal Spine, such as the newly proposed dune construction and back-side levee around the City of Galveston, could be proposed for early implementation by the Corps, while the type of structure for the large gate system across the Bolivar Roads pass connecting the bay with the Gulf is being reconsidered and redesigned to make it perform much better from an environmental impact standpoint. I want to commend the Corps for looking into making these modifications in their plan and look forward to working with them in the future as we attempt to implement these two project components of this regional surge protection system.

There are many other actions that need to take place in order to make the Houston area more resilient to major flood events. For example, the Addicks and Barker federal dams are two of the best flood control investments ever made in Houston, yet about ten years ago, the U.S. Army Corps of Engineers identified them as being 2 of the Corps' 6 dams nationally that were in danger of "catastrophic failure". This is a serious dam safety issue, with hundreds of thousands of human lives at

risk; this issue should have been immediately addressed back in 2009 when it was first discovered. While a portion of the various dam safety issues have been addressed, the disastrous flooding both upstream and downstream of those dams during Harvey (2017) re-enforced the need to address the remainder of the dam safety issues at these dams sooner rather than later.

We also need to move forward more quickly with the federally authorized projects on White Oak, Brays and Hunting Bayous, and Clear Creek, as Harvey also reminded us of their need. And while that does appear to be happening, it is worth noting that even though these actions will improve the current flooding situation, they will not adequately address the flooding problem because their design is outdated because the level of protection they were designed to deliver will be much lower due to our recently increased rainfall standards as set out in NOAA Atlas 14. Perhaps most importantly, we must understand the long-term implications of these increasing rainfall numbers and develop a better methodology to analyze them than is currently in place.

It is also important to have non-structural alternatives to complement these structural alternatives. Non-structural alternatives generally serve to incorporate more natural measures to reduce damage rather than to provide physical protection. In the work we have completed at the SSPEED Center, we focused on developing economic solutions that will pay landowners to keep their land natural and to even create economic development that is – by its nature – resilient. In this regard, two important options have been created – the Texas Coastal Exchange and the proposed Lone Star Coastal National Recreation Area.

The Texas Coastal Exchange has been developed as a private, non-profit organization that is focused on coastal protection and carbon sequestration. Initially, TCX will focus upon the areas of the Upper Texas coast, that are at or below elevation 20 feet which would make them subject to coastal surge flooding. In these areas, TCX is contacting landowners of marshes, coastal prairies and bottomland hardwoods that are, or could be, sequestering carbon dioxide. TCX is proposing to make grants to these landowners to protect their private lands and its carbon storage capacity and create a financial incentive to increase that potential over time. To obtain funding for these grants, TCX is offering the public of the Texas coast and the world the opportunity to donate an amount of money equivalent to the size of their carbon footprint based on the estimated value of that footprint. However, this is not a formal offset system, but rather a contribution to protect the various ecological services of the Texas coast, including flood storage, water supply enhancement, fish and wildlife enhancement and carbon sequestration. In this manner, landowners will receive income for protecting our coastal future, while storing floodwaters, among other things.

The second concept called the proposed Lone Star Coastal National Recreation Area (LSCNRA) involves working with the various owners of conservation lands along the upper Texas coast to better utilize these preserved areas to generate eco-tourism and economic development that is compatible with flooding. The upper Texas coast has hundreds of thousands of acres of national wildlife refuge land, state wildlife management areas, state parks, Corps of Engineers lands, county and city parks and non-governmental organization lands. These lands represent a national ecological resource that has significant

potential for eco-tourism, but there is literally little to no infrastructure or collaboration to support such tourism. To this end, non-governmental and civic organizations and local, state and federal agencies are working together in collaboration with the Lone Star Coastal Alliance. Through this collaboration, the Texas coast is on the verge of becoming a nationally and internationally known recreation venue, having an economic use that does not need extensive physical infrastructure, but rather utilizes nature and local business and talent, making it much more resilient to hurricane surge flooding.

The area of focus for these two non-structural projects is shown in Figure 4. The high-risk surge zone that is the initial focus of the Texas Coastal Exchange is shown in darker green and the conserved lands of the Texas coast that might participate in the Recreation Area are shown in lighter green. Together, these two projects will initiate a different type of economic development that will be much more resilient to hurricane surge, and it is being done by the private sector.

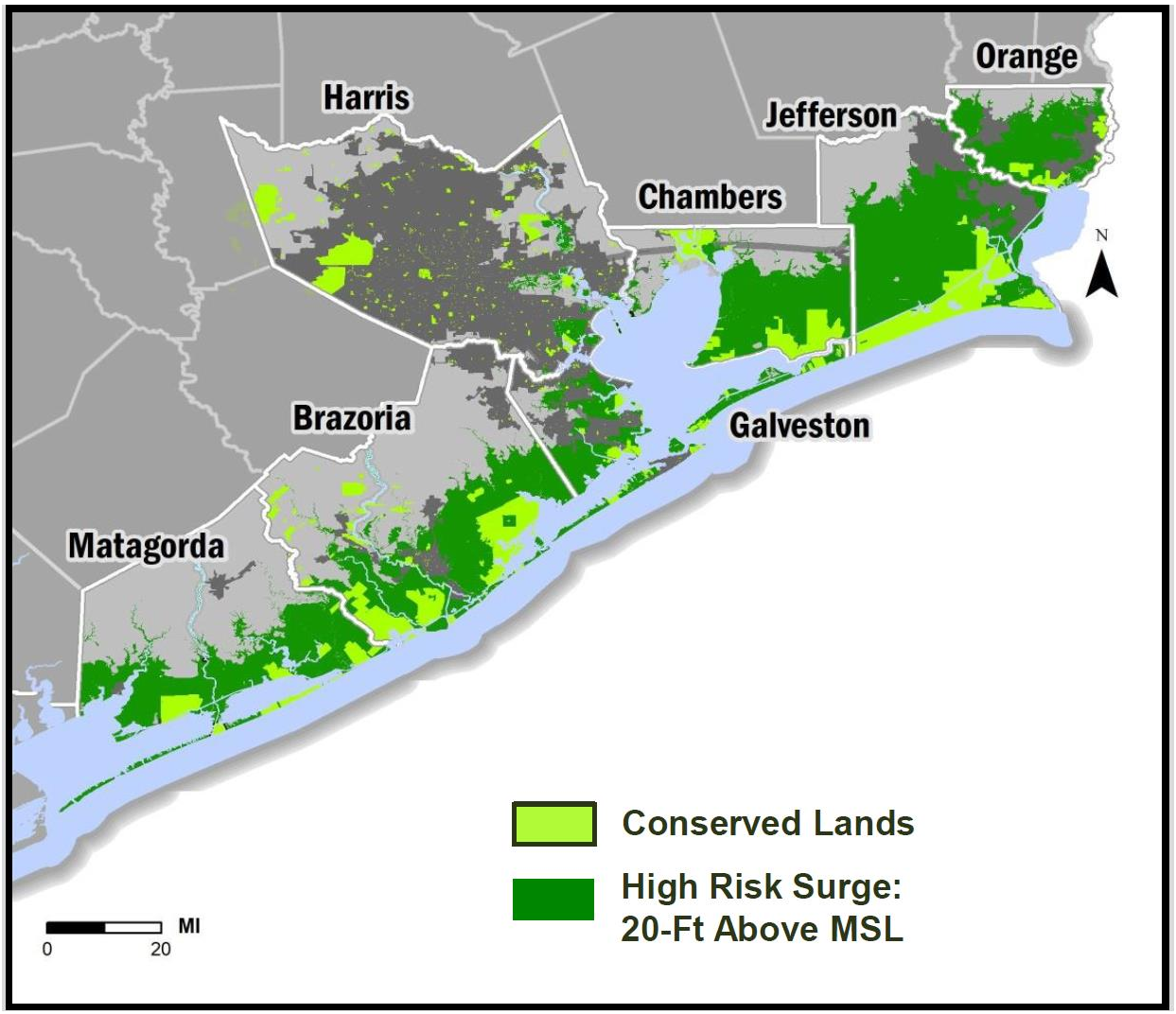

Figure 4. Seven-County Focus Area of SSPEED's Non-structural Flood Damage Reduction Projects. Image by Christina Walsh for the author.

4. How to Improve Hurricane and Coastal Resilience Research

There is a major role for hurricane-related research going forward in the United States and particularly along our coastal areas. Many of the tools we are using today are ill-suited to the storms that we are facing

today – storms much larger and more frequent than previously considered – storms that can destroy an entire industrial complex.

First and most importantly, we need to update our thinking on acceptable levels of risk, risk evaluation, risk avoidance and risk protection relative to flooding. Our storms are getting larger and more frequent. The statistics prove this, and NOAA's recently published Atlas 14 chronicles the fact. The methodologies currently used by engineers and governmental entities rely on past occurrences and past records that do not appropriately account for today's climate conditions. This research should involve a combination of statistical, economic and engineering research done in an interdisciplinary fashion rather than in silos. Our approach to project design for rainfall and surge flooding should be reconsidered and redone because these old methodologies are leading to solutions that are obsolete upon arrival.

Houston is a good example of an area having experienced multiple storm events, each considered as having greater than 500-year or 1,000-year frequency of occurrence, with all occurring within the last 20 years. It is not that solutions based on past determinations of the 100-year flood are not useful; they are. However, these studies and projects are not providing honest information to decision-makers and to the public about the residual risk once these projects are in place and about the need for multiple solutions, including difficult decisions such as buying out flood-prone housing which may be our most effective solution over time. Here, statisticians should be combined with sociologists and engineers and planners and governmental officials to determine risk and the appropriate related reaction that will have long term benefits.

From a climate-related standpoint, we need better projections of future rainfall events and future hurricanes and storm surge. Implicit in this call for research on future storms is that it requires acknowledging the fact that the climate is changing, and not for the better. Forget about why the climate is changing for the moment. The important point is that the climate is changing, and we cannot continue to ignore this fact in our research and in our project design.

In this regard, one serious concern is the potential for the overlap of major rainfall flooding with a major surge event as well. To date, the biggest rainfall events (Harvey, Allison and Claudette) in the Houston-Galveston area were tropical storms that did not produce large surges in our area. Going forward, we need to better understand the potential risk of both surge and rainfall flooding occurring simultaneously. Similarly, in New Orleans, the Mississippi River has been near flood stage for months due to unprecedented upstream rainfall. What is the potential for a surge event occurring while the Mississippi is at bank-full, a situation that has not occurred historically?

From a methodological standpoint, the Corps of Engineers is restricted by Standards and Principles, the rules that guide project decision-making. National Economic Development (NED) calculations are not sufficiently flexible to allow national-security related infrastructure to be protected against these future larger storms. Nuclear power plants, considered as "critical infrastructure", are provided with a much higher level of flood protection than the nation's refining and chemical manufacturing centers. Instead, under Corps procedures, more than one hundred hypothetical storms are averaged to determine the best economic decision for flood protection of these centers rather than protecting them against a certain sized or

recurrence-interval storm. This method can lead to major investment in undersized facilities, thereby failing to achieve either realistic protection or wise economic expenditure.

As stated in the text, the current floodplain maps for Harris County – and much of Texas – are obsolete and in the process of being updated. However, these changes will be based on statistics from decades ago through 2017. These new maps do not look at more recent events going forward, and thus will also be obsolete on arrival. With new methodologies for rainfall prediction, our maps could be anticipatory rather than lagging. This is important not only for the location of homes but also for the protection of hazardous waste treatment, storage and disposal facilities, municipal landfills and the appropriate construction of roads and highways. The infrastructure of the future is dependent upon getting the rainfall (and surge) used for planning and design calculations to be reflective of more recent events and the reality of our changing climate.

Similar reconsideration needs to occur with regard to coastal surge flooding. Current floodplain maps do not accurately depict the future risk of surge flooding. The larger storms of the future will send larger surge events into our coastal areas. We must anticipate this surge and provide high quality information as one of the first steps in developing the best damage prevention measures.

From a social standpoint, the issue of equity in flood protection is an important research topic. The National Economic Development (NED) methodology identified above focuses almost entirely upon economic benefits of a project being greater than the project costs. By such a focus on dollar benefits, a project might qualify for construction in a wealthy part of the community and might not qualify in a lower

income area, even if more people and homes would be benefitted in the lower income area. In this way, discriminatory patterns of federal investment can occur even though unintended. We believe that this situation has occurred in the Greens Bayou area in Houston, the second most populous watershed and among the lowest income areas. It has not qualified in the past for major federally-funded, structural flood protection. The better integration of social concerns into project selection methods is another important research area. Here, policy researchers should be united with sociologists and engineers to find new pathways.

Similarly, research is needed into the pairing of home buy-out programs with the provision of replacement housing. Buy-outs are likely to emerge as a major alternative throughout the Houston-Galveston region if not the United States. We simply will not be able to protect all of our current housing inventory from the storms of the future. Buy-outs are quick and very effective at removing people from harm's way. However, particularly in lower income areas, affordable replacement housing is usually lacking. These two issues must be linked, particularly in lower income areas. Here, architecture and urban planning research should be combined with sociologists and engineers to provide interdisciplinary guidance. In doing so, beneficial use can be provided in the abandoned areas with essential public places such as parks and nature preserves that are compatible with flooding.

From a slightly different perspective, it is important that we maintain and protect undeveloped coastal lands because they are resilient. Here, economic research into the dollar value of these natural lands like coastal wetlands, coastal prairies and coastal forests should be supported, particularly from the perspective of developing markets

for the ecological services provided by these lands. In Texas, much of this land is private property and many of the landowners wish to continue ranching. We should support economic and ecological research into increasing "cash-flow" to these coastal landowners, particularly in the development of a viable carbon dioxide transaction system that works for United States landowners. Similarly, research might be undertaken into diversion of some of the $20 billion in agricultural subsidies to ecological service payments for ranchers and coastal landowners who maintain natural ecosystems to the benefit of us all.

In the discussion above, attention has been focused on specific research areas. However, there is a need for general research into one major topic. We, as a country, need to learn to "live with water". Over recent human history, our settlement patterns have been based upon banishing water from our developed areas through engineering – through channels, underground conduits, dams and reservoirs. And while this infrastructure is very important, the rains of the future cannot be "controlled". No city in the world could have controlled the rainfall from Hurricane Harvey. It is more reasonable to think in terms of "managing" the rainfall from Harvey. However, that means that our concepts of development and developed areas must change a bit, particularly along the coastal areas of the United States.

Living with water involves dedicating a certain amount of land area to water – it means setting floodplains aside for flood waters. It means understanding how much land is required to accommodate the storms of the future. This research combines all of the elements identified above - statistics and risk assessment, hydrology, climatology,

engineering, architecture and urban design, economics, sociology - into a coherent concept of urban design for the future.

In summary, research is needed in the following areas:

(1) Acceptable levels of risk, risk evaluation, risk avoidance and risk protection relative to flooding and flood damage reduction projects;

(2) Better projections of future rainfall events, hurricanes and storm surges, in recognition of climate change;

(3) Potential for major rainfall-related flooding being combined with major surge flooding;

(4) Equity in flood protection, with integration of social concerns into project selection;

(5) Integrating home buy-out programs with provisions for replacement housing;

(6) Economic valuation of our natural, undeveloped coastal lands, including the development of markets for the ecological services they provide; and

(7) Learning to "live with water".

Thank you for inviting this testimony. If you need further information, please contact Jim Blackburn at blackbur@rice.edu.