GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

Research Paper 2: Development Regulations

Kinder Institute for Urban Research Rice University
Texas Southern University
Houston Advanced Research Center
April 2019

April 2019

Contributors

Kyle Shelton, Kinder Institute for Urban Research, Rice University

Earthea Nance, Texas Southern University

Ryan Bare, Houston Advanced Research Center

Grant Patterson, Kinder Institute for Urban Research, Rice University

Reviewers

Antonia Sebastian, SSPEED Center, Rice University

Susan Rogers, Community Design Research Center, University of Houston

Stephanie Glenn, Houston Advanced Research Center

Definitions and Abbreviations

AEP	Annual Exceedance Probability - the probability of a storm event exceeding a particular flood level in one year.
LID	Low Impact Development

EXECUTIVE SUMMARY

Regulations, land use policies, increased knowledge of flood risk, and design standards that embrace a wider array of flood management infrastructure approaches are critical tools for the greater Houston region to embrace as it considers how to manage future flood issues. This report lays out several areas of potential action to consider and highlights national best practices where applicable. It is important to note that this report does not focus on drainage and detention regulations. as those are the focus of separate Greater Houston Flood Mitigation Consortium reports.

The report highlights a need for a three-pronged approach to considering new regulations and policies:

- Create regulation and policies that ensure residents and officials understand the full range of flood risks facing communities located both inside and outside of mapped floodplains.
- Create systems that integrate green and gray infrastructure into both public and private infrastructure.
- Create appropriate land use and development plans that minimize future risk and help address existing issues.

Collectively, these steps will aid in the reduction of risk to flooding damage in the Houston region.

Many of today's regulations date back decades. Our understanding of flooding has improved since then, and so have analysis and design tools. New data indicates the storms we once thought of as rare are in fact common. Computer modeling, once considered cutting-edge, is now routine. Regulations reflect the best knowledge of the time they are adopted. New regulations that take into account new knowledge would make our region more resilient.

Development regulations are instituted and enforced by a variety of local jurisdictions and operate within a legal framework set by the Texas Legislature. Thus, changing the regulatory framework often requires actions at multiple levels, and no one entity can be expected to be solely responsible.

Key Takeaways from Regulatory Best Practice Research:

- Use strategic land-use ordinances to tailor development outcomes in at-risk areas in ways that remove people from harm's way or reduce the number of vulnerable residents and structures.
- Put regulations into place to inform residents about the full range of flood risks they face and options to mitigate risks. Provide this information in proactive, accessible ways to people living inside and outside of mapped floodplains, as well as to both homeowners and renters.
- Focus public funding and programs on helping low-income residents in homes built before floodplain regulations were put into place. These residents face financial challenges when trying to bring homes up to new standards or reduce flood risk on their properties and will need public support.
- Require that broader resilience goals become a part of design standards or development permitting processes to push the region toward incorporating a wide array of resilience strategies.
- Implement regulations and design standards that encourage the use of both gray and green infrastructure solutions. In order to see their use broadened, green infrastructure tools should be incentivized or required as the City of Houston is now studying.
- Because the problems addressed herein are regional in scope and do not adhere to political boundaries, innovation in stormwater and floodplain management regulations is most successful when implemented at the regional level by city, county, and regional institutions. Stormwater and floodplain management professionals within these institutions—some of whom developed the current set of regulations based on the best available data of a previous era and using past theories—are best suited to put in place the new and emerging best practices summarized in this report.
- Many communities have struggled to balance regulatory reform with economic goals. As new data and more advanced technology reveal the new picture of flood risk in the Houston region, the tipping point for this balance will likely shift, resulting in the need for a new set of regulatory practices. This report summarizes best practices from other communities that are potentially relevant for the Houston region.

Many of today's regulations date back decades. Our understanding of flooding has improved since then, and so have analysis and design tools. New data indicates the storms we once thought of as rare are in fact common. Computer modeling, once exotic, is now routine. Regulations reflect the best knowledge of the time they are adopted. New regulations that take into account new knowledge would make our region more resilient.

INTRODUCTION

Scientifically informed, actionable and properly incentivized regulations can play an important role in helping the greater Houston region mitigate future flood-related damages and improve resilience.

Regulatory intervention should not be limited to development regulations such as building elevations, however. While these direct development regulations are critical to overall mitigation strategies, a broader view of the regulatory environment around flood risk can help the region better prepare its residents and critical infrastructure for future disasters.

This report outlines the challenges that regulation can address and points to cases, in the Houston region and beyond, where such practices are in place. It argues that an effective regional approach to establishing regulations aimed at flood mitigation should go beyond development rules and land use requirements. The regulatory environment can also help inform policies and programs that shape flood control and stormwater infrastructure of all sizes and types. Finally, regulatory frameworks should help promote efforts to clearly understand and document flood risks.

The best practices described in this document focus on three interlocking steps that, if pursued jointly, could improve the region's ability to respond to its challenges around water and flooding:

1 Create regulations and policies that ensure residents and officials understand the full range of flood risks facing communities located both inside and outside of mapped floodplains.

2 Create systems that integrate green and gray infrastructure into both public and private infrastructure.

3 Create appropriate land use and development plans that minimize future risk and help address existing issues.

Each of these steps needs to be informed by scientifically accurate knowledge, must be accompanied by clear communication and education to the public, and can be incentivized through grants, tax breaks, or other mechanisms to encourage their use.

The integration of these three elements is essential because no single approach to flood mitigation and risk reduction can adequately address the region's needs now and into the future. A combination of conventional and more modern stormwater management strategies that address flood concerns across scales and with both structural and non-structural interventions will be required to balance social, economic, and environmental objectives.

Jurisdictions within the greater Houston region have overhauled their approaches to development regulation in the past two decades. Much of this updating has focused on direct changes to development and infrastructure regulation such as the implementation of higher elevation requirements on new and renovated structures, the use of streets to convey storm water, detention requirements and the expansion of drainage projects at every level. However, there are many opportunities for the region to enhance current approaches.

Identifying and acting on these opportunities are critical. The region's population continues to grow, and this growth has led to the loss of natural ecosystems, come too close to the banks of many bayous and creeks, and claimed open spaces that could otherwise aid in drainage and reduction of flood risks. In addition, while new flood control infrastructure will play an important role in mitigating flood risks, we recognize that such infrastructure cannot affordably address the region's flood risk and note that local jurisdictions are struggling to address issues with existing flood control infrastructure that is outdated or undersized. . Finally, climate change is worsening storm impacts for the region and increasing the intensity and frequency of rainfall and storm surge flooding.

Regulatory, policy, and programmatic approaches to flood mitigation and stormwater management are not just about dictating what a homeowner or property owner can do to their property to mitigate risk. Instead, they can and should expand to neighborhood, watershed, and even regional scales. They should help shape approaches to major infrastructure projects and give form to policies and programs that lead the region's desired outcomes for safer and more vibrant communities.

EXISTING REGULATORY CHALLENGES

The Greater Houston Flood Mitigation Consortium has identified several challenges with the existing regulatory regime around flood control and stormwater management:

- Different jurisdictions have different regulatory standards. Even within a single watershed, different cities can have different development rules in place. Water, and the issues it can cause, does not follow jurisdictional boundaries. Regulations that aim to address wider watershed issues across jurisdictions will help promote resilience and reduce risk.
- The permitting process for building in floodplains and other vulnerable areas is overseen by a mix of agencies, which creates confusion over approval, inspection, and maintenance issues.[1]
- Most existing regulations are tied to the designated 100-year and 500-year floodplains, which means that regulations do not adequately address flooding that happens outside of those zones. More than half the estimated homes damaged during Hurricane Harvey were located outside the 500-year floodplain.[2]
- Counties and cities do not have equal enforcement powers. Harris County can approve floodplain permits, but not all building standards. Harris County cannot stop illegal development without going to court.
- Grandfathered homes, or those that were built before the passage of current regulations that have higher standards, are often not covered by regulatory interventions and therefore remain vulnerable.
- Further, new building regulations make it difficult for grandfathered homes to be made more flood resistant without demolition and complete rebuild. Such action is often too costly for low-income residents without flood insurance. As a result, many households are trapped in damaged homes because they cannot get permits for repairs and lack the means to rebuild them. Those that are repairing are often doing so without permits.
- Green and gray infrastructure approaches are not adequately integrated in Houston. Programs that exist to encourage this integration are usually voluntary guidelines. To be effective, these approaches must be supported by regulation or incentives.
- Land-use planning is a critical component of flood management. While Houston does not have a formal zoning code, that is not actually a limiting factor in how it approaches land use as a tool for flood management. The city can and has used ordinances to set different development standards or prevent certain land uses in specific areas. Expanding the use of ordinances in strategic ways to address specific risks offers a way to address a wider range of issues in a more flexible way than a traditional zoning code. Further, using other geographic designations such as watersheds or floodplains to plan specific interventions can offer a more tailored way to reduce risks. Counties in Texas are unable to pass ordinances, as such they are currently limited in the strategies they can pursue to influence land-use controls.

Best Practices

This report explores several best practices to provide case studies for the Houston region to learn from and to discuss how potential regulatory or policy changes could be shaped:

- Base local regulations on up-to-date risk maps that rely on the most current data about rainfall and topography and that account for all forms of flooding. Establish regular reviews of floodplain maps. Underpin all of this with adequate education and outreach to residents about the risks they face. Harris County Flood Control is already working in this direction.
- Use regulation and incentives to pursue improved green-gray infrastructure approach. Account for projects at many scales, from single lots to regional infrastructure systems. This would build on existing standards for green infrastructure.
- Continue work to ensure that existing gray infrastructure is in good working order. Use adequate design risk levels to account for changing storms. Gray infrastructure must be large enough to handle major events.
- Consider options for limiting development in areas identified as risk-prone. This could take the form of 1) prohibition on development in specific areas; 2) the use of easements or the transfer of development rights to keep vulnerable areas undeveloped; or 3) encourage the purchase of land by public or private entities with the intent of building on the area's successes with conservation and preservation of greenspace.
- Create programs that address grandfathered buildings in floodplains and areas outside of floodplains. Ensure that residents in areas with these homes have access to a wide array of solutions, and the financial resources to implement them.

- Implement programs and collaborative partnerships that can reduce the mix of jurisdictions responsible for permitting and oversight of development within the region.
- Create interconnected development regulations building for resilience, not just to prevent flooding.3
- Authorize counties to respond to challenges and enforce regulations using ordinances, which could have benefits beyond flood control.

THREE-PRONGED APPROACH TO REGULATION

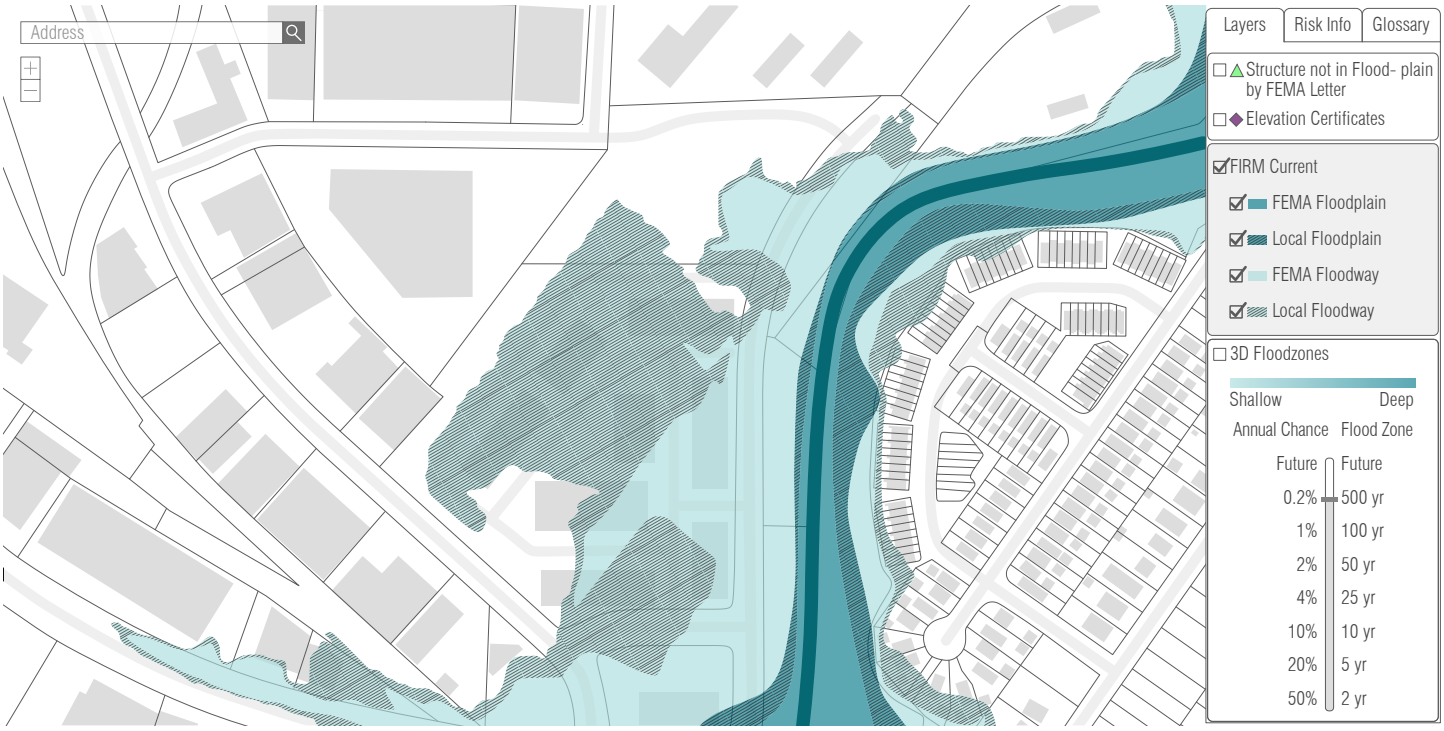
Risk

The flood risks faced by the greater Houston region are currently communicated by traditional floodplain mapping. This usually results in areas that are within the 500-year floodplain being identified as places with significant levels of risk. However, Hurricane Harvey impacted tens of thousands of homes outside of the mapped floodplain. This suggests not only that the floodplain maps should be updated (which is in progress and will include new rainfall total estimates), but also that a more proactive, forward-looking risk map tool should be embraced to assess flood risk across the region. Flood risk mapping should use models that account for all forms of flooding, including localized flood risk away from the mapped floodplains.[4]

There is no sharp line where properties located on one side are at risk of flooding and properties on the other side are not. Houses flood not only from bayous or creeks rising out of their banks, but also but from localized flooding. A flood risk mapping approach estimates the likelihood of all flood scenarios, including issues like overland sheet flow and high water caused by poor local drainage systems. This approach shows risk as a gradient, rather than a sharp cut-off, which would be more useful than the traditional floodplain mapping approach.

The Consortium's Strategies for Flood Mitigation in Greater Houston, Edition 1 highlighted the need to map flood risks in new ways. As discussed in the earlier document, nearly all decisions related to flood mitigation and regulation are based upon floodplain maps created or approved by FEMA based on historical flood data. However, FEMA maps are often outdated and show incomplete flood risk. Moving toward mapping of complete flood risk embraces a strategy to use advanced hydrodynamic, meteorological, geotechnical, and other models to estimate the likelihood and impacts of all possible flood scenarios, using probabilistic analysis, rather than deterministic analysis. A move toward a risk map approach can also be beneficial in that it could allow a city or region to map multiple risks, such as wildfire or earthquake risk, for residents, rather than flooding alone.

However, the creation of more accurate risk maps is just one step. The information the maps contain must also be distributed to all residents—whether renter or homeowner—in order to ensure they have proper understanding of the risks they face. A commitment to publicly accessible risk information could be required through city ordinances that require landlords and those selling homes to alert potential renters/buyers. The State of Georgia, for example, requires that landlords alert prospective renters in writing of a property's flood risks if it has experienced flooding three times in the past five years.[5] Public communication programs could also be run through multiple jurisdictions. The Harris County Flood Control District is already undertaking a major educational campaign



Sample risk maps adapted from Mecklenburg County Floodzone

around the importance of purchasing flood insurance. A similar effort would be needed to educate the public about the existence of risk maps and how to use them.

Beyond mapping risk and disseminating information about that risk, the City of Houston could use its design standards to better account for a wider range of risk in its infrastructure. For example, street drainage standards in Houston require that storm sewers in new development be able to handle at minimum a 2-year event. This standard is lower than in peer cities like Austin, where street drainage must meet the 25-year frequency. As of now the city also only requires storm sewer systems to account for peak rainfall durations of between 3-6 hours. As Hurricane Harvey showed, peak rainfall in the region can remain for days. Ensuring that systems are built to standards that address that possible duration is key.

Wedding more accurate risk mapping with regulations and standards that acknowledge a wider array of challenges and inform residents about those risks can help reduce the number of residents in harm's way and lessen the impact of storm events.

Green and Gray Infrastructure

Regulation and policy can promote the wider use of green infrastructure systems and ensure such systems are effectively integrated alongside existing gray infrastructure where appropriate and feasible. Gray infrastructure is the traditional means of controlling floods and storm water in the U.S. The term "gray infrastructure" refers to a range of physical structures—often made of concrete and steel—designed to store, block, convey, divert, and retain excess water. Gray infrastructure describes both flood control elements that address large-scale inundation problems and stormwater drainage systems at the neighborhood scale.

The broader category of "green infrastructure" is a catchall term that consists of often overlapping systems of low impact development (LID) (sustainable land development + engineered nature based modern stormwater management practices), green stormwater infrastructure (modern stormwater management practices often lacking engineered design features), and large, regional scale green infrastructure (channels and other infrastructure designed to support the natural behavior of waterways, land protection, land restoration, green corridors along waterways, and parklands). Each of these components has its own, often complementary, benefits and, more importantly, distinct cost, user group, and scale considerations.

Promoting wider use of green infrastructure and regulations that support it merits attention because the underlying infrastructure is the foundation for the region's development and its risks. This is especially pertinent in the greater Houston region because municipal and county development regulations and infrastructure design manuals give shape to a huge amount of privately built, public infrastructure. Throughout the region, developers, working in conjunction with municipal utility districts, build streets, drainage and water systems in new subdivisions. After the construction of these systems their maintenance is passed to public entities. Local regulations, therefore, are critical to implementing new practices in infrastructure design.

Gray infrastructure is the legacy substructure of all U.S. cities, including Houston. This includes both major public infrastructure projects and local drainage systems. The condition of the nation's gray flood infrastructure across these scales, however, is worsening.[6] Regional systems and local stormwater systems alike require maintenance, rehabilitation, and upgrading. Moreover, many of the existing gray infrastructure systems were not designed to handle the increasingly large storms facing the Houston region as result of climate change. Finally, the benefits of conventional gray infrastructure and the upgrades that are made to the system have not been distributed equitably in most American regions. Historically, cities have invested most heavily in the construction of infrastructure systems that benefit wealthier areas with more white residents.[7] The same has been true of maintenance interventions. Addressing these issues takes focus on both major public infrastructure systems and the installation of a regulatory framework that encourages best practices for smaller scale development and local public systems. It also requires that an equity lens be brought to all planning processes to ensure that protection and adequate infrastructure is being provided to all residents.

Actors in the Houston region, particularly the Harris County Flood Control District (HCFCD), have already moved away from many of the most traditional forms of gray infrastructure approaches to flood control. While bayous once were channelized in concrete, in recent years local entities have turned to a range of structural and non-structural approaches to mitigation. These vary from adhering more closely to the natural course of bayous, preventing erosion, and relying more on retention and detention. FEMA and the U.S. Army Corps of Engineers have made these shifts possible by opening up federal funding sources to support projects that include these practices.

Private LID project

While new frameworks provide an opportunity to build new types of public infrastructure, we have not made a corresponding shift in how we regulate and incentivize corresponding private investments in our region's development. While both Harris County and the City of Houston maintain guidelines for implementing LID and green infrastructure projects, there has been little uptake by developers and only a few smaller scale demonstration projects by public entities. Developer participation agreements, which reimburse developers for building infrastructure that has larger public benefit as part of their projects, and other tools could help. The City of Houston is currently researching what incentives could improve uptake, with a report slated for release in 2019. This challenge is one shared by numerous cities and regions. As green infrastructure has emerged worldwide as a tool that can augment gray infrastructure systems, many jurisdictions have struggled to embrace it. Regulation and incentive structures can encourage the use of integrative gray and green projects. A combination of scaled and layered gray/green strategies could form integrated infrastructure that serves the region as a dynamic evolving stormwater network and flood control system. Finding mechanisms to get private homeowners and developers to use LID and green infrastructure techniques on individual lots and projects could go a long way toward addressing collective risk.

Similarly, greater Houston could benefit by ensuring that infrastructure systems and regulations that govern flood control and stormwater drainage adequately account for the likely severity of future rainfall events and storms. The region must also assess the realistic limits of green infrastructure given the clay soil structures that dominate most of the area. In some regions, the primary goal of green infrastructure is infiltration; here, evaporation and the slowing of drainage may be more important. Green infrastructure practices working in conjunction with gray infrastructure systems can help address storms of different sizes and a wider array of flooding issues than either approach can alone. Changes in this area would need to be applied to both public and private infrastructure.

Low Impact Development & Green Stormwater Infrastructure

LID is a holistic sustainable land development approach that incorporates ecological, hydrological, and engineered design elements. LID considers the project site as a whole to make efficient use of available land, control and process stormwater, and reduce the amount of total impervious cover. A primary objective of LID is to preserve the original hydrology of the project site by engineering modern stormwater management features into the site design. This serves to reduce the overall volume of runoff and improve the quality of water that flows from the site. LID practices can be applied to almost every type of site.

Private LID project

Green stormwater infrastructure (GSI) is a subset of LID that typically uses nature-based practices in lieu of engineered design features. LID and GSI offer a set of options for both small and large-scale areas.

- Bioretention systems
- Bioswales
- Rainwater harvesting systems / rain gardens
- Permeable pavements / reduction of impervious ground cover
- Green roofs
- Native landscapes
- Pocket prairies
- Rain barrels

Harris County Infrastructure

Harris County instituted LID criteria in 2011. The standards that the County instituted are not mandatory and there is no regulatory requirement for any projects to include LID elements. The criteria were put into place in part because of a U.S. Environmental Protection Agency (EPA) call to use Green infrastructure/LID to improve water quality. The County also sees the projects as likely to save money for both initial construction and long-term maintenance. Developers that want to use LID practices must still meet all other development standards and cannot increase the maintenance burden for the county. Those using LID elements are able to reduce the level of detention they are required to create if they meet all requirements and show that the LID elements reduce runoff.[11] There are no incentives or requirements for use of LID.

Example of County LID Project

Birnamwood Drive, North Central Harris County – LID elements were used for the first time by Harris County during the construction of a new portion of this roadway. The median saw the placement of rain tanks, high infiltration soils, and native landscaping. In addition to saving an estimated $100,000 on design and construction of traditional storm sewers[8], the county has to spend fewer resources on maintenance such as mowing.[9]

Image courtesy of Harris County Engineering Department

City LID Criteria

The City of Houston has LID criteria as a part of its infrastructure design manual. Similar to Harris County, LID elements are not required and there are no incentives to promote their use (although the city is studying an incentive program at this time). They can be used to replace the required amount of detention. The design manual lays out the specific requirements that any LID element must meet in order to count towards the detention requirement and to pass inspection.

Example of City LID Project

Darling Street/Cottage Grove Demonstration Project, Central Houston – In partnership with the Texas Commission on Environmental Quality, the City of Houston and its partners implemented a large set of LID practices along a residential street. The project was conducted to demonstrate the environmental benefits of the approach, with soil and water quality testing following implementation.[10]

Image courtesy of Texas Commission on Environmental Quality (TCEQ)

Land Use & Comprehensive Planning

The Houston region is known for its limited amount of land use and development regulations in place. The City of Houston and the City of Pasadena have no zoning, but even in the region's smaller cities with traditional zoning laws, overarching land use planning and comprehensive planning play less of a role than in many other regions. This is partly a product of the role of private development in the region. Much of the region's growth occurs outside of municipalities where planning is done by developers in accordance with basic standards and as approved by a planning commission if they are within a city's extraterritorial jurisdiction (ETJ). Finding ways to connect private and public development both inside and outside of cities in more coordinated ways could benefit the region greatly. Watershed level planning efforts and the implementation of common land use controls aimed at reducing flood risks to homes and businesses would help improve resilience in the face of flood issues across the region.

Coordinate various plans in the region.

Land use planning is a long-standing method for mitigating development's flood impacts. The process can also help shore up the gaps in existing development codes and help protect sensitive ecosystems. The planning process can direct conversations about the most appropriate use of land across a region, raise public awareness about hazards, and increase the priority of hazard mitigation. Land use plans should be blended with regulations and development standards put in place at the local level that support and reinforce the plans.[12] Likewise, state and federal frameworks that require local land use plans are an essential step in seeing them implemented.[13] By using ordinances, incentives, and plans, Houston and other area cities have the ability to shape the form of, limit or prohibit development in vulnerable areas. Creating cross-jurisdictional efforts that ensure similar approaches to reducing risks in areas such as floodways would also be beneficial.

A major challenge with implementing prohibitions on development in certain at-risk areas will be the need to address existing buildings within those areas. Alternative strategies to remove existing homes from risk must be a part of overarching planning and resilience efforts. While regulations put in place by the City of Houston and Harris County may require bringing a home up to current regulations when significant repairs are done, there are no existing tools to compel or help property owners mitigate risk to a smaller scale where practical.

UPDATED REGULATIONS SINCE HURRICANE HARVEY

After Hurricane Harvey, local leaders immediately moved to update development regulations, with both the City of Houston and Harris County making significant changes since the storm. As noted above, some key elements have not yet been updated, such as the assumed rainfall durations and rainfall intensity.

City of Houston Updated Regulations

Chapter 19, Floodplain Ordinance

The City's post-Harvey flood ordinance relies primarily on requiring higher structural elevations based on the 500-year floodplain, up from earlier regulations based on the 100-year floodplain. This change was in response to the impact of Hurricane Harvey, which was estimated to have damaged nearly 210,000 homes inside the city; 123,790 of those were outside of the 500-year floodplain.[14] In applying new elevation requirements to all structures built within the 500-year floodplain, the city's regulatory changes effectively anticipate that on future floodplain maps that incorporate new rainfall data in floodplain calculations, the city's current 1% AEP event will more closely mirror the existing 500-year floodplain.

Some key changes included:

- Requiring that new structures inside the 500-year floodplain be built to 500-year base flood elevation (BFE) + 2 feet, up from 1 foot above 100-year BFE.
- Requiring higher elevation standards to be put into place as a part of major renovations. The same elevation standards of 500-year + 2 feet apply if more than one-third of a building's footprint is being added.

Table 1 compares the City of Houston's prior regulations with the updated regulations. It does the same for Harris County regulations, discussed after the table. The City of Houston regulations are in force for newly constructed or substantially improved (more than 50 percent of the existing structure) homes and buildings situated inside the 500-year flood plain inside the city. In a supporting policy analysis document released in March 2018, the City argued that while the additional elevation requirements might add between $11,000 and $32,000 per home built, they would also create many times that in savings by preventing future flooding. It also found that 84 percent of all the homes flooded during Harvey would not have been impacted by flooding if they had been built to the 500-year plus 2 feet standard established in the new regulations.[15]

Notably, the City's changes did not impose greater standards outside of the 500-year floodplain, where the majority of structures impacted by flooding damage during Harvey occurred. The current standards require the base floor to be 4 inches above the crown of the street, which is lower than Harris County's standard of one foot above the crown. This lower regulation may limit the City's ability to address the impacts of localized flooding on new buildings outside of mapped floodplains.

In general, additional attention to areas outside of mapped floodplains could help the region better understand and account for the risks residents face in those areas. Such work can also identify how new development outside of floodplains, which faces fewer regulations, may impact both localized and downstream flooding. The Greater Houston Flood Consortium's Drainage and Detention Regulation document lays out some additional information about the need to better calibrate detention standards across the region—both inside and outside of mapped floodplains. As it stands, Houstonians have turned to lawsuits to look into how development outside of floodplains has exacerbated localized flooding issues, but, unlike wider development standards that could be applied across the city, this is an inherently unequal tool only available to those groups or individuals with the financial resources to utilize it.[16]

Infrastructure Design Manual, Chapter 9 and 13

Before Hurricane Harvey, the City of Houston initiated a drainage and development taskforce to examine the city's approach to drainage and development. The effort took on greater meaning after the storm. The report was released in February 2018 and influenced the updating of the City's Infrastructure Design Manual.[17]

The taskforce's findings focused on three elements—detention, fill, and encroachments on city right of ways.

The city updated its infrastructure design manual in September 2018 to reflect many of the recommendations from the taskforce.

Select changes included:

- Requiring redevelopment to meet the same detention requirements as new development and counting all existing impervious cover toward requirement.
- Including detention credits for green infrastructure elements.
- Removing a previous one-acre threshold and now requiring that all new development not alter existing overland flow or redirect flow to adjacent property.

The City's Public Works Department is also currently studying what types of incentives could be given for additional LID or green infrastructure pieces.

Rebuild Houston

In November 2018, City of Houston voters approved an extension of the Rebuild Houston program, which includes use of a drainage fee to pay for street and drainage improvements. The vote makes the program a part of the city charter. While the program is not a regulatory mechanism, it effectively dictates that the city spend a certain amount of money on drainage and streets. The program, therefore, could play a role in working to weave green and gray infrastructure together. It also serves as a disincentive to development patterns that pave large areas of sites for low-value development as compared to more urban development.

Harris County Updated Regulations

Harris County Floodplain Management Standards (Amended Dec. 2017)

Harris County updated its floodplain management standards in December 2017, resulting in several changes aimed at reducing flood risks.[18] Table 1 shows the changes between the old and new regulations.

Select key changes included:

- Elevating new structures in the floodway 3 feet above the 500-year flood, up from 18 inches.
- Elevating new structures in the 100-year floodplain 2 feet above the 500-year flood, up from 1 foot.
- Requiring new structures built outside of the 500-year floodplain to build 1 foot above nearest grade or street, up from no requirement. This provides the county with greater oversight of development outside of the mapped floodplains.

Harris County Flood Bond

In addition to updated regulations, in August 2018 county voters passed a major bond of $2.5 billion, which is slated to support a range of flood control projects. Many of these projects have elements of green infrastructure as a part of the approach, largely in the form of greenspace tied to detention, right-of-way purchases in floodplains, and mitigation banking efforts, which account for about 30 percent of the bond proposal projects.[19] While there are multiple neighborhood-level drainage projects, no specific LID or green infrastructure are spelled out in the bond package. Similar to Rebuild Houston, this funding offers an opportunity to pay for integrated green and gray projects.

Major Changes in Regulations since Harvey

	Floodway	1% Floodplain (SHFA)		0.2 % Floodplain	Outside
		A1-30, A99	AO/AH (shallow flooding)		
CITY OF HOUSTON (NEW)					
Finish Floor Elevation	Lowest habitable floor = 0.2% BFE + 24 inches 12 in. above manhole or 4 in. above crown of street or 24 in. above grade	Lowest habitable floor = 0.2% BFE + 24 inches 12 in. above manhole or 4 in. above crown of street or 24 in. above grade	Lowest habitable floor = depth no. + 24 inches If no depth no. => adjacent grade + 36 inches. 12 in. above manhole or 4 in. above crown of street or 24 in. above grade	Lowest habitable floor = 0.2% BFE + 24 inches 12 in. above manhole or 4 in. above crown of street or 24 in. above grade	12 in. above manhole or 4 in. above crown of street or 24 in. above grade
Balancing Fill	Fill not allowed Fill conveyance offset volume requirement	No net fill on site		Fill must not affect 100 year overland sheet flow in watershed	
Foundation Types	Elevated floor construction Structural members = 0.2% BFE + 36 inches				
CITY OF HOUSTON (OLD)					
Finish Floor Elevation	Lowest habitable floor = 1% BFE + 12 inches 12 in. above manhole or 4 in. above crown of st.	Lowest habitable floor = 1% BFE + 12 inches 12 in. above manhole or 4 in. above crown of st.	Lowest habitable floor = depth no. + 12 inches If no depth no. => adjacent grade + 3 ft. 12 in. above manhole or 4 in. above crown of st.	Critical buildings floor = 0.2% BFE + 12 inches 12 in. above manhole or 4 in. above crown of st.	12 in. above manhole or 4 in. above crown of st.
Balancing Fill	Fill not allowed Fill conveyance offset volume requirement	Fill mitigation required			
Foundation Types	Pier and beam Structural members = 1% BFE + 18 inches				
HARRIS COUNTY (NEW)					
Finish Floor Elevation	Lowest habitable floor = 0.2% BFE + 36 inches If non-conforming, 12 inches above crown of adjacent street or nearest grade	Lowest habitable floor = 0.2% BFE + 24 inches If non-conforming, 12 inches above crown of adjacent street or nearest grade	Lowest habitable floor = depth no. + 36 inches If no depth no., => adjacent grade + 6 ft If non-conforming, 12 inches above crown of adjacent street or nearest grade	If non-conforming, Lowest habitable floor = 0.2% BFE If non-conforming, 12 inches above crown of adjacent street or nearest grade	If non-conforming, 12 inches above crown of adjacent street or nearest grade
Balancing Fill	No fill allowed	Fill mitigation required			
Foundation Types	Open foundations eg. piers or openings in continuous walls Lowest structural member > 0.2% BFE + 36 in. No basement in residential or commercial	Open foundations eg. piers or openings in continuous walls No basement in residential	No basement in residential		
HARRIS COUNTY (OLD)					
Finish Floor Elevation	TOS = 1% BFE + 18 in.	Lowest habitable floor = 1% BFE + 18 inches Or raised to level of crown on adjacent street[1]	Lowest habitable floor = depth no. + 18 inches If no depth no., => adjacent grade + 3 ft		
Balancing Fill	No fill allowed				
Foundation Types	Posts or pilings	Open foundations eg. piers or openings in continuous walls			

[1] *Old regs had 10% floodplain regulations: Finish Floor = 10% BFE + 24 inches and foundations need openings.*

Note: City of Houston regulations come from City Ordinance, Chapter 19 and Harris County from Regulations of Harris County, Texas for Floodplain Management, Chapter 4.

BEST PRACTICES

The remainder of this report outlines ideas and best practices from case studies from across the U.S.

Risk Maps Data

Base local regulations on up-to-date risk maps that rely on the most current data about rainfall and topography and that account for all forms of flooding. Establish regular reviews of floodplain maps. Underpin all of this with adequate education and outreach to residents about the risks they face.

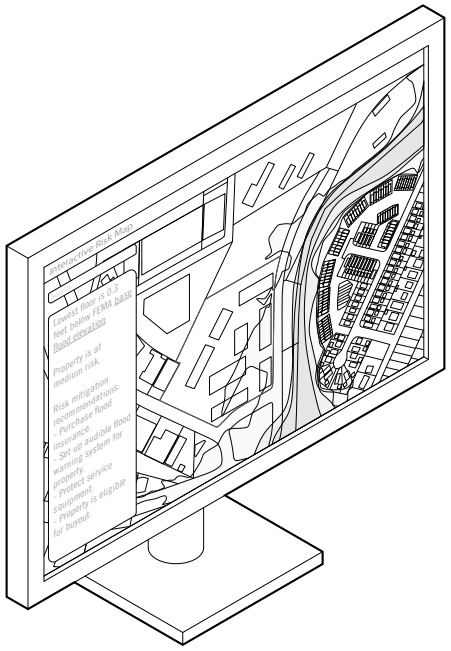
The City of Houston and Harris County rely solely on conventional floodplain maps. HCFCD has produced the maps used in the region since the 1980s. While the district is in the process of working with FEMA to update the maps to include new rainfall levels for 100-year events as well as on updated models and mapping methods, at this time it is not moving toward implementing broader risk mapping that would include issues with overland flow in areas far from riverine floodplains. Similarly, while HCFCD[20] and City of Houston[21] each have interactive tools to help residents locate their homes in relation to floodplains, the systems are not as comprehensive as those in place in other peer cities nor do they account for all forms of flooding. The HCFCD tool does account for ponding outside of floodplains, but not overland flow risks. Overall, Hurricane Harvey demonstrated that there is a clear need across the region to more appropriately inform residents of the risks they face.

The states of North Carolina[22] and California[23] work closely with FEMA and private engineering firms to produce broader risk maps that are made available to the public through accessible web interfaces. North Carolina's Flood Risk Information System provides a wealth of information to residents and ensures that the most up-to-date information is easily available and accounted for in risk maps.[24] North Carolina presents both the FEMA maps and those developed by the state in partnership with private engineering expertise in an attempt to provide the most information possible to the public at the widest scale. The current system allows residents to zoom to a specific property and see the flood risk for a variety of storm levels for that location. The tool also includes a "Reduce My Risk" tab that displays a variety of mitigation options and their estimated cost for that property.

The California Coastal Analysis/Open Pacific Coast study began in 2011 with the intent of remapping both coastal flood risk and wave hazards for the entire southern California coast. Beyond flood risk, the State of California uses its "MyHazards" site to display public information about different forms of risk that residents face.[25] By entering an address a resident can find not only the level of risk they face for flooding, but also for earthquakes and wildfire.

Tulsa, Oklahoma is one of the leading cities in both its proactive approach to flood risk mapping and on providing good information to its residents. The city has expanded the existing regulatory floodplains beyond what FEMA designates by identifying additional areas that are subject to shallow flooding or that have a large drainage area that could impact other properties. Different permitting requirements apply in these special areas and in the general FEMA floodplains. The Director of Public Works is also specifically charged in city code with keeping floodplain information up to date, including the collection of data and information beyond what FEMA produces. The city also has a robust repetitive loss area planning program. For residents living in communities surrounding repetitive loss properties, the city provides a full repetitive loss planning document and ensures that residents are informed about the mitigation approaches being undertaken.[26]

Similarly, Charlotte and Mecklenburg County in North Carolina rely on "community floodplains" that account for the impacts of future growth on the current floodplains. The use of this tool allows for more careful planning and a more expansive floodplain that can help reduce long-term risk.[27]



Incentives for Green-Gray Infrastructure

Use regulation and incentives to pursue improved green-gray infrastructure approach. Account for projects at many scales, from single lots to regional infrastructure systems.[28]

As previously discussed, Harris County and the City of Houston each have LID and green infrastructure guidelines, but do not obligate or incentivize the use of the programs. Several other cities and counties rely on a wide array of incentives and regulations to ensure that green infrastructure elements are implemented.[29] LID practices can create a mutual benefit by detaining water on individual properties and reducing runoff.

There are a number of LID incentives on the books in cities across the U.S.

Philadelphia offers LID retrofit incentives to commercial, condominium, and large multi-family properties that update their properties to include stormwater management practices and LID elements. The use of a range of elements can allow for the reduction of stormwater fees. There are also incentive programs to encourage the use of green roofs and grant programs to help assist in the funding of a broad range of strategies.[30] Several of the grants are available to single-family homeowners as well.

Dallas incentivizes LID by offering system development charge credits and residential density bonuses to developers.[31] The system development charges are used to cover the costs to the city to provide water/wastewater and streets to new development. In exchange for LID practices that reduce the amount of stormwater runoff, developers can see reductions to those fees. Density bonuses allow developers to build more units or a higher building in areas where they would otherwise be limited as a benefit of mitigating some of the building's impacts.

Similarly, San Antonio offers two primary incentives for voluntarily implemented LID—development offsets/credits such as density bonuses and fee-based discounts on stormwater fees.[32] The fee discounts are on stormwater fees. The San Antonio River Authority also offers programmatic incentives through the Watershed Wise Rebate which provides funds for LID projects that improve water quality.[33]

Chicago operates a broad-based Green Permit Program that offers expedited permitting and potential reduction of permit fees for projects that include a variety of LID practices such as green roofs.[34]

There are also a number of examples of programs that incentivize property owners to implement green stormwater infrastructure elements on individual lots. Seattle offers a rebate to homeowners within targeted sewer overflow areas with rebates for a range of green stormwater infrastructure and LID practices. The program also offers a range of grants and loans to help all residents cover upfront costs of projects.[35] Montgomery County, Maryland, for example, offers up to $7,500 per parcel in rebates to homes, and $20,000 to commercial properties that implement green infrastructure practices ranging from rain gardens to permeable pavements.[36] The rebates are funded out of the county's water quality protection charge.

Several cities have gone a step beyond LID incentives to look at full-fledged LID ordinances that require the use of certain LID practices.

Los Angeles has developed an award-winning stormwater program to guide flood prevention and the reduction of pollutants using an integrated approach.[37] The city realized the need for a unified vision to dictate planning, budgeting, and funding efforts to optimize the improvement of stormwater quality and reduce flood related risks.[38] In combination with efforts such as the 2009 Water Quality Compliance Master Plan for Urban Stormwater Runoff, the City of Los Angeles passed a 2011 LID ordinance which requires development and redevelopment projects to mitigate stormwater runoff by capturing it on-site with nature based infrastructure.[39]

In 2009, Flagstaff, Arizona passed an ordinance that requires LID to be used for retention and infiltration to treat and control the first inch of stormwater runoff from impervious surfaces for sites that have a detention requirement. The program is unique because it was structured to be implemented on a rolling schedule. The first year of the program was voluntary. During the second year, developments were required to treat the first half inch of rainfall. During the third year and beyond, the full one inch guideline was required to be met.[40] The goal of the program is to mitigate downstream flood impacts from stormwater and to protect water quality. The city's LID policy was designed to be supported by a series of LID resources including a Guidance Manual for Site Design and Implementation [41] and a design spreadsheet to assist with the sizing of detention basins for sites using LID.

Tree and shrub ordinances can aid in the creation and encouragement of LID and green infrastructure practices. Trees can serve as a link in the urban stormwater treatment network by intercepting rainfall, delaying runoff, and increasing stormwater dissipation through infiltration and transpiration. Trees in the

City of Houston were estimated to reduce stormwater volume flowing into bayous and storm drains by 173 million cubic feet per year providing a total value of $7.8 million annually.[42] Increasing the requirements to have more trees placed on new development could increase capacity for stormwater retention. The city currently requires one tree to be planted or preserved on residential sites of less than 5,000 square feet and two on those larger than 5,000.[43] The focus of the city's current regulation is that trees be placed along rights-of-way, though they can be placed elsewhere on the property. For non-residential properties, the city lays out a requirement that developers place one tree on the frontage along the street for every 30 linear feet of outside property lines, and one tree inside a parking lot for every 10 parking spots. There are a variety of ways for developers of both residential and non-residential properties to get credits for preserving existing trees.

Portland has a robust tree ordinance that requires that a "tree area" be set aside on all new development. Tree area is calculated as percentage of the property area, including 40 percent of all single and double residential uses and 20 percent of multifamily sites. Within the tree area, the city requires that at least six trees be planted for every 1,000 square feet of tree area across all uses.[44] It also requires a variety of types of trees to ensure the healthy development of a canopy.

Gray Infrastructure Standards and Maintenance
Ensure that existing gray infrastructure is in good working order. Use adequate design risk levels to account for changing storms. Gray infrastructure must be large enough to handle major events.

The City of Houston and Harris County already operate several programs that focus on repair and maintenance. Rebuild Houston, the Storm Water Action Program, and the Harris County Flood Control Bond all offer the chance to significantly improve existing infrastructure. These efforts should be continued and applied to a mix of both green and gray infrastructure. Finding ways to use these funds to encourage and support property owners in implementing green infrastructure elements on individual properties could be beneficial as well.

The City of Houston and Harris County should consider strengthening the severity of storm that sets the standard for models and flood control infrastructure in order to shape adequate infrastructure. Currently, the design storm is the storm that has a 1% chance of happening in any year, also known as the 100-year flood. Raising this design storm standard could lead to the construction of larger capacity in the region's gray infrastructure. This could apply to every stage of the system from street storm drainage capacity to overall bayou conveyance. Of course, a larger design storm would mean higher costs for infrastructure projects that could not likely be met by local funding alone.

The Netherlands relies on massive gray infrastructure built to withstand 10,000-year flood levels, but those elements are just one piece of a multi-level approach. The Dutch invest in several interlocking pieces of flood resilience at a number of scales. This includes spatial planning, elevation, evacuation, floating homes, underground homes, secondary levees, community-based disaster response, green infrastructure, water management, and land reclamation. The nation's mixture of gray and green infrastructure is a model other nations and cities could emulate.

A channelized bayou

Special Regulations for Vulnerable Areas

Consider options for limiting development in areas identified as risk-prone. This could take the form of 1) prohibition on development in specific areas; 2) the use of easements or the transfer of development rights to keep vulnerable areas undeveloped; or 3) encourage the purchase of land by public or private entities with the intent of building on the area's successes with conservation and preservation of greenspace

Prohibition or Limited Development

The City of Houston and Harris County could consider fully prohibiting certain types of development in floodways or along particular buffer zones near bayous and other waterways. There are a variety of ways to create such an approach. Similar to other land use controls that Houston does exercises, it could prohibit construction of buildings within a certain distance of waterways through an ordinance. Or it could allow only less vulnerable uses such as golf courses or other, more flood resistant, uses. There is concern that such a move would encounter stiff legal resistance, as a move in the mid-2000s did. , which resulted in regulations that raised standards on development in floodways but did not prohibit it, However, there is a stronger case to be made today for the public safety need to eliminate development that cannot safely be evacuated during a flood event. Iif done in conjunction with detailed variances or with buyout funding or other financial support for landowners in effected areas, a new approach could be more successful.

Some cities have approached prohibition of construction in the floodplain through other means. In Pierce County, Washington, non-developed land in the floodplain is preserved through the combination of state and local rules. The State of Washington allows for the creation of urban growth boundaries, but couples that with a requirement to have a comprehensive urban growth area plan. Outside of the urban growth area only low-density building is allowed, which helps control the development and populations outside of urbanizing areas. This in effect helps preserve natural landscapes. In Pierce County, home to Tacoma and just south of Seattle, the urban areas plan prohibits including new areas of the floodplain in plans for future growth. This effectively prevents their development. In Tulsa all forms of development within floodplains in the city have additional permitting requirements that require developers to meet a broader set of rules and that permit the city to block development that creates greater risks for the broader public.

Development in vulnerable areas

A watershed or buffer zone ordinance also may work well for Houston given its lack of zoning regulation and inability to do traditional overlay zoning. Aquatic buffer zone ordinances have not been pursued in many areas, but a good deal of model legislation exists from EPA and other entities. Austin has a history of protecting water resources and mitigating flood impacts through the establishment of waterway ordinances. The city created two categories of stream buffer guidelines (critical water quality zones and water quality transition zones) within its land development code. Requirements for development within each zone are then based on five watershed classifications as well as whether or not the water resource is used for water supply. With few exceptions such as open space, trails, and utility crossings all development in the five watershed types is prohibited in the critical water quality zones.

Short of full prohibition, Houston and Harris County could create regulations for specific areas that allow for greater oversight and require greater approval for vulnerable areas than what exists today. The previously-discussed watershed-based ordinances in Austin offer a way to regulate specific locations without creating blanket, citywide requirements. Short of a complete prohibition of development, building in previously identified vulnerable areas could be subjected to additional regulations or permitting. Existing regulations could be updated in select geographies

Easement and Transfers of Development Rights

Another tool that could be considered to minimize concerns about reducing property values of land within floodways or floodplains would be to create a way for landowners to transfer development rights for areas where new development is prohibited. The transfer of development rights is used frequently in California as a part of land management practices. In most cases, the owner of a property that will be protected sells the "development rights" to a developer who purchases them as a way to add density or height to another project. In this manner the landowner whose land has changed prospects is being compensated and a more sustainable, less risky form of development is being encouraged. While Houston does not have many of the density and height caps of other cities that make the transferring of development rights attractive, an altered version of this idea could be pursued tailored to the city's existing land use controls. For example, limited height requirement could exist adjacent to major activity corridors and in some situations an exception to those requirements might be attractive to a developer. Similarly, a developer could purchase development rights in exchange for an alteration to setback requirements.

Purchase of Land for Greenspace Conservation

The Houston region has numerous greenspace preservation and acquisition initiatives that can serve as the backbone for the implementation of a broader prohibition of development in risk-prone areas. The expansion of park, conservation, and greenway areas would keep more territory in risky areas from being developed. Strategic acquisition of these conservation properties will help with downstream impacts of upstream development. Large expanses of land exist in surrounding counties that can provide implementation of large-scale conservation projects for stormwater management. But even smaller scale, more fragmented conservation projects can have a large impact; as more are added in a watershed, the positive impacts compound. Both types of projects play a critical role in greenspace conservation, which is an important tool in the flood mitigation toolbox.

Grandfathering

Create programs that address grandfathered buildings in floodplains and areas outside of floodplains. Ensure that residents in areas with these homes have access to a wide array of solutions, including financial resources and regulations that support more resilient solutions.

For property owners with buildings inside the existing floodplains, reconstruction of damaged homes can be expensive. This is especially true in homes where damage costs trigger the requirement of meeting new floodplain standards. Under Houston's new regulations this can require significant elevation costs. In low-income areas of the city and county, these costs may be greater than the value of the home itself. This leaves property owners with few viable options to fix their homes or recoup their investment in it. In some cases residents will either need to live in a damaged home or abandon it.

Some regions dealing with disaster have explicitly created funding streams to help low-income homeowners deal with meeting the criteria for repairs that meet new standards. In New York after Superstorm Sandy, for example, the state used the New York Homeowner Recovery Program to support low-income households in paying for elevation of homes to new standards.[45] The City of Houston Action Plan has a similar plan, but does not explicitly aim to grant funds for elevation or help homeowners with substantial damage.[46]

A different, but pressing issue is the fact that large numbers of homes outside of the existing 500-year floodplain were damaged during Harvey and previous storms. Providing property owners in this situation with options to mitigate their risk is essential.

One tool already used by the region to address the issue of older flood-prone homes is buyouts.

For homes inside the floodplains that cannot be reasonably repaired, buyouts and relocations are an essential tool. When pursuing buyouts and relocations all efforts should be made to expedite the process so residents can recover as quickly as possible. When buyout funding is available months if not years after a storm, the number of residents interested in the program decreases. There is a clear need to reform the way the federal buyout funding process works in order to reduce the time it takes for federal funds to become available. The Consortium's Strategies for Flood Mitigation in Greater Houston, Edition 1, and the Kinder Institute's Rethinking Disaster Recovery and Mitigation Funding in the Wake of Hurricane Harvey, each discuss the types of reform needed at the federal level.

The need for expedited buyouts and the creation of buyout funding was noted in the Kinder Institute's Case Studies in Floodplain Buyouts report[47] and in the Texas General Land Office's Hurricane Harvey: Texas at Risk report.[48] In shaping the use of local funds for buyouts, local jurisdictions can create programs or regulations that alter existing cost-benefit formulas used for federally funded buyouts. In many cases, the existing formula favors high-value homes as targets for buyouts, limiting the applicability of the program to low-income areas. Local funding mechanisms can be designed to address this equity issue and ensure programs are available to all residents. One existing local funding mechanism, Rebuild Houston, could be altered to include support for an expedited buyout fund. This would likely require the raising of the drainage fee for the program and the amending of the city charter to allow such a use.

Buyout and relocation strategies should also be tied closely to greenspace strategies and connected to broader projects. Harris County has a great deal of experience in buyouts and has a large proportion of the bond proposal dedicated to that purpose. In addition to doing reactive buyouts in damaged areas, the region should consider ways to fund a program for expedited buyouts and relocations in future events.

The City of Charlotte and Mecklenburg County's stormwater services department has not only operated a buyout program similar in scale to Harris County's, but has also established a rainy day fund from local funding to pay for buyouts immediately after a storm. The Quick Buys program prevents residents in damaged homes from spending money on repairs only to have the house bought out some time in the future. The city and county also operate a risk-based buyout program funded by local money raised through stormwater fees. Both local and state funds are used to assist with relocation of bought out households.

Programs that help remove people from harm's way should connect with and support the outcomes sought by regulations. For example, buyout programs should feed into regulatory work that aims to reduce the populations of people living in vulnerable places.

In addition to buyouts, retrofits of existing homes could be a valuable tool.

Retrofitting and other smaller interventions offer an opportunity to reduce risk to homes outside of the mapped floodplains or with low levels of risk. In practice, retrofitting is an effort to either allow a structure to flood without damage or to resist flood water and keep it out of a structure. FEMA terms these retrofit practices "wet floodproofing" and "dry floodproofing," respectively. These strategies are almost always pursued on a lot by lot, building by building basis. Wet floodproofing is usually allowed for many secondary building types—garages, barns, and other outbuildings that are not likely to take significant damage or result in a public safety threat. Dry floodproofing is used in most cases for commercial buildings, but FEMA provides guidance for use in homes.[49] Floodproofing is rarely a stand-in for elevation because it only applies in certain flood zones, for certain levels of flood risk, and for certain types of structures. In select cases, however, it can be far less expensive and reduce the vulnerability of homes. Such cases have not yet been identified for the Houston area.

The current Houston floodplain ordinance includes floodproofing as a viable tool to be used for structures within the 500-year floodplain, but outside the 100-year floodplain. Inside the 100-year floodplain the city only allows the use of floodproofing on non-residential buildings and mainly for the protection of sanitary sewers and utilities.

Expanding regulations to require or incentivize a broader population of residents and property owners to use floodproofing could reduce the amount of damage in future storms. This is likely to be most helpful in areas where flooding tends to occur at lesser depths and without velocity. A key tactic would be to secure financial support for floodproofing efforts, through programs such as the FEMA Flood Mitigation Assistance Grants, U.S. Department of Housing and Urban Development Community Development Block Grant—Disaster Recovery funds, and the use of local funds. Charlotte-Mecklenburg runs the retroFIT program to offer 75-95 percent of cost reimbursement for projects that help address flooding issues in commercial and resident homes that are not a part of other major projects.[50]

Finally, regulations could require that any home repairs after flooding use more resilient materials. Following FEMA regulations, the City of Houston and other local jurisdictions require homes where damage exceeds 50 percent of the value to be brought up to new standards. Homes with less damage, though, can be rebuilt in current form. Intermediate regulations could require or promote materials and construction practices that make these homes somewhat more resilient when they are reconstructed.

Simplify Jurisdictional Responsibilities

Adopt programs and initiate collaborative partnerships that can reduce the mix of jurisdictions responsible for permitting and oversight on development within the region.

Development in Harris County is controlled to a great extent by the City of Houston and its planning commission. The city possesses a large extraterritorial jurisdictional within which it approves all development plats (site plans). The county cannot regulate development, but it does issue floodplain permits. This mixture of approving agencies and rules can be confusing and lead to gaps in management and oversight of development. It also puts hurdles in front of developers and residents who must aquire set expertise to navigate the required steps.

Previous Consortium documents have shown how jurisdictional lines can lead to properties' sitting in one jurisdiction but having water systems draining to another.[51] These documents outline a lack of clarity over which entities oversee different elements of the flood control system. For example, the HCFCD is primarily responsible for creeks, tributaries, and bayous, but in some cases the City of Houston owns and maintains smaller channels. Clarifying such conflicting responsibilities has been a point of discussion since Harvey. Additional collaboration and clarification through direct structural changes could be beneficial.

Multiple jurisdictions have established ways to reduce this mix. In Charlotte-Mecklenburg the city and county merged their stormwater service departments into one broad department. While the city and county still oversee employees within the department, their roles and assignments are clear to all. In Tulsa, the city maintains a standing task force on drainage and flood control infrastructure to solicit direct input from residents and local agencies. This group offers a constant cycle of feedback. Finally, some regions have created cross-jurisdictional positions tasked with overcoming artificial regulatory boundaries and working to coordinate flood control efforts. In Massachusetts, for example, several communities on Cape Cod have installed a shared Community Rating System organizer to coordinate their efforts.[52]

Rotterdam, Netherlands, provides a good case study for coordinating across not just local entities, but also with state and national actors on development and water management issues. The city of Rotterdam has adopted multi-level integrated water management and spatial planning/neighborhood redevelopment policies that focus on multiple goals and benefits, including reduced flood risk and increased resiliency. Rotterdam's municipal policies and regulations for water management, however, must align with those established by the regional water authorities, as well as those of the provincial and national governments. As a result, a considerable amount of the large flood risk management infrastructure in or impacting Rotterdam is under the authority of regional water boards, the provincial government, or the national government, not the municipality. Thus, the flood risk profile of Rotterdam is a function of policy and investment in projects from various governance levels. The Dutch "Room for the River" program is an excellent example of green and gray infrastructure implemented with a multi-level regulatory approach.[53]

Changes to state law could change regulatory jurisdictions, placing all flood regulation within a single entity across Harris County or beyond. This would allow regulations to be easily coordinated across watersheds and prevent projects from falling through the gaps. Further, it would offer homeowners and developers a single place to go to address all their flooding permits.

However, new laws are not required for agencies to better coordinate. Much like Houston TransStar has brought multiple transportation agencies under one roof, local jurisdictions could create a joint office where staff from multiple agencies work together, each exercising their own legal jurisdiction but coordinating more directly.

These examples offer very different scales of response to the jurisdictional challenges and each offers an approach to simplifying regulation and encouraging coordination.

Existing housing

Holistic Regulations

Create interconnected development regulations building for resilience, not just to prevent flooding.[54]

Currently most of the local jurisdictions in the Houston area address flood control and floodplain regulation as separate elements from other resilience-related issues. While flood control is certainly a pressing issue locally, it is interconnected with other elements such as sustainable development, greenhouse gas reduction, and development standards. It would be beneficial for Houston, Harris County and other jurisdictions to approach regulation with an eye toward tackling multiple vulnerabilities or encourage the pursuit of broader resilience goals. The 100 Resilient Cities (100RC) process that the City of Houston has recently launched offers the opportunity to think through ways to encourage policies and strategies that accomplish a broad set of resilience goals.

Norfolk, Virginia used its 100RC process to jump start just such an intervention. In recent changes to its zoning and land use controls, Norfolk installed a series of broad-based resilience regulations. The most pertinent is the addition of a "resilience quotient" to its building standards code. This rule requires that all new development be able to include several resilience building measures into all projects in order to obtain needed permits. While flooding and sea level rise are two of the city's major challenges, the jurisdiction used its code to address not only those issues but others as well. The quotient includes measures aimed at general risk reduction (wind-load, storm-resistant windows, elevated buildings), stormwater management (LID practices, greenspace and trees) and energy resilience (shade and electric vehicle stations). Most new development must account for at least some measures from all three categories.

Residents in homes and buildings situated outside of the mapped floodplain often face flooding issues. However, residents of these areas are either unaware of the risks or unprepared for those impacts in terms of having insurance or on-site mitigation strategies. Creating additional regulatory zones for areas outside of the mapped floodplain could help address this issue and provide a foundation for additional education and outreach. Like the examples of Tulsa and Charlotte cited under Best Practices, Cedar Falls, Iowa, established a floodway fringe zone for areas just outside of the 500-year floodplain, and the city has put into place new standards there. Houston could take a similar approach by seeking additional regulations, such as LID interventions or retrofitting (, that result in less vulnerable homes outside mapped floodplains.

Which Authorities Do You Need Approvals from at Each Site?

		Site Located In		
Drains to Facility Operated by	**Regulation Type**	**Houston City Limits**	**Extraterritorial Jurisdiction**	**Unincorporated Harris County**
City of Houston		A	B	C
	Detention & Outflow	City of Houston	Harris County	Harris County
	All Other Flood Regulations	City of Houston	Harris County	Harris County
	Platting, Code, & Other Permits	City of Houston	City of Houston	Harris County
Harris County		D	E	F
	Detention & Outflow	Harris County	Harris County	Harris County
	All Other Flood Regulations	City of Houston	Harris County	Harris County
	Platting, Code, & Other Permits	City of Houston	City of Houston	Harris County
HCFCD		G	H	J
	Detention & Outflow	HCFCD	HCFCD	HCFCD
	All Other Flood Regulations	City of Houston	Harris County	Harris County
	Platting, Code, & Other Permits	City of Houston	City of Houston	Harris County
TxDOT		K	L	M
	Detention & Outflow	TxDOT	TxDOT	TxDOT
	All Other Flood Regulations	City of Houston	Harris County	Harris County
	Platting, Code, & Other Permits	City of Houston	City of Houston	Harris County

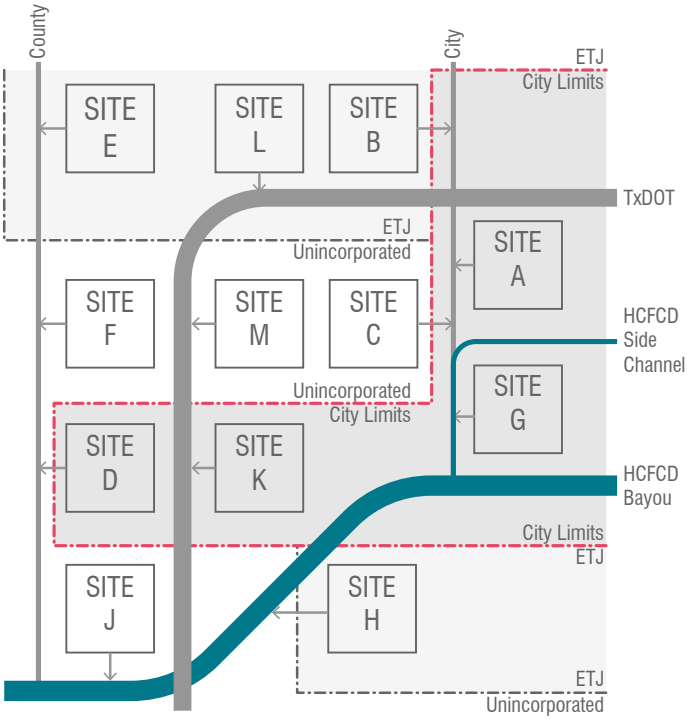
These requirements would be in addition to regular floodplain regulations and would require that development be built to a higher standard. Ultimately the goal is that more comprehensively resilient building will result in a community that is more resilient to a variety of shocks, not just flooding.

Enforcement

Authorize counties to respond to challenges and enforce regulations using ordinances, which could have benefits beyond flood control.

As mentioned above, counties and cities in Texas do not have equal enforcement powers when it comes to development. This limitation is particularly problematic for fast-growing, urban counties, such as Harris County, that have few tools to deal with rapid growth. While the county approves floodplain permits for development, it does not have direct say over all building standards, nor can it stop illegal development in the same manner that a city can.

One way to address this issue, as laid out in a recent Kinder Institute report on regional governance, would be to empower counties with ordinance-making ability.[55] This would allow Harris County to more directly oversee development in its territory.



CONCLUSIONS

None of Houston's flood vulnerabilities can be addressed by a single set of regulations. Rather, taking a broad approach that begins with accurate data and information about risk, relies on a broad toolbox of infrastructural options, and uses land use control in proactive, well-planned ways can help reduce the risks the region currently confronts.

The best practice case studies outlined here are not intended to be directly translated to Houston, rather, the region should take pieces of the lessons learned in other cities and regions and work to apply them here. Flexible but effective regulation that enables the implementation of resilience building systems at numerous scales is critical.

CONTRIBUTORS

Kyle Shelton, Kinder Institute for Urban Research, Rice University

Earthea Nance, Texas Southern University

Ryan Bare, Houston Advanced Research Center

Grant Patterson, Kinder Institute for Urban Research, Rice University

For More Information Visit

Greater Houston Flood Mitigation Consortium

HoustonConsortium.com

CITATIONS

1 For a visual depiction of this confusing structure see the Greater Houston Flood Mitigation Consortium's Regulations Briefing Document, http://www.houstonconsortium.com/graphics/BD3-FloodRegulations.pdf.

2 City of Houston, Draft Local Housing Needs Assessment, September 2018.

3 Kinder Institute for Urban Research, "Governing a Growing Region: Addressing Problems of Service Provision and Development in Houston," October 2018.

4 National Research Council. Levees and the National Flood Insurance Program: Improving Policies and Practices. (2013). Washington, DC: The National Academies Press.

5 State of Georgia Property Code, § 44-7-20.

6 The American Society for Civil Engineers gave the United States an overall grade of D+ for its infrastructure in 2017. The State of Texas received low grades for its flood control, wastewater, and drinking water infrastructure. https://www.infrastructurereportcard.org/state-item/texas/

7 For a discussion of the infrastructural history of U.S. water systems see Martin Melosi, The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present (University of Pittsburgh Press, 1999). For a more global perspective on issues of underinvestment and resilience see Isabelle Anguelovski, et. al., "Equity Impacts of Urban Land Use Planning for Climate Adaptation: Critical Perspectives from the Global North and South," Journal of Planning Education and Research, September 2016, 36 (3), 333-348. Discussion of Houston area issues see John Hennenberger, "Houston flooding plan fails to provide needed investment or protect civil rights," TexasHousers, August 2016, https://texashousers.net/2016/08/23/houston-flooding-plan-fails-to-provide-needed-investment-or-protect-civil-rights/

8 Harris County Low Impact Development & Green Infrastructure Design Criteria for Storm Water Management, April 2011. https://www.hcfcd.org/media/1543/2011-final_lid_gidc.pdf

9 Harris County Engineer, Harris County LID Status and Trends, https://www.h-gac.com/community/low-impact-development/documents/6-4-15-Workshop-Harris-County-LID-Status-and-Trend.pdf

10 City of Houston, Cottage Grove Subdivision LID Demonstration Project, https://www.tceq.texas.gov/assets/public/waterquality/nps/projects/90464FinalReport.pdf

11 Harris County Low Impact Development & Green Infrastructure Design Criteria for Storm Water Management, April 2011. https://www.hcfcd.org/media/1543/2011-final_lid_gidc.pdf

12 Raymond Burby and Linda Dalton, 1994. "Plans Can Matter! The Role of Land Use Plans and State Planning Mandates in Limiting the Development of Hazardous Areas", Public Administration Review Vol. 54, No. 3 (May - Jun., 1994), pp. 229-238

13 National Research Council. 2012. Disaster Resilience: A National Imperative. Washington, DC: The National Academies Press.

14 City of Houston, Draft Local Housing Needs Assessment, September 2018.

15 City of Houston, Floodplain Management Data Analysis Chapter 19, March 2018, https://drive.google.com/file/d/1FKBVOuEzhGY-YIiNgRBz-mwHQZV6cZQo/view

16 Rebecca Elliot, "Memorial City residents sue city over flooding," Houston Chronicle, May 25, 2016.

17 City of Houston Redevelopment and Drainage Taskforce Final Report, February 2018, https://www.houstontx.gov/council/g/Final-Report-Redev-Drainage.pdf

18 Harris County Engineer, Floodplain Management Regulations, December 2017, http://www.eng.hctx.net/Portals/33/Publications/FPMRegs120517.pdf

19 Greater Houston Flood Mitigation Consortium researchers analyzed the Harris County bond proposal project list and determined that approximately 30 percent of the projects could qualify as green infrastructure. An additional 30 percent are conventional gray infrastructure projects. Project list available at https://www.hcfcd.org/2018-bond-program/bond-program-project-list/.

Type of Project	No.	%
New / Modified Channels	44	19%
Major Maintenance of Channels	15	6%
New / Improved Detention	43	18%
Major Storm Repairs	20	8%
Sediment / Silt Removal	1	<1%
Voluntary Buyouts	17	7%
Wetland Mitigation	4	2%
Preserving Natural Floodplains	6	3%
Improved Drainage	42	18%
Upgraded Flood Warning System	1	<1%
New / Improved Flood Control Structures	13	5%
Studies, Maps, Investigations, Administrative	31	13%
Total	237	

20 http://www.harriscountyfemt.org/

21 http://www.gims.houstontx.gov/FloodplainWAB/

22 https://fris.nc.gov/fris/Home.aspx

23 FEMA, Open Pacific Coast Study, 2012, http://www.vcfloodinfo.com/pdf/FEMA-Brochure_OPC_web.pdf

24 North Carolina's is a part of the state's Flood Risk Information System, https://fris.nc.gov/fris/Home.aspx?ST=NC.

25 California's MyHazards, http://myhazards.caloes.ca.gov/

26 http://maps.cityoftulsa.org/floodplains/

27 Charlotte Mecklenburg Storm Water Services, "Floodplain Regulation Technical Guidance Document," March 2008.

28 Environmental Protection Agency, "Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure," 2010. http://www.h-gac.com/community/low-impact-development/documents/Green-Infastructure-Case-Studies.pdf

29 Environmental Protection Agency, "Encouraging Low Impact Development: Incentives Can Encourage Adoption of LID Practices in your Community," 2012. https://www.epa.gov/sites/production/files/2015-09/documents/

bbfs7encouraging.pdf

30 City of Philadelphia, “Stormwater Water Retrofit Guidance Manual” https://www.phila.gov/water/PDF/SWRetroManual.pdf

31 City of Dallas Development Code, https://www.ci.dallas.or.us/DocumentCenter/View/826/Development-Code-Article-2

32 City of San Antonio Development Code, https://docsonline.sanantonio.gov/FileUploads/DSD/LIDAmendments.pdf

33 San Antonio River Authority, Watershed Wise Rebate Program. https://www.sara-tx.org/wp-content/uploads/2017/07/Watershed_Wise_Stormwater_Rebate_2017_18_Form-1.pdf

34 https://www.cityofchicago.org/city/en/depts/bldgs/supp_info/overview_of_the_greenpermitprogram.html

35 City of Seattle and King County, RainWise Program, http://www.700milliongallons.org/rainwise/

36 Montgomery County RainScape Rewards Program, https://www.montgomerycountymd.gov/water/rainscapes/rebates.html

37 City of Los Angeles, “Planning and Land Development Handbook for Low Impact Development,” 2016 http://www.lastormwater.org/green-la/low-impact-development/lid-documents/

38 City of Los Angeles, Watershed Protection Division, “Water Quality Compliance Master Plan for Urban Runoff,” 2009, http://www.lastormwater.org/wp-content/files_mf/wqcmpur.pdf

39 City of Los Angeles Stormwater Ordinance, http://www.lastormwater.org/wp-content/files_mf/finallidordinance181899.pdf

40 City of Flagstaff, Stormwater Management Design Manual, 2009. https://www.flagstaff.az.gov/DocumentCenter/View/55367/LID_Standards-Chap-9?bidId=

41 City of Flagstaff, “Low Impact Development Guidance Manual for Site Design and Implementation,” 2009, https://www.flagstaff.az.gov/DocumentCenter/View/8401/COF-LID-Manual-1-09?bidId=

42 United States Department of Agriculture, “Houston’s Urban Forest, 2015,” https://www.srs.fs.usda.gov/pubs/rb/rb_srs211.pdf

43 City of Houston, Tree Ordinance, Chapter 33, Article 5.

44 City of Portland, Tree Ordinance. https://www.portlandoregon.gov/citycode/article/514733

45 New York Governor’s Office of Storm Recovery Action Plan, NY Rising Homeowner Recovery Program. https://stormrecovery.ny.gov/sites/default/files/crp/community/documents/NYS_Consolidated_Action_Plan.pdf

46 City of Houston Local Action Plan Hurricane Harvey Housign Recovery, Homeowner Assistance Program, https://houstontx.gov/housing/Houston_local_action_plan_6.26.2018.pdf

47 Grant Patterson, Case Studies in Floodplain Buyouts: Looking to best practices to drive the conversation in the Houston region, February 2018

48 Andrew Natsios, Texas General Land Office, Hurricane Harvey: Texas at Risk, 2018. http://www.glo.texas.gov/recovery/files/texas-at-risk-report.pdf

49 Federal Emergency Management Agency, “Homeowner’s Guide to Retrofitting,” 2014, https://www.fema.gov/media-library/assets/documents/480

50 https://charlottenc.gov/StormWater/Flooding/Pages/retroFIT.aspx

51 Greater Houston Flood Mitigation Consortium’s Regulations Briefing Document, http://www.houstonconsortium.com/graphics/BD3-FloodRegulations.pdf

52 https://www.floodsciencecenter.org/products/crs-community-resilience/success-stories/barnstable-county-massachusetts/

53 https://www.ruimtevoorderivier.nl/english/

54 Kinder Institute for Urban Research, “Governing a Growing Region: Addressing Problems of Service Provision and Development in Houston,” October 2018.

55 Kinder Institute, “Governing a Growing Region.”