HOUSTON FLOODING 3.5 YEARS AFTER HARVEY

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Introduction

Hurricane Harvey came ashore on August 25, 2017, and Houston and Harris County will never be the same after experiencing 48 inches of rain over four days. According to 20th century statistics, Harvey was perhaps a 50,000-year storm (meaning there was a one-in-50,000 chance of it occurring), yet we know this to be untrue in the 21st century, as flooding and extreme weather events are happening more often than probability predicts. We are not sure yet how to make sense of climate change, but we know our climate is changing. Such is the reality and the uncertainty upon which the future of Houston, relative to flooding, will be determined.

From the outset, it is important to note that many of our problems are self-inflicted. As Houston has expanded in almost all directions, we covered hundreds of thousands of acres with concrete and highly efficient drainage where there was previously very little. We converted natural sponges like the Katy Prairie above the Addicks and Barker Reservoirs and in upper Brays Bayou and upper White Oak Bayou and made them impermeable, generating much greater runoff than before. This increased runoff contributes to flooding in almost all our bayous. For decades we did not give this flooding problem the attention it deserved, but these problems cannot be ignored any longer. Our past mistakes, combined with a changing climate, have created our current flooding problem, and it is substantial.

One the one hand, there is much that is positive that has occurred since Hurricane/Tropical Storm Harvey flooded most of the Texas coast from the Louisiana border south to Corpus Christi. Harris County passed a $2.5 billion bond issue dedicated to flood abatement and drainage improvement. The federal government authorized four major channelization projects from the U.S. Army Corps of Engineers. Congress allocated over $2 billion for housing assistance to Harris County and the city of Houston. Work is unfolding on flood protection projects at an unprecedented rate. Positive actions indeed have occurred since over 160,000 homes were flooded during Hurricane Harvey.

Despite this progress, however, major concerns remain. In this paper, three major Harris County problem areas are discussed that exemplify the types of issues that make addressing flooding in Houston so difficult. These problem areas are (1) the difficulty in addressing flooding both above and below the Addicks and Barker Reservoirs, (2) the difficulty of relieving flooding in the low-income areas of northeast Houston/Harris County, and (3) the difficulty of protecting the Houston Ship Channel industries and residential, commercial, and industrial development on the east side of Houston. But, before addressing each of these specific areas, the issue of climate change and increasing storm intensity will be addressed.

I. Climate Change and Increasing Storm Intensity

The storms of the recent past are unprecedented, and our methodologies for predicting and using information about storms of the future are inadequate to the extent they exist at all. There are two types of flooding to consider. The first is rainfall flooding from either a tropical
system or from the passage of a frontal system. The second is flooding from a storm surge, which is related to hurricanes coming ashore. The former could occur almost anywhere, and the latter is restricted to the coastal areas. They are both important, but a storm surge is more likely to cause massive loss of life and extensive environmental contamination along the Texas coast as well as impairment of our regional and national economy.

The rainfall flooding issue is summarized by the information presented in Figure 1. Prior to Hurricane/Tropical Storm Harvey, the 100-year and 500-year storm events for Harris County for a 24-hour time period were 13.2 and 18.9 inches of rainfall, respectively. After Harvey, the National Oceanic and Atmospheric Administration (NOAA) issued the NOAA Atlas 14, which provided an update of the rainfall statistics current through Harvey and the end of 2017. This document changed the 100-year and 500-year rainfall for Harris County to 17 and 25.4 inches for a 24-hour time period, respectively. This was significant, representing a 29% increase in the 100-year rainfall and a 34% increase in the 500-year rainfall. Despite this, scientists remain concerned that this increase was not large enough.

**Figure 1.** Current 100-Year, 500-Year, and NOAA Atlas 14 Rainfall for Various Recurrence Intervals and Data Reported by Harris County for Various Storm Events

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Source: The existing rainfall data is from the Federal Emergency Management Agency, the proposed 100-year and 500-year rainfall data is from the NOAA Atlas 14, and the rainfall data for Harris County was reported by Jeff Lindner from the Harris County Flood Control District.

The question is, are the proposed 100-year and 500-year storms from NOAA Atlas 14 large enough? Each of the five storms shown on this chart exceeded the NOAA Atlas 14’s 100-year rainfall, and two exceeded the 500-year rainfall amount. A study by Kerry Emmanuel of the Massachusetts Institute of Technology after Hurricane Harvey suggests that a 20+ inch rainfall event might have a recurrence interval once every five-and-a-half years by
This is quite concerning, as a 20+ inch rainfall under NOAA Atlas 14’s reconsideration is between a 100-year and 500-year event.

This new rainfall information raises several concerns. First, the current official 100-year floodplain for Harris County is still based upon 13 inches in 24 hours, which is obsolete yet still considered “official.” Both Harris County and the city of Houston have changed their regulations to require the use of the current 500-year event, which is a definite improvement, but state and federal agencies still use the current, obsolete 100-year floodplain for designing roads and other infrastructure elements and for pollution control programs, such as siting or protecting hazardous facilities located in the 100-year floodplain. The failure of the state and federal governments to make these adjustments is irresponsible and dangerous and should be addressed as soon as possible.

Secondly, as a region, state, and nation, we must begin to integrate these new rainfall projections into our flood-infrastructure thinking. As will be discussed in this paper, our current methodologies restrict our problem-solving ability by putting us in a box defined by past rainfall data. We must think outside of this box to solve the problems that are facing us today.

A similar problem exists with surge flooding. The Gulf Coast—from Freeport, Texas to Mobile, Alabama—is particularly susceptible to hurricane surge flooding due to the extent of the outer continental shelf that will cause an increase in surge flooding as storms move ashore. The concern is that relying only upon historic patterns and surge levels will lead to an underestimation of hurricane surges across the Gulf Coast and the East Coast of the United States.

Although the number of hurricanes appears to remain constant, multiple sources agree that hurricanes are getting larger. Category 4 and 5 storms are becoming more abundant, with the rate of increase reported to be 25% to 30% for each one-degree centigrade increase in temperature. Another source indicates that the number of Category 4 and 5 storms may double by 2100. These storms are also intensifying very rapidly as seen with Harvey (2017), Irma (2017), Maria (2017), and Laura (2020), to name a few. The destruction that could be brought by a Category 5 surge of 25 feet or more up the Houston Ship Channel would be horrifying, not to mention the environmental damage and loss of life it would incur.

We are not correctly anticipating these larger storms and currently give little to no warning to property owners, industry, or adjacent residents of the true risk that these storms represent. Scientists must develop methodologies for foreseeing the recurrence intervals of

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future storms and integrate these models into future planning. Without such tools, much of
the money being spent today on flood protection projects will not be nearly as effective as
it could be.

This issue of storm frequency is pervasive. It is a key element of the U.S. Army Corps of
Engineers’ benefit-cost methodology. It is a key element of the flood insurance program. It
is central to all flood-related policies and programs. If we do not get this adjusted and soon,
we will not be planning for the future—we will simply be planning for the past. With a
changing climate, that is a losing strategy.

II. Addicks and Barker Reservoirs in Houston

Addicks and Barker Reservoirs are two excellent flood control reservoirs constructed in the
mid-20th century. Built by the U.S. Army Corps of Engineers after major flooding in 1929
and 1935 in downtown Houston, these reservoirs have protected downtown Houston from
flooding for decades. These reservoirs and their watersheds are shown in Figure 2 as is the
proximity of Addicks Reservoir to Cypress Creek, which overflows into the Addicks
Reservoir watershed during severe storm events. However, there have always been
problems with these reservoirs. Initially, the condemnation process to obtain land for these
reservoirs became very political, leading to the legal process being stopped before all land
within the “flood pool” of the reservoir was obtained by the federal government. As a
result, if a large-design storm occurred, private property at the upper end of both
reservoirs would be inundated by the operation of the reservoir.
This situation became more serious when Houston’s growth extended westward beyond Addicks and Barker. Over time, much of the private property behind Addicks and Barker became developed. Today, there are about 20,000 homes located within the flood pool of Addicks and Barker Reservoirs. Additionally, about 50 governmental subdivisions known as utility districts exist either wholly or partially within the flood pool of the Addicks and Barker Reservoirs. These districts are formed to finance development by issuing bonds to finance construction of roads, sewer and water systems, and drainage systems. These bonds are repaid by taxes upon the development within their boundaries.

Until Hurricane Harvey, there had been no major flood problems with Addicks and Barker’s upstream neighbors. However, as early as 2008, dam safety concerns began to arise over the condition of the dirt levees at these reservoirs. Today, both dams are
classified as DSAC 1,\textsuperscript{4} meaning they are at risk of catastrophic failure as determined by the U.S. Army Corps of Engineers. Due, at least in part, to that classification, the operational plans for Addicks and Barker were altered to allow more releases downstream. To address this dam safety issue, the outlet structures have been replaced, but other structural repairs have not yet occurred.

Against this backdrop of development in the flood pool and concern about dam safety, Hurricane Harvey reformed in the Gulf of Mexico as a tropical storm on August 23, 2017. It became a Category 4 hurricane on August 24 and made landfall on August 25 near Rockport in the mid-Texas coastal region. Upon coming ashore, the storm stopped and reversed course and then meandered back up the coast as a tropical storm until finally coming ashore in western Louisiana on August 30. Harvey dumped between 40 and 50 inches of rain across the Houston region between August 25 and 29 and caused massive home flooding upstream on the Addicks and Barker Reservoirs and downstream as well. However, this flooding was not a surprise to the Corps, who internally had predicted this flooding (which occurred in the early morning hours of August 28) as early as August 24, with their flood predictions becoming more accurate each day until the actual flooding occurred. Why this information was not released to those who were flooded, both upstream and downstream, remains unclear.

Starting around August 28, many woke up to water in their homes. About 10,000 of 20,000 homes in the flood pool of the Addicks and Barker Reservoirs flooded, with several thousand more homes flooding downstream on the Buffalo Bayou below the dams. The areas flooded by Harvey and within the flood pool are shown on Figure 3 along with the various utility districts within which these homes lie.

\textsuperscript{4} The Dam Safety Action Classification System (DSAC) is intended to provide guidelines for appropriate actions to address dam safety issues and deficiencies. Dams are placed into a DSAC class based on their individual dam safety risk. For more information, see https://www.usace.army.mil/Missions/Civil-Works/Dam-Safety-Program/Program-Activities/.
Figure 3. Flooding Issues Behind Addicks and Barker Reservoirs

Note: The land owned by the federal government within Addicks and Barker Reservoirs is shown in light red. The darker red indicates the area where about 10,000 homes flooded during Harvey. The area in the darker blue is within the flood pool, but the homes therein were not flooded during Hurricane Harvey. The polygons shown in light green and extending down into the flood pools of Addicks and Barker are the utility districts.

Source: Image by Christina Walsh for Jim Blackburn.

Shortly after Harvey, many of the flood victims both upstream and downstream of Addicks and Barker contacted attorneys and filed suit against the government for an unconstitutional taking of property without due process of law. In 2019, the upstream landowners won in the U.S. Court of Federal Claims, which found that the U.S. Army Corps of Engineers had “taken a permanent flood easement.” The federal government must pay a yet-to-be-determined amount to these flooded homeowners for this easement, which is estimated to be between 80% and 90% of the value of the homes. The downstream case was decided against the homeowners who were flooded by releases from Addicks and Barker. That case currently is on appeal.
In the midst of this controversy over flooding and “takings,” the U.S. Army Corps of Engineers began a study under Section 216 of the Flood Control Act of 1970 to evaluate what action the Corps could undertake to address this problem that had been percolating for over 50 years. In October 2020, several months later than expected, this study, titled “Buffalo Bayou and Tributaries Resiliency Study, Texas,” was released as an interim feasibility report, a type of report seldom issued by the Corps and never issued in the history of Galveston District. This study was presented without the usual appendices and has been negatively received by the residents of Harris and Fort Bend Counties where these flood problems exist. Inherent in this Section 216 study are systemic problems that are likely to be encountered in every Corps district.

The report was poorly received at least in part because no solution was proposed by the Corps. Many alternatives exist and were considered including (1) buying out either the flooded homes or the flood pool, (2) digging out the 10,000 acres of federal land within Barker and Addicks to create more storage, (3) constructing one or more configurations of upstream reservoirs, (4) building a flood diversion tunnel from west of these reservoirs to the Houston Ship Channel, or (5) channelizing the Buffalo Bayou downstream of Addicks and Barker. While the report seemed to favor channelizing Buffalo Bayou and building a third reservoir upstream of the Addicks Reservoir, a careful reading of the document indicates that not one of these alternatives came close to meeting the U.S. Army Corps of Engineers’ national economic development (NED) criteria for a viable federal project. They all failed. If this NED criteria were strictly followed, there would be no relief available through the Corps of Engineers’ study, unless special exceptions were triggered.

The problem, simply stated, is that the NED methodology currently used by the Corps is inadequate to address the problems arising from climate change. This methodology sets a project life of 50 years and requires that the selected project generate benefits higher than its costs within that time period. However, the statistical database being used for rainfall does not reflect the increased frequency of extremely large rainfall events (as discussed in section 1). To address a problem like Hurricane Harvey, solutions have to be quite large to match the storm event, yet the methodologies of the Corps do not allow these larger storm events to be considered. Because of this, only solutions that do not solve a Harvey-type problem can qualify.

A second major problem arose in the context of the pending litigation at the U.S. Court of Federal Claims. Recall that the Court of Federal Claims had ruled that the Corps had “taken” a permanent flood easement. However, the fact of that ruling and the fact of the litigation were ignored in the Corps’ report when, in fact, it should have been considered a “without-project” or “no-action” alternative. Indeed, the implications of this federal unconstitutional “takings” litigation on the resolution of these Addicks and Barker Reservoir issues, and indeed on the future of Houston and Harris County, are significant.

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Consider the no-action alternative. Assume that the Corps determines that all alternatives fail the NED benefit-cost test and takes no further action. The Court of Federal Claims awards 90% of the flood value, and the homeowners receive compensation after attorney fees are deducted. They now own a home with permanent flood easement and cannot receive federal flood insurance. Although many say they wish to stay, over time these homes will be sold for some percentage of their original value, most likely to lower-income home buyers or, more likely, to commercial entities that seek to rent these homes. Over time, a scenario occurs where lower-income and minority residents move into this area that the Corps can legally flood. In this way, lower-income and minority citizens seeking a better life and better living conditions could become “trapped.”

Environmental justice is a very serious and important issue. In part 3 of this paper, current environmental justice issues in the northeastern part of Houston and Harris County are presented. However, in the case of Addicks and Barker, the federal government and our local governments could plant the seeds to allow the creation of very serious environmental justice situations. But rather than lay out the potential consequences of the “without-project” or “no-action” alternative, the Corps is silent about any consequences from the lawsuit. This is how major problems unfold, and this deficiency must be addressed.

Similarly, if the federal government pays 90% of the value of these homes to obtain a permanent flood easement, then the remaining cost of purchasing the home and removing the residents from harm’s way could be accomplished by purchasing the remaining 10% of the value. This would essentially turn an infeasible alternative into a viable one. This would, however, raise the residual issue of the potential bond failure by the 50 or so municipal utility districts with a significant tax base in the buy-out zone. The cost of paying off this bonded indebtedness should also be evaluated and considered as part of a buy-out proposal. Again, these types of issues simply were not discussed in the 216 study.

Additionally, various alternatives were considered that go against decades of work and support in the Houston community. To build a third reservoir to protect against overflows from Cypress Creek into the Addicks watershed as proposed by the Corps would destroy a significant portion of the approximate 25,000 acres preserved by the Katy Prairie Conservancy since the 1980s. Another proposal that seemed to receive a positive recommendation was the channelization of Buffalo Bayou, the preservation of which was fought for and secured in the late 1960s. These two features are among the core values—or core attributes—of Houston and Harris County. All effort should be made to solve this problem without resorting to destroying ecologically significant properties. Instead, work should have been focused on finding feasible projects that solve this problem—and such solutions do exist.

What the U.S. Army Corps of Engineers has managed to do is to galvanize opposition to this interim report and bring the Houston-Harris County community together in a remarkable show of unity. Groups that have opposed each other over the years are finding common ground in organizing to come up with solutions that evaded the Corps. Solutions exist. It just takes commitment and creativity. Here are some examples.
First, the Addicks and Barker Dams must be repaired, and the Houston public should be fully informed about the risk that is posed by failure to do so. The Corps modeled potential dam failure during the Harvey event, and that result should be shared with the Houston community. This would help ensure that the DSAC 1 classification is addressed and lifted, something that should have happened years ago.

Second, a first-class warning system must be set up to ensure residents living within the flood pool and downstream from Addicks and Barker receive adequate warning about projected flooding. If the Corps projects flooding, the public should be informed.

Third, additional capacity should be provided by digging out the approximate 10,000 acres within the Addicks and Barker Reservoirs owned by the federal government. This alternative did not appear to be fully evaluated in the interim document. There might be geologic reasons for not pursuing this option, but since the geotechnical documentation was not released as an appendix, the public does not have this information at this time. It should be possible to provide a significant portion of the 200,000 additional acre feet of storage that is needed to alleviate the problems associated with the Addicks and Barker Reservoirs.

Fourth, a buy-out of the flooded homes, from which a permanent flood easement has been “taken,” should be fully considered, assuming that approximately 90% of the value will have already been paid by the federal government. This buy-out proposition should include evaluation of compensation for the utility districts, and the Houston community should fight to protect the bond rating for these governmental entities.

Fifth, the potential construction of several smaller reservoirs rather than one large reservoir should be fully evaluated. The Katy Prairie Conservancy has developed a plan that involves smaller reservoirs that would be able to hold a collective amount of roughly 200,000 acre-feet of flood storage, the approximate amount needed to make Addicks and Barker perform well. This plan should be fully evaluated.

Sixth, the potential for constructing a tunnel to Galveston Bay should be fully considered. Tunnel technology has advanced significantly, and this alternative deserves full consideration. Such a tunnel could handle the 15,000 cubic feet per second of release required for the adequate operation of Addicks and Barker during extreme flood events, thereby avoiding flooding along Buffalo Bayou downstream of Addicks and Barker and the need for channelizing this waterway.

There are two alternatives that should be rejected on environmental grounds. These are the construction of a third reservoir over lands owned by the Katy Prairie Conservancy and the channelization of Buffalo Bayou. The endangered alligator snapping turtle has been confirmed in Buffalo Bayou, and that alone should place Buffalo Bayou off-limits for a federal project. Similarly, the community has worked for decades to protect remnants of the Katy Prairie. It also should be considered off-limits.
The bottom line is that the Corps’ failure has galvanized the community to develop its own set of alternatives. A united community can achieve what the Corps has been unable to do. This may be one of those turning points in addressing climate change. Our community may have to develop its own methods due to the failure of the federal government to adjust to this challenge.

III. Equity and Northeast Harris County

Harris County has 23 watersheds, and there is no doubt that these areas have not been treated equally over the years. Some are wealthier than others. Some have had better representation in government than others. Some have been left out of the city and do not have the same services as other areas. Some qualify for flood protection funding from the Corps, and some do not. However, from an overall standpoint, this inequity is most apparent in the Greens and Halls Bayou watersheds in northeast Harris County, a situation that needs to be addressed.

The Greens Bayou watershed (which includes Halls Bayou) is highlighted in Figure 4. The Greens Bayou watershed has a population of about 529,000 people, second only to Brays Bayou’s 700,000+ people. Greens Bayou was hit hard during Harvey, with almost 25,000 structures flooded, again second only to Brays Bayou’s almost 27,000 homes flooded. However, unlike Brays Bayou, Greens Bayou did not qualify for a federally funded flood control project.
Any inquiry into Greens and Halls Bayous must begin with the infrastructure that is present within these areas. Much of the Greens Bayou watershed is not served by curb and gutter drainage and storm sewers. Instead, open ditch drainage is the norm, as shown in Figure 5. And while this alone does not represent inequity, if these ditches are not maintained and if they do not flow, then they will not and cannot work. Within the city of Houston, each landowner is responsible for the maintenance of the culverts beneath their driveways. Outside the city limits, each landowner is responsible for the culverts and the drainage ditch itself. Regardless, the absence of maintenance ensures that even the more common larger storm events will cause flooding problems, and that is where the inequity begins—inadequate maintenance, if not an inadequate system.
Figure 5. Typical Open Ditch Drainage System

Note: This shows about 50% blockage of the culvert and siltation of the roadside drainage, which will inhibit the collection of stormwater and its ability to flow to the larger drainage outlets.

Source: Photo by Jim Blackburn.

Although this problem exists within Houston, it becomes worse when one moves outside the city’s jurisdiction and into the unincorporated areas of Harris County (within the extrajurisdictional area of the city of Houston). Here, utility districts, which were mentioned in section 2 of this paper, typically perform city functions until the area is annexed by the city of Houston. But, as can be seen from Figure 6, there are very few utility districts in the Greens Bayou watershed when compared to most of the unincorporated areas of Harris County. This means that these areas have no access to city-scale services such as municipal water and sewage, garbage pick-up, or local drainage maintenance. Essentially, some of the poorest residents of Harris County have been left with the greatest financial burden to gain access to basic services, which are often simply lacking.
And make no mistake about it: This area was ravaged by the rains of Hurricane Harvey. In Figure 7, a map of the flooding during Harvey is shown as depicted by a HEC-RAS\(^6\) two-dimensional model. While one can discern major flows down Greens and Halls Bayous, it is also clear that this water is finding its way through neighborhoods, following gravity. There was not much of this area that was spared from some flooding; a large portion experienced several feet of inundation during Hurricane Harvey. This map, perhaps more than any other, emphasizes the overwhelming nature of these 21st century rain events that

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\(^6\) This stands for Hydrologic Engineering Center River Analysis System, a computer program that models the hydraulics of water flow through natural rivers and other waterways.
illuminate every shortcoming in the system, while also raising doubts about what can be done to address these problems short of massive buy-outs and redevelopment. What is more likely to occur is that as these floods continue and buy-outs become more common over time, likely leaving a shortage of lower-income housing.

**Figure 7.** HEC-RAS Two-Dimensional Computer Modeling of Harvey Flooding in the Greens and Halls Bayou Watersheds

Note: Both Greens Bayou and Halls Bayou flow from west to east and merge further to the east off of this diagram.

Source: Modeling by the Severe Storm Prediction, Education, & Evacuation from Disasters (SSPEED) Center, Rice University.

It is reasonable to ask, “Why has there not been a federal flood control project in this watershed?” And the answer is because this area does not meet the requirements of the benefit-cost methodology used by the U.S. Army Corps of Engineers, even though it has the second highest number of flooded homes in Harris County. The problem is that this is not a wealthy area. It was not designed by developers using utility districts. It does not receive city services. The income status of the Greens Bayou watershed is shown in Figure 8.
After Harvey, Congress passed H.R. 1892\(^7\) to provide funding for proposed flood control projects, for which studies had been conducted but funding had never been authorized for construction. In H.R. 1892, money was set aside for four Harris County projects—Clear Creek ($295,165,000), Hunting Bayou ($65,000,000), White Oak Bayou upstream of Loop 610 ($45,000,000), and the completion of Project Brays ($75,000,000). Of particular concern, however, was the absence of a major federal project for Greens Bayou (and its tributary, Halls Bayou). One reason that Greens and Halls Bayous have been neglected is because the methodologies of the U.S. Army Corps of Engineers rely on benefit-cost analysis.

In particular, the concern here is that an approach that makes project approval contingent on greater monetary benefits than costs unfairly penalizes lower-income communities where relatively low home values can make it difficult for a capital-intensive channel modification or a major retention/detention facility to be justified. This is the case even if

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more homes would be protected in the lower-income area than in a wealthier area for the same or even a lower cost. In this manner, people living in lower-income areas are more easily overlooked by federal projects, potentially leading to geographic, income, and racial inequities in the provision of flood protection.

This problem is illustrated in Figure 9, which shows that a $5 million project benefitting only six homes (worth $1 million each) can be approved using benefit-cost methodologies, but the same project benefitting 20 homes (worth $100,000 each) cannot be approved using those same methods. This diagram, which is intentionally simplistic, clearly shows the inequity of this approach when deciding which projects should be built and which ones should not, particularly when the lower-income community is also a minority community. We need better metrics than dollar costs versus dollar benefits.

Figure 9. Conceptual Benefit-Cost Comparison

Source: Image prepared by Natalia Gaiser.

The reason for this disconnect, as well as the problem identified with the project life analysis in section 2, is that the U.S. Army Corps of Engineers is obligated to adhere to federal policy for project evaluation dating back to the Flood Control Act of 1936. This act states that "the Federal Government should improve or participate in the improvement of navigable waters or their tributaries, including watersheds thereof, for flood-control purposes if the benefits to whomsoever they may accrue are in excess of the estimated costs." Mandated to use a benefit-cost analysis, the Corps currently observes the Economic

and Environmental Principles and Guidelines for Water and Related Land Resources
Implementation Studies\(^9\) (often referred to as Principles and Guidelines or P&G), which was
adopted in 1983 as proper procedure for project evaluation.

The P&G outlines four accounts for analysis:

A. National Economic Development (NED)—changes in the value of the national
output of goods and services, expressed in monetary units.

B. Regional Economic Development (RED)—changes in the distribution of regional
economic activity (regional income and regional employment).

C. Environmental Quality (EQ)—effects on ecological, cultural, and aesthetic resources
that cannot be measured in monetary terms.

D. Other Societal Effects (OSE)—effects on social aspects such as urban and
community impacts, life, health and safety factors, and displacement.\(^{10}\)

The NED account is the only account that is mandatory to be used in the evaluation of
federal water projects. Specifically, the plan with the greatest NED benefit-over-cost is
selected, unless an exception is granted. As a result, the Corps' project evaluations largely
rely on this monetary factor alone. There are important equity considerations unaddressed
in the Corps' benefit-cost analysis, especially when the NED account is the only one
considered in project evaluation.

It is worth noting that one federal project has been constructed in Harris County in a low-
income area—the Sims Bayou project. A second project—the Hunting Bayou project—has
been proposed for another low-income area. However, it is relevant to note that the
benefit-to-cost ratio of the Hunting Bayou project is only 1.01 to 1.00 and was made
feasible by extensive warehouse development adjacent to Loop 610. There could and
should be much more reliance on additional factors, including other societal effects when
environmental justice issues are raised, as is in the case of Greens Bayou.

It is also worth noting that over $2 billion in federal housing assistance was provided by
Congress to Harris County and the city of Houston through the U.S. Department of
Housing and Urban Development. In Texas, that money must come through the Texas
General Land Office (GLO). Unfortunately, this money was held up for over two years in a
dispute between the city, the county, and GLO, which led to the city of Houston filing a
lawsuit to force the release of those funds. Although this dispute has since been settled,
while it was still pending, thousands of flooded residences went un repaired. In many cases,
this meant that owners or renters were living with black mold or were living in only one or
two rooms of homes that were otherwise filled with muck from Harvey. This situation was

\(^9\) The Corps has incorporated these planning guidelines in its Planning Guidance Notebook. For
more information, see
https://www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/er_1105-2-
100.pdf.

\(^{10}\) Ibid.
further compounded by the rains of Imelda in 2019 that flooded many of these same homes in the northeast sector.

Without federal funding, it is up to Harris County to provide drainage assistance to the Greens and Halls Bayou watersheds. Harris County did approve a bond issue in 2018, and Greens Bayou is slated to get a fair share of these bond proceeds. But, an argument exists that, based on historical spending and current flood damage, the Greens and Halls Bayou watersheds might be due a greater percentage of this local flood bond money than other watersheds that have done better over the years. Such an argument was included in Section 13G of the order authorizing the bond issue:

Since flooding issues do not respect jurisdictional or political boundaries, the Commissioners Court shall provide a process for the equitable expenditure of funds across Harris County, recognizing that project selection may have been affected in the past and may continue to be affected by eligibility requirements for matching Federal, State, and other local government funds.\(^\text{11}\)

The effect of this section was changed to some extent by the promise of certain flood control projects by the Harris County Flood Control District prior to the passage of the bond issue. While such representations may not be legally binding, they were used to induce votes, and fairness arguments have been made (and will continue to be made) to follow through on these representations—something the Commissioners Court has tried to do. Indeed, the court has adopted an equity allocation process, which will apply after the initial 163 projects are started, as promised prior to the bond issue.

We have yet to see how this equity issue in the Greens and Halls Bayou watersheds will be resolved. The important point is that an equity issue exists in these areas, and it will be a challenge for the city of Houston, Harris County, the state of Texas, and the federal government to correct this decades-long pattern.

**IV. Galveston Bay Surge Flooding**

Greens Bayou and Addicks and Barker Reservoirs mostly face challenges with rainfall flooding. The problem on Galveston Bay is surge flooding. In 2008, Hurricane Ike missed the Galveston Bay system yet caused about $25 to $30 billion in flood damage, with major damage to residential and commercial areas on Galveston Island, the Bolivar Peninsula, and along the Galveston Bay western shoreline. The worst of the surge flooding was east of Galveston Bay in largely undeveloped prairie grasslands and wetland ecosystems. That surge, which was in excess of 17 feet, would have caused massive damage in Galveston and Harris Counties had the eye come ashore near the southern tip of Galveston Island. Luckily, it did not.

\(^\text{11}\) Section 13(G) of Order issued by Harris County Commissioners Court on June 12, 2018 authorizing a bond election on August 25, 2018.
After Hurricane Ike, significant studies were undertaken on solutions to Galveston Bay surge flooding, leading the U.S. Army Corps of Engineers to propose a coastal barrier comprised of sand dunes 14 feet high on Bolivar Peninsula and the west end of Galveston Island and a sea wall/gate structure 17 feet high. That project also includes a backside levee around the city of Galveston and two gate structures within the bay—one on Clear Lake and another on Dickinson Bayou. An image of this proposed solution, with an estimated cost in excess of $21 to $31 billion, is shown in Figure 10.

**Figure 10.** U.S. Army Corps of Engineers depiction of Alternative A (2020 Version)

Note: Sand dunes are in dark blue and the storm surge gate system is in medium blue. The figure also shows the backside levee around Galveston with pump stations and gates on Dickinson Bayou and Clear Lake.

Source: Coastal Texas Protection and Restoration System, Figure 2-1, p. 2-6.

It is clear from Figure 10 that the Corps’ analysis identifies a residual risk behind the coastal barrier. To address that issue, they propose gates at Dickinson Bayou and Clear Lake and non-structural measures such as home elevation in the cross-hatched zone, which is the developed area east of Texas State Highway 146 along Galveston Bay. However, what is not discussed in the Corps’ analysis is the extent of the residual risk associated with Category 4 and 5 storm events that are larger than the project design storm (which is an average Category 2 storm).
This is not a criticism of the work of the Galveston District of the U.S. Army Corps of Engineers but again a reflection of the problems with the design methods of the Corps, which originate from Corps headquarters, the executive branch, and Congress. Under these methodologies, only the smaller storms (such as Category 2 hurricanes) generate project benefits within the allowed 50-year project time frame, reflecting the failure of the statistical methods to incorporate climate change and/or to allow flexibility based upon climate change projections. Most of the benefits to justify the coastal spine come from the backside protection for the city of Galveston and not from protecting the massive industrial complex and urbanized area of western Harris County, which is contrary to common sense.

To better understand the residual risk, the Severe Storm Prediction, Education, & Evacuation from Disasters (SSPEED) Center at Rice University asked Clint Dawson of the University of Texas to run ADCIRC\textsuperscript{12} computer modeling of a Category 5 storm coming ashore on the southern end of Galveston Island with the coastal spine in place. The results are illuminating. This storm would overtop the 17-foot Galveston seawall and cause major flooding on the western shore of Galveston Bay. The potential extent of this western shoreline flooding is shown in Figure 11. In generating this map, the assumption was made that the gates on Clear Lake and Dickinson Bayou would be effective in preventing flooding further inland, and surge flooding was halted at Texas State Highway 146, with the exception of the low area at the Bayport Industrial Channel, where the surge is depicted as extending west past the state highway as per the modeled result.

\textsuperscript{12} The ADCIRC model is a high-performance, cross-platform numerical ocean circulation model for simulating storm surge, tides, and coastal circulation problems.
Figure 11. Surge Modeling Result for a Category 5 Storm with the Coastal Spine in Place

Note: The area in red shows flooding greater than eight feet in depth, the yellow area shows flooding between four and eight feet, and the blue area shows flooding of one to four feet. The area in light brown shows the places that would have flooded but for the gates proposed by the Corps at Clear Lake and Dickenson Bayou.

Source: Modeling by Clint Dawson, University of Texas at Austin and SSPEED Center, Rice University. Graphic by Christina Walsh.

In order to gain a better understanding of the extent of this damage, Rice undergraduate student Briggs Weathington undertook an extensive land use analysis of this flooded area. The result of Weathington’s investigation is shown in Figure 12, which breaks down the flooded areas by industrial, commercial, and residential land use categories based upon extensive interpretation of land use data from aerial photographs in Harris County and data from Galveston County. The number of flooded structures is shown in Table 1.
**Figure 12.** Properties Flooded by Land Use Category from a Category 5 Storm with the Coastal Spine in Place

Source: Modeling by Clint Dawson from U.T. Austin for SSPEED Center, Rice University. Graphic by Christina Walsh and Briggs Weathington.

**Table 1.** Number of Properties in Harris and Galveston Counties by Land Use Type Flooded by a Category 5 Storm with the Coastal Spine in Place

<table>
<thead>
<tr>
<th></th>
<th>Residential</th>
<th>Industrial</th>
<th>Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harris County</td>
<td>8,575</td>
<td>534</td>
<td>1,046</td>
</tr>
<tr>
<td>Galveston County</td>
<td>4,698</td>
<td>41</td>
<td>193</td>
</tr>
<tr>
<td>Total</td>
<td>13,272</td>
<td>575</td>
<td>1,239</td>
</tr>
</tbody>
</table>

Source: Table prepared by Briggs Weathington.

At an average listed value of about $200,000 per home, the residential damage would exceed $2.5 billion. The extent of industrial and commercial property damage is much more difficult to evaluate at the scale shown in the maps above. To attempt to make a more detailed analysis of potential industrial damage, Blake Eskew, the SSPEED Center’s
economics project manager, undertook a more detailed analysis of three sites—the Odfjell Baytank Facility at Bayport, the Kinder Morgan Facility near the Beltway 8 bridge, and the Valero Manchester Facility near Loop 610 on the Houston Ship Channel. The potential extent of flooding in these three areas is shown in Figures 12, 13, and 14.

**Figure 13.** Area Flooded by Category 5 Storm at the Western End of the Bayport Channel with Coastal Spine in Place

Note: The labeling is based upon Harris County tax roles and may not reflect current ownership.
Source: Computer modeling by Clint Dawson, UT Austin for SSPEED Center. Land use analysis by Christina Walsh and Briggs Weathington.

At the Odfjell Facility shown in Figure 13 (with the label Baytank, Inc.), the primary function is the storage of chemicals prior to transport. Within the Odfjell facility alone, there are 107 chemical storage tanks of various types that would flood. The assumption was made that flooded tanks would be sufficiently damaged to the point that they would need to be replaced, an assumption that may or may not be correct. The cost to replace these 107 tanks is estimated at $53 million. Monthly lost revenue is estimated to be about $3 million per month, and repairs would likely take months if not a year or more.
**Figure 14.** Extent of Flooding along the Houston Ship Channel from a Category 5 Storm with the Coastal Spine in Place

Note: Kinder Morgan acquired GATX Terminals, and World Energy Biofuels is actually a bit to the north. The labeling is based upon Harris County tax roles and may not reflect current ownership.

Source: Surge modeling by Clint Dawson, U.T. Austin. Land use graphics by Christina Walsh and Briggs Weathington.

At the Kinder Morgan Liquids Terminal, the area flooded by a Category 5 storm with the coastal spine in place is shown in Figure 14. Here, there are 121 tanks that would flood with a replacement cost of $170 million. Monthly lost revenue is estimated to be $6.2 million.
The Valero Manchester Refinery would also be affected by this surge from a Category 5 storm with the coastal spine in place as shown in Figure 15. In addition to 38 storage tanks with a replacement cost of $53 million, all of the refinery processing units lie within the area that would be flooded by the storm surge from this event. The replacement cost for the processing units is estimated to be about $2.5 billion with a monthly gross margin of $42 million.

In addition to replacement costs and lost monthly income, there would also be costs associated with spillage from the tanks. In an earlier analysis, Jaimie Padgett of the SSPEED Center and the Civil and Environmental Engineering Department at Rice University identified spillage from tanks along the Houston Ship Channel based upon surge height. This surge is estimated to reach a height of about 22 feet up the ship channel, resulting in the release of about 60 million gallons of oil and hazardous substances, according to the estimates prepared by Padgett (shown in Figure 16).
Figure 16. Estimated Spillage of Oil and Hazardous Substances based upon Various Surge Heights within the Houston Ship Channel

Source: Jamie Padgett, SSPEED Center and Rice University Civil and Environmental Engineering Department.

Using just three of 575 flooded industrial facilities for example purposes, the potential damage is substantial. There would be a total of 266 flooded storage tanks and one flooded refinery. The replacement cost of flooded tanks is estimated to be about $276 million, and the replacement cost for the refinery is estimated at $2.5 billion. The lost income for these three facilities is estimated to be about $50 million per month with the likelihood that replacement would require at least six months for the tanks and over two years for the refinery. Added to that is the potential cost of spill clean-up and long-term damage to Galveston Bay, which would be in the billions. Additionally, there would be damage to commercial facilities. The two container ports—Bayport and Barbours Cut—would be flooded. The extent of this damage has not been computed.

When considered together, it is reasonable to anticipate the damage from a Category 5 storm event could range from $50 to $100 billion with the coastal spine in place. The question is—could these additional damages with the coastal spine be addressed? And the answer is yes.

The SSPEED Center and Rogers Partners have designed the Galveston Bay Park Plan, an in-bay complement to the coastal spine that can prevent this additional surge damage from occurring with a margin for sea level rise. The Galveston Bay Park Plan is shown in Figure 16.
Figure 16. Galveston Bay Park Plan

Note: The Galveston Bay Park Plan is shown extending from the Texas City Flood Protection Levee along the Houston Ship Channel northward to Houston Point in Chambers County.
Source: Diagram by Rogers Partners for SSPEED Center.

The Galveston Bay Park Plan is proposed as a 25-foot flood levee along the Houston Ship Channel extending from Houston Point in Chambers County westward to the Houston Ship Channel and then along the Houston Ship Channel to connect with the Texas City levee system in Galveston County. This project will be constructed from material dredged to widen the Houston Ship Channel from its currently proposed width of 700 feet to 900 feet. This dredged material will also be used to create land area to be used for recreation and environmental enhancement, and additional capacity will be provided for dredge disposal for the next 50 years or so.

The Galveston Bay Park Plan provides a level of protection beyond that currently allowed by current U.S. Army Corps of Engineers methodologies for federal spending. For this reason, it is proposed to be constructed with local funds under permits to be applied for from the U.S. Army Corps of Engineers. This project has been approved for further study by the Port of Houston Authority with supplemental funding being sought from the city of Houston and Harris County. Among other aspects, the cost of this project, initially estimated at between $3 to $6 billion, will be studied in detail (along with creative funding concepts) prior to a decision being made on whether or not to move forward with a permit application for construction.
Conclusion

These three case studies indicate that evaluating and understanding climate change is a key issue to solving Houston-area flooding. Climate change is clearly present in all three areas included in this analysis. The conclusion is warranted that there are major problems with the current methodologies of the U.S. Army Corps of Engineers when it comes to solving significant issues that the Houston region faces relative to future flooding. Climate change has altered the baseline statistics that have been used for decades for civil works projects. From a policy standpoint, there is an urgent need to develop better alternatives than the plans that currently exist, but there has been little support or enthusiasm for such reform. The time is now for that reform to take place.

Here in the Houston region, we have been forced to address these problems on our own. In the case of the Addicks and Barker Reservoirs, the community has come together to search for and demand solutions. In the case of the northeastern part of town, issues of inequity demand change. And on Galveston Bay, the risk is too great to ignore. Fortunately, in Galveston Bay, an alternative approach is being developed outside the traditional national economic development approach that relies upon the U.S. Army Corps of Engineers and Congress.

Although this author has not studied other regions in the same detail as the Houston area, it is reasonable to conclude that these same types of problems exist across the entire United States. Changing rainfall patterns will affect us all, and stronger hurricanes will affect the Atlantic and Gulf Coast regions of the United States along with sea level rise. Additionally, issues of inequity are likely present to varying degrees in many major urban areas. These are issues of national concern, and the time to act is now. In the meantime, the city of Houston, Harris County, and the surrounding region must act in the absence of federal leadership.