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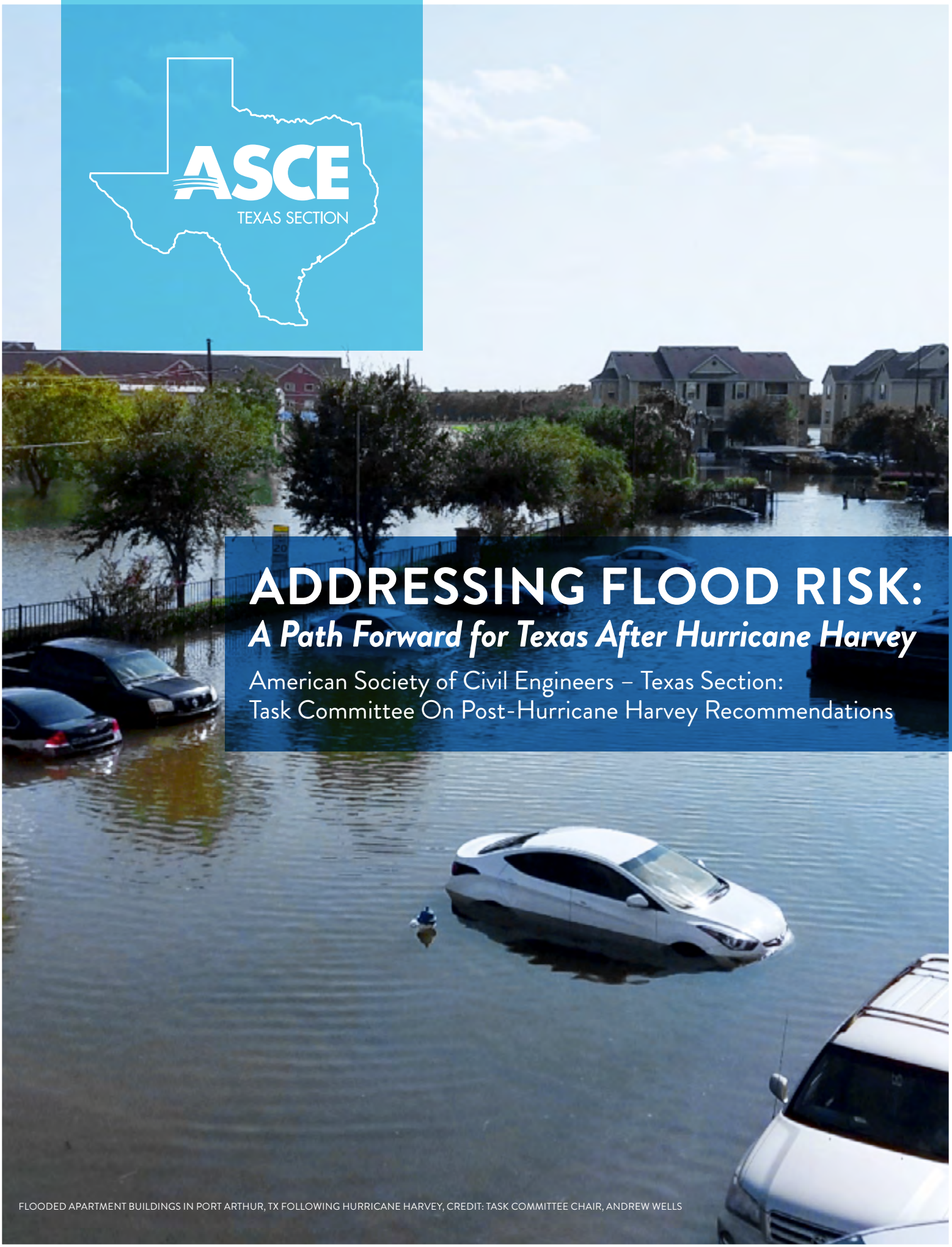
ADDRESSING FLOOD RISK:

A Path Forward for Texas After Hurricane Harvey

American Society of Civil Engineers – Texas Section:
Task Committee On Post-Hurricane Harvey Recommendations



FLOODED APARTMENT BUILDINGS IN PORT ARTHUR, TX FOLLOWING HURRICANE HARVEY, CREDIT: TASK COMMITTEE CHAIR, ANDREW WELLS

Harvey flooding caused a major Houston-area arterial, the Sam Houston Tollway approaching Interstate 10 in Memorial City, to completely shut down. Credit: iStock photo by Karl Spencer.

ABOUT THE AMERICAN SOCIETY OF CIVIL ENGINEERS

This report was written by the Texas Section of the American Society of Civil Engineers (ASCE): Task Committee on Post-Hurricane Harvey Recommendations. ASCE represents more than 150,000 members of the civil engineering profession in 177 countries around the world. Through the expertise of its active membership, ASCE is a leading provider of technical and professional conferences and continuing education, the world's largest publisher of civil engineering content, and an authoritative source for codes and standards that protect the public welfare.

Established in 1913, the Texas Section of ASCE represents nearly 10,000 members throughout Texas. Headquartered in Austin, the Section is composed of 15 regional branches, seven technical institute chapters and 17 student chapters (including one at each major Texas university).

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About the Task Committee

The Task Committee on Post-Hurricane Harvey Recommendations was formed by members of the ASCE Houston and Southeast Texas Branches whose communities have been severely impacted by flooding due to Hurricane Harvey. The impetus to form this task committee came from a desire to improve flood management practices based on their personal and professional experiences. The committee now includes members from across the State. Committee members, as well as their various positions within ASCE, can be seen below.

All committee members are practicing engineers and serve on the committee on a volunteer basis.

COMMITTEE CHAIRMAN:

Andrew Wells EIT
Past President, Southeast Texas Branch

COMMITTEE MEMBERS:

Curtis Beitel PE
Past President, Texas Section; Chair, Environmental & Water Resources Institute, Texas Chapter

Michael Bloom PE
President, Environmental & Water Resources Institute, Houston Chapter

Griselda Gonzales PE
Member, Government Affairs Committee, Texas Section

Liv Haselbach PhD, PE
Texas Section Director, Southeast Texas Branch

Michael Kelley PE
Member, Infrastructure Report Card Committee, Texas Section

Brandon Klenzendorf PhD, PE
Vice President of Professional Affairs Elect, Texas Section

Andres Salazar PhD, PE
Past President, Environmental & Water Resources Institute, Houston Chapter

ASSISTANCE ALSO PROVIDED BY:

Lawrence Goldberg PE
President, Texas Section

Kate Osborn EIT
President, Southeast Texas Branch

Gareth Young PE
President, Houston Branch

CONTRIBUTING ASCE STAFF MEMBERS:

Anna Denecke
Senior Manager, Infrastructure Initiatives, ASCE

Maria Matthews
Senior Manager, Grassroots Programs & State Government Relations, ASCE

Becky Moylan
Senior Manager, Media Relations, ASCE

Lindsay O'Leary PE
Executive Director, Texas Section

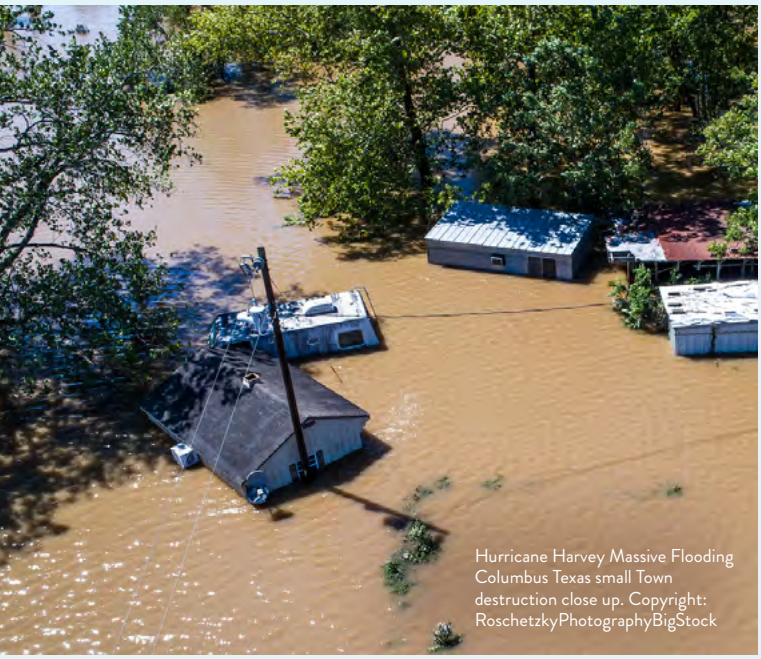
Document Review

This document was distributed to a large number of government agencies and organizations for review prior to publishing. Many responded with valuable feedback. The Task Committee greatly appreciates these stakeholders' time and has done its best to incorporate their comments into this report.

EXECUTIVE SUMMARY

In the 2017 Report Card for Texas's Infrastructure, the Texas Section of the American Society of Civil Engineers (ASCE) graded the State's overall flood control infrastructure a "D." This grade does not reflect the quality or adequacy of any individual local government's facilities, but is rather a statewide grade. To improve this grade, civil engineers made several recommendations to lawmakers and the public, including increasing funding for flood control infrastructure, flood warning systems, flood risk mapping, and enhancing state involvement in these programs.

The issues identified in the 2017 Report Card for Texas's Infrastructure were highlighted when Hurricane Harvey made landfall as a category four hurricane near Rockport, Texas on August 25, 2017. The storm went on to impact over 40 counties in Texas, dropping more than 60 inches of rain in a matter of days on some areas and becoming the costliest natural disaster in Texas history. It is the second most costly natural disaster in U.S. history, behind only Hurricane Katrina.



Hurricane Harvey Massive Flooding Columbus Texas small Town destruction close up. Copyright: RoschetzkyPhotographyBigStock

While eliminating the risk from extreme storm events such as Hurricane Harvey is impossible, communities across the State can reduce risks associated with larger storms, reduce their impacts, and improve recovery capabilities. Because flood water does not respect political boundaries, the Texas Section of ASCE calls for improved communication and coordination among local governments within each watershed.

This report expands on the 2017 Report Card for Texas's Infrastructure by exploring the existing landscape of flood risk management in the State and identifies measures that can be taken to better prepare for the next event. The report makes a series of recommendations to guide local, state, and federal decision-makers to use in improving inland flood risk management throughout Texas. It does not specifically address the issue of coastal flood risk management.

Recommendations from ASCE Texas Section for a path forward after Hurricane Harvey include:

DEVELOP A STATEWIDE FLOOD MITIGATION PLAN

The Texas Water Development Board should develop and regularly update a statewide flood mitigation plan, with input from all levels of government, citizens and the private sector. The state legislature, in partnership with localities and the federal government, should provide funding to support projects identified in the statewide flood mitigation plan. Investing in flood mitigation infrastructure will save taxpayers money in the long run; for every $1 invested in mitigation, $6 is returned, according to the National Institute of Building Sciences.

FUND DAM SAFETY

The state should provide additional funding for Texas's Dam Safety Program as well as a funding program for dam improvements. A 2008 Audit Report found that, "[The Texas Commission on Environmental Quality's] dam safety program, as currently designed and operating, is not able to accomplish its statutory mandate to ensure the safe construction, maintenance, repair, and removal of dams in the State of Texas." Increased funding is necessary for this important program. Additionally, grants and loans designed to assist owners with dam repair, abandonment, or removal should be provided, either through the Dam Safety Program or another administrative process.

IMPLEMENT A STATEWIDE LEVEE SAFETY PROGRAM

The Texas Commission on Environmental Quality should develop and implement a program for inventorying the condition of all levees in Texas. Levees are owned by a variety of local, regional and federal agencies, but the inspection of non-federal levees is not widely available, and their condition is often unknown. The state legislature, in partnership with the federal government, should establish a program to ensure the safe construction, maintenance and repair of levees in Texas.

FOCUS ON A WATERSHED APPROACH

Communities should take a watershed approach to flood risk management. Communities within each Texas watershed should coordinate their flood risk management regulations and infrastructure plans so that upstream activities don't adversely impact downstream property owners and localities. Coordinated activities should also be used to plan and implement flood risk reduction programs and projects that help reduce flood risks for everyone within a watershed, not just those living in one community. Neighboring watersheds should work together to create regional planning groups, which in turn could be integrated to create a statewide flood mitigation plan. This structure would be similar to the existing state water planning framework, which includes 16 regional planning groups. Additionally, the State should establish minimum flood risk management standards and give all local jurisdictions sufficient authority to implement locally appropriate land development and floodplain management regulations.

EDUCATE CITIZENS ABOUT RISK

Entities with authority over floodplain management should collaborate to implement a public outreach program to educate the Texas population about flood risk management and preparedness, including the roles of public agencies during emergency conditions. Increased education will help better inform residents about the watershed they live in, what infrastructure may affect their homes, and where to look for information during an emergency. Additionally, more robust flood risk maps that identify multiple risk levels, not just the boundary between areas with greater than a one percent annual chance of flooding and those with less, are needed. Risk maps should also show risks from other types of inundation, not just riverine flooding.

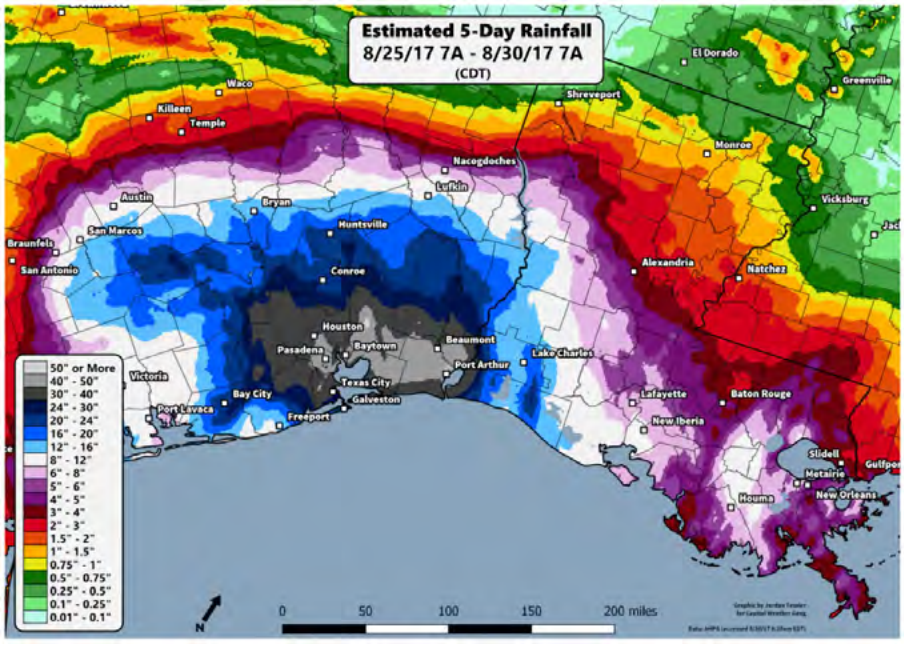
EMPLOY ALTERNATIVE FLOOD MITIGATION STRATEGIES

Continue to invest in the development and deployment of alternative flood mitigation strategies, including green stormwater infrastructure (also known as "low impact development"). Technological advancements in permeable pavement, green roofs, and small-scale sedimentation and filtration ponds, as well as the installation of rain gardens, vegetated swales, and disconnecting flow paths can be effective tools to reduce flood risk and increase resiliency when implemented on a watershed basis. The natural environment should also be considered as an asset for flood risk management purposes.

The report that follows includes detailed explanations of the recommendations listed above.

Introduction

Hurricane Harvey made landfall as a category four hurricane near Rockport, Texas on August 25, 2017. The storm went on to impact over 40 counties in Texas, dropping over 60 inches of rain in a matter of days in some areas, becoming the costliest natural disaster in Texas history and the second most costly natural disaster in U.S. history, behind only Hurricane Katrina.



Estimated 5-day Rainfall during Hurricane Harvey along the U.S. gulf coast. Credit: Capital Weather Gang, Jordan Tessler.

As the State rebuilds and looks to the future, the Texas Section of the American Society of Civil Engineers (Texas Section) has developed a comprehensive set of recommendations to improve inland flood risk management, to enhance resiliency and to help mitigate the adverse impacts of future storm events throughout Texas. Coastal flooding is not specifically addressed. The committee tasked with writing this report is composed of civil engineers throughout Texas, many of whom were personally affected by Hurricane Harvey.

In the *2017 Report Card for Texas's Infrastructure*[1], ASCE graded Texas's flood risk management infrastructure a "D." This grade does not reflect the quality or adequacy of any individual local government's facilities, but is rather a statewide grade. The report found that flood preparedness, floodplain management and flood prevention are largely the domain of local jurisdictions as the State of Texas does not have a central authority to guide these activities. While the major urban centers have implemented increasingly sophisticated flood risk management programs and flood mitigation systems, the needs of both large cities and less populated counties consistently outpace the funding required to provide reliable flood risk mitigation statewide. Enhancing state involvement in planning, financing, and funding of flood risk management activities will help to improve the effectiveness of all flood risk management activities across Texas.

In addressing the challenges ahead, it should be recognized that the adverse impacts from extreme events such as Hurricane Harvey cannot be fully prevented. Likewise, the approach to flood risk management must change from a philosophy of "control" to one of "risk reduction." This underscores the understanding that there is a limit to which any storm or natural disaster can be controlled and recognizes that there will always be some measure of risk no matter how extensive the State's flood risk management system might be.

Throughout Texas, communities are reevaluating their flood risk management strategies, their floodplain maps and funding for flood risk reduction infrastructure. Building off the recommendations to raise the grade in the 2017 Report Card for Texas's Infrastructure, **this report proposes solutions applicable across all levels of government to address the issues highlighted by the results of Hurricane Harvey.**

[1] Texas Section of the American Society of Civil Engineers (www.TexASCE.org/IRC), 2017. *2017 Report Card for Texas' Infrastructure.*

The Task at Hand

The Federal Emergency Management Agency (FEMA) defines a flood as a *temporary condition of partial or complete inundation of two or more acres of normally dry land area or two or more properties from overflow of inland or tidal waters or unusual and rapid accumulation or runoff of surface waters.*[2] Flooding is not a new phenomenon. For thousands of years, people have sought to control the flow of water during extreme weather events to protect property and promote public safety. As infrastructure designers, civil engineers seek to accomplish those same goals today. However, as the population grows and Texas continues to develop, it is increasingly likely that two or more properties will be flooded rather than two or more acres of land. This poses many challenges because the very nature of development removes natural ecosystems that serve to collect and infiltrate rainwater and thereby reduce flood risk. Further, the introduction of infrastructure to collect rainwater can introduce new hazards when they become overwhelmed. As a result, the sophistication of infrastructure must increase with increasing development. Similarly, flood risk management structures and strategies must be able to keep pace with an ever more spatially connected society.

According to the Texas Demographic Center, the population of Texas is projected to increase from 28 million (January 1, 2017) to 54 million by 2050.[3] This growth will drive the construction of additional infrastructure, homes, roads, businesses and other facilities. Local governments control how and where many of these new facilities will be constructed and what flood risk they will experience. State government controls how state institutions locate and construct new facilities. Similarly, the state governs where highways and certain roadways are built and how they might impact flood risks.

In general, there are two interconnected infrastructure strategies for managing rainwater. **Stormwater infrastructure**, which includes street curbs and drains, parking lot inlets, and buried pipes and culverts, is designed to handle rainwater that falls on developed land and transport it to streams, rivers or other water bodies. These systems are typically designed for smaller, more frequent storms and handle water on a neighborhood or city level. While these systems still function during extreme events, they are designed to handle smaller rain events, so they are routinely overwhelmed by larger storms. This leads to inundation and possible flooding. Conversely, **flood risk management infrastructure**, such as detention facilities, channels, dams and levees, is designed to handle rainwater that has already accumulated in water bodies. These structures are designed to function during larger, more extreme events and may handle water on a neighborhood, city or regional scale.

In addition to infrastructure, **natural systems**, such as undeveloped river corridors, wetlands, prairies, and other features can also serve a flood risk management function by containing and infiltrating rain water, as well as providing an important buffer for communities from overland flow. As such, the incorporation of natural ecosystem components into a flood risk management strategy can minimize flood risk and provide important benefits similar to manmade infrastructure.

Stormwater infrastructure, flood risk management infrastructure and the natural environment work together to reduce flood risks. The task at hand is to better leverage each of these assets to sustainably reduce flood risk, increase public safety and protect the environment for future generations.

[2] National Flood Insurance Program, FEMA (https://www.fema.gov/national-flood-insurance-program/definitions#F)

[3] 2014 Texas Populations Projections, Texas Demographic Center (http://txsdc.utsa.edu/Data/TPEPP/Projections/)

FLOOD RISK MANAGEMENT IN TEXAS

Local cities and counties conduct most flood risk management activities in Texas. Local communities plan and implement stormwater infrastructure projects; they devise and implement flood risk management projects, sometimes in partnership with federal agencies; and they adopt and enforce floodplain management rules for land development. By State law, cities and counties must participate in the **National Flood Insurance Program (NFIP)**, which makes them eligible to receive federally subsidized flood insurance and federal assistance. In return, each community agrees to adopt and enforce a minimum set of floodplain development standards. Communities may also choose to exceed the NFIP minimum criteria.

Flood risk management activities related to the NFIP are led by the floodplain administrators in each community, guided by the specific floodplain management regulations for urban development that community leaders have selected according to their acceptable level of risk and local conditions. The **Texas Floodplain Management Association (TFMA)**, a state chapter of the Association of State Floodplain Managers (ASFPM), provides training and certification for professionals working in the flood risk management field in both the private and public sectors. Through the auspices of ASFPM, which credentials nationally, TFMA has credentialed over **2,000 Certified Floodplain Managers** in the state of Texas, more than any other state.

At the state level of government, the **Texas Water Development Board (TWDB)** provides limited funding assistance for flood risk management projects to political subdivisions of the State. This generally consists of small grants and low-interest loans. The **Texas Commission on Environmental Quality (TCEQ)** defines the stream and environmental regulations in the State, either by administering federal regulations on behalf of the U.S. Environmental Protection Agency (EPA) or enacting the State's own rules for environmental regulations. TCEQ also administers the statewide Dam Safety Program, which monitors and inspects private and public dams. The **Texas Department of Emergency Management (TDEM)** is responsible for emergency preparedness and emergency response activities that are associated with flooding and other natural disasters. The **General Land Office (GLO)** administers the state's coastal management program, receives and manages post-disaster recovery funds from the U.S. Department of Housing and Urban Development, and has developed a coastal resiliency master plan for the state. There are also a number of **river authorities** in Texas, created by state law, that are authorized to conduct drainage and flood risk reduction activities.

At the federal level, the **U.S. Army Corps of Engineers (USACE)**, **U.S. Department of Agriculture (USDA)** and other federal agencies own, operate and/or regulate a

Inundation of the main spillway area of the U.S. Army Corps of Engineers' Barker Reservoir during emergency releases during Harvey. Credit: iStock photo by Karl Spencer.

number (but by no means all) of Texas's dams and levees. In many instances, the USACE will construct infrastructure and then transition into a regulatory role after passing ownership on to a local sponsor, such as a drainage district, to operate and maintain. In 2016, the Water Infrastructure Improvements for the Nation (WIIN) Act authorized the High-Hazard Potential Dam Rehabilitation program, which would help fund the repair, removal, or rehabilitation of the nation's non-federal, high-hazard potential dams. The Water Resources Reform and Development Act (WRRDA) of 2014 created a new National Levee Safety Initiative (NLSI). This program will promote consistent safety standards, create levee safety guidelines, and provide funding assistance to states for establishing participating levee safety programs; however, the authorized funds have yet to be fully appropriated.

FEMA administers the NFIP and develops Flood Insurance Rate Maps (FIRMs) that delineate special flood hazard areas (regulatory floodplains) that have at least a one percent chance of flooding annually, as well as other flood risk information. These maps are not comprehensive in that they typically only include flooding along major studied streams and do not consider all potential sources of flooding. They also typically only represent two risk levels; the one percent annual chance and the 0.2 percent annual chance.

While different public and private entities use these maps for a variety of purposes, they are strictly developed and intended to be used to assess compliance with NFIP standards, which is necessary for citizens in each community to receive federally subsidized flood insurance and federal assistance. They are not meant to be comprehensive flood risk management tools.

FEMA is also responsible for overseeing the National Dam Safety Program.

Additionally, FEMA sponsors the **Interagency Flood Risk Management (InFRM)** team, which brings together Federal partners with mission areas of hazard mitigation, emergency management, floodplain management, natural resources management and conservation to determine the needs of communities, define solutions and implement measures to reduce long term flood risk throughout Arkansas, Louisiana, New Mexico, Oklahoma and Texas. Partners include the USACE, the U.S. Geological Survey (USGS) and National Weather Service (NWS) .[4]

COORDINATION AMONG STAKEHOLDERS AND FLOOD RISK MANAGEMENT LEADERSHIP

Because flood risk management activities are defined at the local level, with each community having some degree of autonomy to set their own policies, regions with multiple neighboring communities can end up with a collection of flood risk management strategies and regulations that differ in protection levels and land development requirements. The common denominator is the NFIP minimum criteria, but from there two adjacent communities may elect to enact additional standards, which may or may not be consistent.

This is the case in the Greater Houston Area. Harris County has 33 different municipalities, with the unincorporated areas under the jurisdiction of Harris County. Thus, there are 34 floodplain administrators in the county. Harris County Flood Control District also designs, builds, and maintains the primary channels and tributaries throughout the county. Urban development extends to the adjacent Counties of Montgomery, Fort Bend, Brazoria, and Galveston, which adds to the number of communities enacting their own flood management standards that affect the Houston area.

Although the boundaries of each community are well defined, these boundaries do not correspond to watershed boundaries and streams that traverse multiple communities. This creates the need for collaboration and coordination. Each adjoining community, although politically independent

[4] Interagency Flood Risk Management (https://webapps.usgs.gov/infrm/)

of each other, should be somewhat consistent with their neighbors in their approach to flood risk management.

When considering new development, it is important that communities recognize that these developments are not isolated from the surrounding community or its infrastructure. Not only does new development remove natural ecosystems that buffer existing developments and infrastructure, but merely by existing in a natural environment that is subject to rainfall and runoff, it exposes people and property to flood risk and can often increase risk levels for those upstream or downstream, even if locally mitigated. Over time, this can reduce the effectiveness of existing large flood risk management infrastructure, drive a requirement for upgrades, or make it more expensive to implement new risk management systems. Since the owners of flood risk management systems are often not the same entities who permit new development, decisions are often not harmonized. This also means that the those who pay to reduce risks and those who benefit are not the same people.

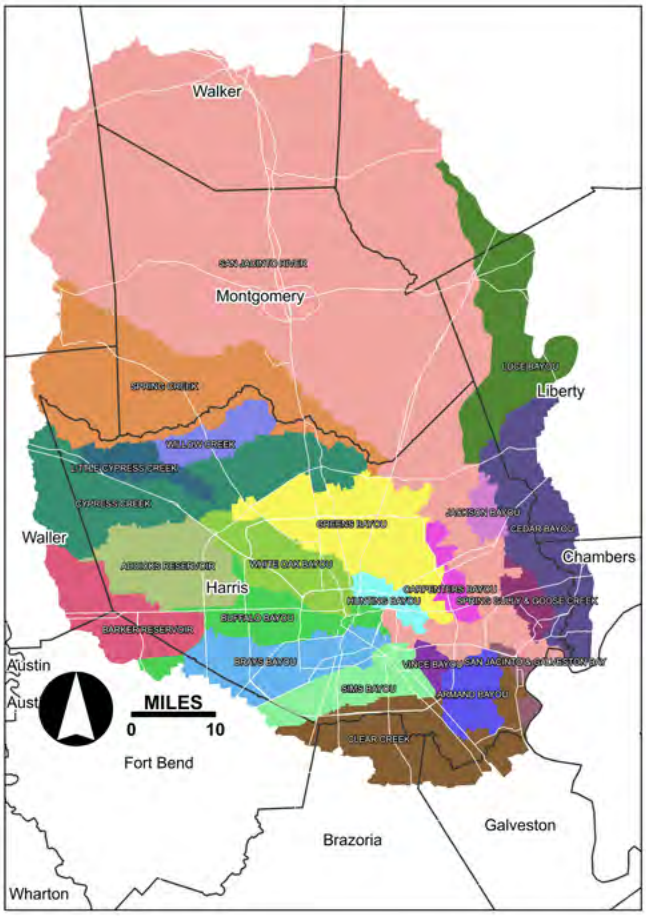
This is especially true for dams, which are given a hazard rating of high, significant or low based on whether there is probable loss of life, significant economic losses with no expected loss of life, or minor damage to normally unoccupied buildings or land, respectively, if a dam fails. According to the Texas State Soil and Water Conservation Board (TSSWCB), approximately 50 percent of dams in Texas built since 1948 under the Small Watershed Programs have exceeded their 50-year life expectancy.[5] By allowing new development below these and other dams, even if local mitigation rules are followed, communities may inadvertently increase the hazard rating of upstream dams, which can require millions of dollars in renovations and repairs.

Most communities have a well-defined process to regulate land development to avoid increases in flood risk and to meet NFIP minimum requirements, however the NFIP's primary goal is to determine insurance premiums for properties located in different flood risk zones. The NFIP and related policies do not define the infrastructure needed to reduce flood risk. In other words, it is not within the scope of the NFIP to define what infrastructure is needed in a particular watershed to reduce flood risks. Such solutions are developed in a regional context by local stakeholders or in some cases with participation from the State and Federal Government.

TWDB is currently conducting a **statewide flood assessment**, which seeks to estimate the total cost of all flood risk management projects across the state. Billions of dollars will be needed to reduce flood risks in Texas to acceptable levels, especially in areas that were developed prior to the creation of the NFIP and the production of FIRMs. Flood risk management infrastructure projects must be devised on a watershed basis, which requires multi-agency coordination and the participation of all communities within that watershed.

Texas has been exemplary in water supply planning with the development of a State Water Plan, which is updated on a five-year cycle by regional stakeholder groups under the administration of TWDB. However, no such statewide planning framework exists for flood risk management planning.

Recent flood events such as Hurricane Harvey, the Wimberley floods, and Brazos River floods, among others, have highlighted the need for flood risk reduction projects in urbanized areas. Such projects are not easy to implement



Various Watersheds in Harris County and neighboring counties. Source: Illustration adapted from Harris County Flood Control District and the Texas Water Development Board, prepared by Task Committee member Michael Bloom.

[5] TSSWCB Flood Control Program and USDA NRCS Watershed Program Maintenance, Repair and Rehabilitation; June 2016. Texas State Soil and Water Conservation Board.

as they require feasibility studies, reliable funding mechanisms and, as stated before, participation from multiple communities. A **statewide flood plan** could identify specific projects for future funding and implementation.

Following the philosophy of the State Water Plan—which draws from 16 regional planning groups—the statewide flood plan could be developed by regional planning groups, composed of local agencies, and stakeholders each representing different interests, but which consider local contexts and priorities. Also, similar to the process of the State Water Plan, a flood reduction project would need to be in the statewide plan and determined feasible to be eligible for funding or financing from TWDB. Planning regions should be developed based on interconnected watersheds appropriate for the protection of life and assets. Closer to the coast, they may be smaller than those in the State Water Plan; however, planning regions may be able to cover a larger area with the same effect in other parts of the State.

Planning activities should include all communities in a watershed, regardless of size or population, because stormwater and flood risk management in upstream communities has a direct impact on those downstream. It should be recognized that availability of funding and resources for flood planning and mitigation are not distributed equally among cities or regions. A comprehensive approach that considers large and small communities would provide an opportunity to identify not only projects, but also the needs and resources required to implement the plan.

All projects should be selected based on a cost-benefit analysis. This requires accurate and widely available data and models. The TWDB currently serves as a repository for information related to water planning throughout the State. That role should be expanded to include flood risk management data to help guide Federal, state and local authorities throughout the planning process.

Besides collaborating to fund new projects, the State should also monitor and fund repairs to current infrastructure. While Texas has a statewide dam safety program, it is sorely underfunded. In 2008, the State Auditor's Office completed an Audit Report on the **Dam Safety Program** at TCEQ that concluded, "[TCEQ's] dam safety program, as currently designed and operating, is not able to accomplish its statutory mandate to ensure the safe construction, maintenance, repair, and removal of dams in the State of Texas."[6] This report has not been recently updated. Because of poor funding, only 259 of approximately 4,000 non-exempt dams were inspected in 2015.[7]

Texas also does not have a **statewide levee safety program**. Many levees throughout Texas were originally used to protect farmland, and now are protecting developed communities. The reliability of these structures is unknown in many cases and there is no dependable catalog of the location, ownership, condition, or hazard potential of levees in Texas. Along the lines of the Dam Safety Program, a levee safety program could include funding for the inspection, construction oversight, maintenance and repair of levees across the State. Such a program would also assist in the development of emergency action plans in the case of a levee breach or failure.

In addition to building, inspecting and maintaining appropriate infrastructure, the State should establish minimum flood risk management standards and give all local jurisdictions sufficient authority to implement locally appropriate land development and floodplain management regulations. Minimum standards should include a prohibition of positive net fill, which displaces floodplain storage volume and increases flood risks for other properties, require the mitigation of increased peak flow rates from development, and require the routing and sizing of a flow path for stormwater runoff generated during the one percent annual chance event so that it does not inundate the occupied space of any structures. It may be necessary to vary minimum criteria by region, but consideration should be given to the watershed that standards influence.

At the federal level, the 1968 National Flood Insurance Act required that a **Unified National Program (UNP) for Floodplain Management** be prepared. While several UNPs have been issued, the most recent version was published in 1995 and its recommendations, including the need for coordinated risk management at all levels of government, have not been seriously addressed.[8] Furthermore, much of the program does not reflect current needs and must be updated.[9]

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[6] *An Audit Report on the Dam Safety Program at the Commission on Environmental Quality*, May 2008. Texas State Auditor's Office, Report No. 08-032.

[7] Texas Commission on Environmental Quality, June 2016 and January 2017. Interviews and data from Dam Safety Program. (www.tceq.tx.gov)

[8] Traver, R. et al., 2017. *Flood Risk Management: Call for a National Strategy*. American Society of Civil Engineers.

[9] Galloway, Gerald E., and Lewis E. Link, 2012. A White Paper: The Need for a Unified National Program for Floodplain Management in the 21st Century. Report prepared for the Federal Interagency Floodplain Management Task Force. Bethesda, MD: Abt Associates

Implementing an updated UNP would establish the roles and responsibilities of federal agencies and provide a framework for their interaction with state and local governments. This is critical for minimizing flood risk before flooding events and having a coordinated post-disaster response. As with the state flood plan, a UNP must give adequate consideration to local priorities and represent the spectrum of challenges faced around the country.

Recommendations

- Adjoining communities in a region should establish a consistent set of flood risk management policies to avoid large variations of land development and floodplain management rules within the same watershed.
- Create a statewide flood plan to continuously determine the needs of flood protection projects across the state, estimate the costs, and propose funding mechanisms and priorities. This plan should supplement the current federal NFIP for flood risk management.
- Projects proposed in the statewide flood plan should be formulated at the local level with participation of local stakeholders, as activity at the local level encourages collaboration among stakeholders and establishes the roles for implementation.
- Multi-purpose projects that provide recreational, flood risk management, and ecosystem preservation and restoration functions should be considered in any future statewide flood risk management plan.
- Establish a statewide database for flood risk management information.
- Create a statewide levee safety program to ensure the safe construction, maintenance and repair of levees throughout Texas.
- Establish minimum, statewide flood risk management standards.
- Update the 1995 UNP for Floodplain Management to reflect current challenges and define the relationship between various levels of government in reducing flood risk.
- Develop a national vision and supporting framework for flood risk management in the United States that includes input from all levels of government.

Devastation of Hurricane Harvey in Pearland Texas USA with pile of debris from flooding damaged. Huge heap of throw away belongings materials garbage of ruined houses. Copyright: trongnguyen.

COMMUNICATION OF FLOOD RISK

Flood control design, management, and planning are typically based on statistical analyses of available historic rainfall data for a given geographic region. Statistical models are used to characterize past rainfall into a recurrence interval or return period, such as a 100-year event. The use of the term "100-year storm" has been debated because it implies that a rainfall event of such magnitude will happen only once every 100 years, but it is actually a statistical artifact of the method that more precisely states that there is a one percent probability of the event being equaled *or exceeded* in any given year.

The methodology used to determine recurrence intervals only considers data from past rainfall records and is only as good as the data available as well as the accuracy of the statistical methods used. Since the statistics are based on historical rainfall record, they do not account for potential changes in long-term, future rainfall trends. It should be noted that some areas do not have sufficient historical records to produce statistically significant results. In these instances, expected flooding is interpolated from locations with more data or through computer modeling. When considered in conjunction with a changing climate, the 100-year event (or one percent chance event) may not remain constant over time.

Communication is further complicated by the work engineers must do to convert the rainfall amount to a runoff amount, and, in turn, the river flood stage. Even if the rainfall statistics are periodically updated with new data, the calculation of stormwater runoff and flood stage needs to account for changing land use, which it often does not. As more areas are developed, the amount of rainfall converted to stream runoff increases. Therefore, the runoff flow rate associated with a one percent annual chance event will increase as additional development occurs. Mitigation and planning for these changes is required to provide a level of risk the public is willing to accept for the given cost of that protection.

Over the last several years, there has been an ongoing public discussion surrounding the applicability of floodplain maps in southeast Texas. Much of the discussion since Hurricane Harvey has revealed a fundamental misunderstanding of risks when reading FIRMs. Since the one percent flood level is used to determine whether a mortgage lender will require flood insurance, many people see it as a line distinguishing between areas that are susceptible to flooding and areas that are not. However, the reality is that all low-lying, coastal areas have some degree of flood risk.

In fact, there is statistically a 26 percent chance that a storm equal to or greater than the one percent chance event will occur over the duration of a 30-year mortgage and a 5.8 percent chance that a 0.2 percent chance event ("500-year event") will occur over that same 30-year mortgage.

FIRMs, are developed to calculate flood insurance rates and to regulate compliance with NFIP standards. While the maps sometimes include other information, their main purpose is to illustrate areas that have at least a one percent chance of flooding each year due to riverine flooding (i.e. from streams, rivers and bayous) with drainage areas usually greater than one square mile. Below dams, these areas are typically determined assuming that dams will perform as designed.

However, flood waters can come from a variety of sources during an extreme storm event. When storm drains exceed their capacity, streets are designed to function as a secondary drainage system to transport water to streams, rivers and other natural water conveyors. Water will also flow over ground when the underlying soil becomes completely saturated. As a result, water can collect in localized, low lying areas that are outside of floodplains shown on FIRMs.

Most dams are designed to contain runoff from a one percent annual chance event. As a result, the release of water from dams during large flood events is not typically shown on FIRMs. However, higher flows could occur downstream of a dam due to an uncontrolled release of its reservoir if its embankment is breached. Areas that could be inundated in the event of a dam breach are mapped separately and included in an **Emergency Action Plan**, which is required by TCEQ for each dam.

As previously mentioned, the one percent chance (100-year) floodplain established in FIRMs is used to determine flood insurance premiums and whether a mortgage

Piles of construction demolition debris accumulate in a residential neighborhood two weeks after Hurricane Harvey floodwaters subside (Port Arthur, Texas). Credit: Task Committee Chair Andrew Wells.

lender will require flood insurance on a loan as collateral. While it may be appropriate for insurance companies, lenders and government agencies to use this metric, it is critical that residents and businesses are aware of the limitations of these floodplain maps and educate themselves on their own flood risk. To that end, it is similarly important that communities invest in mapping that considers a number of risk categories and incorporates a broad range of flooding sources as a part of their floodplain management strategy. This information could also be a helpful tool for local planning and zoning boards as they consider the development of different areas within their communities.

Recommendations

- Update current floodplain maps and include multiple risk levels with a more robust consideration of flooding sources.
- Discuss events in a manner that emphasizes annual risk rather than an event's recurrence interval.
- Implement a public outreach program to help residents and business owners interpret and better understand the flood risk in their communities.

COMMUNICATING WITH THE PUBLIC DURING A FLOODING EVENT

Hurricane Harvey revealed several short comings in communicating flood emergency conditions to the public. Information related to flood forecasting, water elevation increases, road closures, evacuations (mandatory or voluntary), and other relevant information needed to be disseminated in a timely manner and, equally as important, the public needed to understand the information and take proper action.

Although many residents have a working knowledge and understanding of how drainage networks function, there is a large portion of the community that does not know which watershed they live in, what infrastructure may affect their homes and where to look for information during an emergency. For example, when news stations began reporting that releases from Addicks and Barker Reservoirs were increasing with the corresponding increase in flooding, residents in other watersheds unrelated to these reservoirs were unsure if such releases would impact their homes. Similarly, upon the possibility of levee breaches, some residents did not know if their homes were protected by a levee or which government entity had jurisdiction over the levees that protected their homes.

Besides a county or a municipality, other public entities with jurisdiction over drainage and flood control infrastructure include Municipal Utility Districts, Drainage Districts, and Levee Improvement Districts. The jurisdiction that these entities have for flood risk reduction and flood emergency management needs to be better defined and communicated to the general public, so all stakeholders and the public are better prepared and know where to look for information during the next emergency.

Responders travel through flood waters at an inundated apartment complex, aiding stranded residents on August 31, 2017 (Port Arthur, Texas). Credit: Task Committee Chair Andrew Wells.

Recommendations

- Implement a public outreach program to educate the general public on fundamentals of flood risk management and preparedness, including the roles of public agencies during emergency conditions.
- Develop warning systems that can notify citizens of the timing and degree of potential flood hazards.
- The Texas Department of Emergency Management should coordinate with all local jurisdictions to create and implement a statewide public outreach and educational program with consistent messages and information about what to do in a flood emergency.

THE WATERSHED APPROACH

Reducing community flood risks can take several forms, depending on the design storm size and the area under consideration. In general, stormwater infrastructure, such as storm drains, is designed to handle water that falls on developed land during smaller, routine storms and convey that runoff to existing water bodies; while flood risk management infrastructure, such as dams and levees, are designed to handle flows from existing water bodies and mitigate flooding during large and extreme storm events.

Since flood risk management infrastructure is a recipient of water from surrounding land and stormwater infrastructure, the need for flood risk infrastructure is directly related to the effectiveness of land use strategies and stormwater management in their respective watersheds.

The increase in population across Texas over the past several decades has been substantial. Between the 2000 and 2010 census, the Texas population grew from 20.9 to 25.1 million people—an increase of approximately 20 percent.[10] The corresponding development has replaced many open areas that naturally infiltrate water (and thus keep water from flowing to adjacent land and water bodies) with impervious structures and surfaces that do not.

Most communities in Texas, though not all, currently allow land development to occur as long as the highest *rate* of stormwater runoff flowing off the newly developed area (post-development flowrate) does not exceed the highest *rate* of stormwater runoff that would have flowed off the site before the development was constructed (pre-development flowrate). New developments achieve this *rate control* approach using detention ponds, which temporarily detain (hold) stormwater on the property and then slowly release it over a long period of time such that the post-development flowrate does not exceed the pre-development flowrate. This controls the *rate* of discharge, but not the *total volume* of runoff, which is often increased when compared to a pre-developed state.

Alternatively, strategies labeled as **Low Impact Development (LID)**, or green stormwater infrastructure, have been implemented across the country. They are known as "low impact" because they reduce the frequency and likelihood of adverse stormwater impacts (inundation, erosion, etc.) to downstream properties by handling stormwater more holistically. These approaches seek to control the *total volume* of runoff (as well as flowrates) by attempting to mimic a more natural hydrological cycle, promoting rainwater to remain where it would have infiltrated or been detained prior to development. In other words, LID encourages developed land to manage stormwater in the same way that it would have prior to development. This decreases runoff volumes to downstream communities and can help mitigate flooding.

LID strategies include: rain gardens, vegetated swales, green roofs, rainwater harvesting, small-scale sedimentation and filtration ponds, permeable pavement, the disconnection of flow paths and increased tree canopy. These approaches have proven effective at improving the water quality in developed areas, but due to their small size and contributing drainage area have only demonstrated the ability to mitigate stormwater flows up to approximately 10 percent chance storms. However, it should be noted, that if implemented on a watershed basis, upstream communities using LID would decrease the volume of water discharged during storms greater than 10 percent chance events and thus decrease the impact of storms on downstream communities. Leadership in Energy and Environmental Design (also known as LEED) has additional credits for using LID for the 98th percentile storms, so larger controls through LID are developing.

LID has been mandated in other areas of the country—many times for its ability to reduce stormwater runoff volumes to address combined sewer overflow issues or its benefits to stormwater quality, used to achieve waterbody restoration goals—however, it has received little traction in Texas at a statewide level. This is largely due to the tendency for relatively slow changes to design and construction specifications, a lack of training in their implementation, concerns about long-term maintenance, and a lack of awareness on the local level.

[10] U.S. Census Bureau. (www.census.gov)

Photo of low impact development drainage system used in a single-family residential subdivision in the Houston area. Credit: R. G. Miller Engineers, Inc.

Funding for LID research to increase the ability to address these issues in a sustainable and cost-effective manner is required to fully implement a watershed approach to stormwater management in Texas. A bill was submitted in the 2017 Texas Legislature (HB 1536) that directed TCEQ to include information about the use of LID in the State in a biannual report already issued by TCEQ. The bill required the report to include a list of communities that allow the use of LID, an estimate of the number of LID projects in the state; an estimate of the amount of stormwater managed through LID in the state; an estimate of the investment made in LID projects; an assessment of the social, economic, and environmental benefits realized; a description of barriers to installing and using LID; and recommendations to encourage the utilization and deployment of LID. This bill did not pass during the 2017 legislative session.

As discussed, there is a limit to which LID or any other stormwater system can mitigate flooding. At some rain gages in southeast Texas, Hurricane Harvey produced 24-hour rainfall totals that had a 0.5 percent to 0.1 percent annual chance of occurrence.[11] In extreme events, such as Hurricane Harvey, it is not practical to design stormwater systems to manage the peaks of these events. Consequently, there is always some risk of localized flooding, whether LID or conventional stormwater systems are implemented.

[11] Harris County Flood Control District, 2017. *Immediate Report No. 1: Hurricane Harvey, Storm and Flood Information.* Houston, TX.

Once rainwater enters an existing water body, the approach to flood risk management significantly changes. Where stormwater systems are required to force developed land to behave similarly to undeveloped land, flood risk infrastructure is specifically designed to alter natural water bodies to protect human life and property.

Flood risk management infrastructure includes dams, levees, detention and retention basins, and other similar infrastructure. Channel widening and straightening offer other means of increasing the capacity of water bodies to mitigate flooding. Flood risk management infrastructure ranges in size from neighborhood level systems to large regional ones and while some act to collect water, others divert it. Thus, a hierarchy of flood risk management infrastructure exists across a watershed.

Given the results of Hurricane Harvey, a significant investment in flood risk management infrastructure will be necessary. When considering any flood risk management infrastructure, a project's impact on the region's waterflow must be considered. This is particularly true for levees and channel straightening, which may reduce flood risk in some areas at the expense of increased risk in others. Dams also intentionally inundate land for the purpose of water storage. Selection of these projects should be based on a cost-benefit analysis that considers, not only the community benefiting from the infrastructure, but all communities in the watershed.

While large infrastructure has proven effective during many storm events, it is important to recognize that one single piece of infrastructure cannot protect communities from all hazards in all storm events.

Thus, proper flood risk management on a watershed basis must consider the interconnected nature of water flow across a region and incorporate resiliency at every level of stormwater and flood risk management infrastructure.

Protecting new and existing developments, communities and those downstream from flooding during extreme events is a challenging task. Due to an ever-increasing population, it is unreasonable to expect or require development to cease. However, it is vital to consider the impacts of localized decisions in a regional context. As communities continue to develop post-Hurricane Harvey, they must recognize that they are a part of a larger flood risk management system. Adopting holistic flood risk management practices in conjunction with surrounding communities will maximize the value of investments, minimize risk, add resiliency and promote sustainability.

Recommendations

- Consider stormwater and flood risk management infrastructure at all levels of government in a regional context based on watersheds.
- Incorporate resiliency into flood risk management systems.
- Consider the value of open or undeveloped land as a part of flood risk management strategies.
- Develop local ordinances that address the increase in total stormwater runoff volume diverted from developed areas as well as the increase in peak flowrates.
- Assemble a state-wide case study report similar to the one envisioned in HB 1536 (85th Regular Session).

ADDRESSING THE NEED

There have been **94 federally declared disasters in Texas** between 1953 and 2016, with 72 of these involving widespread, damaging flooding.[12] Between 1999 and 2009, approximately 47 percent of flood insurance claims in Harris County occurred at locations with less than a one percent annual chance of flooding.[13] This suggests that funding for more frequent updates to flood risk maps and additional flood risk management projects are necessary.

Many of the existing floodplain maps have been developed by FEMA to regulate compliance with NFIP and establish insurance premium levels. To that end, FEMA has implemented an aggressive Risk Mapping Assessment and Planning (RiskMAP) program across the nation, with the goal of updating all FIRMs. The program requires state or local participation in the mapping projects to receive federal participation and funding. The target for local participation is approximately 20 percent of project costs. Additional funding is needed to increase the frequency of map updates and to create maps that detail more risk levels throughout watersheds, from all sources of inundation.

As has been discussed, flood risk management takes place on a variety of scales and by all levels of government. Flood risk management activities include everything from local storm drains and site detention ponds, to channel improvements and regional detention facilities, to dams and reservoirs. Except for dams and levees, which are owned by a variety of public and private entities, local governments are responsible for stormwater management and flood mitigation projects under the current floodplain management structure. However, various pressures have caused a decrease in funding in many communities.

Apart from limited grants requiring a 50 percent match and low-interest loans, Texas does not substantially fund or finance flood risk management activities or infrastructure. Several state agencies administer Federal grants but provide no financial assistance to meet local match requirements. The total for all grant funding received by Texas from FEMA through 2016 was 298 flood mitigation projects totaling over $408 million.[14] Local communities have provided the local matching funds for all of those projects.

Current TWDB funding activities are focused on water supply with only a minor portion dedicated to flood mitigation grants. Considering the devastation of recent floods and that flood risk management falls within the mission of TWDB, it is justifiable that TWDB funding be substantially increased for financial support of flood risk management programs and projects. Additionally, TWDB funding should be increased to support the collection and creation of data necessary to support flood risk management throughout Texas.

Presently, TWDB is conducting a State Flood Assessment. The report's goal is to assess statewide flood risks, estimate mitigation costs, and recommend an approach for future of flood planning in the state. It is expected to be released in December 2018, just before the start of the 86th legislative session.

In addition to stormwater runoff, flooding can be caused by uncontrolled releases or breaches of the many dams throughout the State. There are 1,373 high hazard dams,

Women in Houston Heights on Sunday, August 27, 2017. Credit: Candace Brakewood

[12] Federal Emergency Management Agency. Disaster Declarations for Texas. (https://www.fema.gov/disasters/grid/state-tribal-government/24)

[13] Highfield, W. E., et al., 2013. "Examining the 100-year floodplain as a metric of risk, loss, and household adjustment." Risk analysis: an official publication of the Society for Risk Analysis, 33(2), 186-191.

[14] Federal Emergency Management Agency, August 2016. Flood Insurance Statistics, National Flood Insurance Program.

588 significant hazard dams, and 5,283 low hazard dams in Texas[15]. In 2016, the TCEQ Dam Safety Program estimated the rehabilitation cost for the State's non-federal high-hazard dams at $2.5 billion[16]. This estimate covers all high hazard dams (including USDA's Natural Resources Conservation Service dams) that need rehabilitation, other than dams owned by the USACE, Bureau of Reclamation and International Boundary Water Commission. Additionally, continued growth in rural areas downstream of dams is resulting in changes to hazard classification for some dams. This will cause changes in requirements for the dams, possibly resulting the need for rehabilitation of these structures.

Funding for the rehabilitation or repair of hazardous dams must be obtained by the owners, many of which are private entities that cannot afford these projects. As Texas continues to grow, State and local governments must prioritize funding for dam inspection, maintenance, repair and rehabilitation as these structures protect life and property during all flooding events. Local governments with land development permitting authority should consider any dams in developing areas, how the new development might impact the dam hazard rating and the flood risk exposure levels for those above and below the dam. Similar considerations should be given to levees, which are not currently regulated by the State.

While TCEQ administers the Dam Safety Program, no initiative exists to inventory levees or fund their maintenance and repair. Given recent levee breaches and failures, it is reasonable for the state to provide funding for levee inspection, construction oversight, maintenance and repair through a levee safety program.

In 2007, Congress called for the President to conduct a national flood vulnerability assessment, however Congress has not funded such a measure in the 11 years since. In 2014, Congress created a new National Levee Safety Initiative (NLSI) as a part of the Water Resources Reform and Development Act (WRRDA). WRRDA authorized $395 million for the NLSI; however, the funds have not been fully appropriated, nor has the program been identified in the Presidential Budget Request as a priority. In 2016, the Water Infrastructure Improvements for the Nation (WIIN) Act authorized the High Hazard Potential Dam Rehabilitation program, which will help fund the repair, removal, or rehabilitation of the nation's non-federal, high-hazard potential dams. This program has never been funded. Over the past year, the need for such initiatives has become all the more relevant—not only for Texas, but the nation as well.

According to a National Institute of Building Sciences report, every $1 invested in flood risk mitigation yields $6 in return.[17]

As the State rebuilds from Hurricane Harvey, all levels of government must consider flood risk mitigation as investments and prioritize its funding.

Recommendations:

- Increase funding for flood risk management infrastructure across all levels of government.
- Continue participation in FEMA's RiskMAP program and create maps that show more detail about the gradation of risk levels throughout watersheds, from all sources of inundation. The State should also identify resources to assist communities with this effort.
- Develop a robust statewide funding plan for flood risk management, which acknowledges local, state and federal responsibilities.
- Increase funding for the TCEQ Dam Safety Program.
- Create a state loan or grant funding program for dam repair, abandonment, or removal.
- Provide state funding for inspection, construction oversight, maintenance and repair of levees.
- Fully fund a national flood vulnerability assessment, the NLSI and the High Hazard Potential Dam Rehabilitation Program outlined in WIIN.

[15] Texas Commission on Environmental Quality, July 2018. Correspondence with Dam Safety Officials.

[16] Texas Commission on Environmental Quality, June 2016 and January 2017. Interviews and data from the Dam Safety Program. (www.tceq.texas.gov)

[17] National Institute of Building Sciences, 2015. *Developing Pre-Disaster Resilience Based on Public and Private Incentivization.* Washington, DC.

CONCLUSION

The population of Texas is expected to increase by approximately 25 million people in the next 30 years. Development in areas potentially subject to flooding can be expected to increase to accommodate the demand for homes, businesses, and public infrastructure. Without a robust strategy that equitably shares responsibility and funding between various government agencies and stakeholders, the risk and costs of periodic flooding will continue to increase across Texas.

While eliminating the risk associated with extreme storm events such as Hurricane Harvey is impossible, communities across the State must be able to appropriately assess the risk associated with large storms and mitigate against their impacts. This report has outlined a number of issues that have come to light during recent floods and, specifically, Hurricane Harvey. **The Texas Section of the American Society of Civil Engineers recommends:**

- **developing a statewide flood mitigation plan;**
- **funding dam safety;**
- **implementing a statewide levee safety program;**
- **focusing on a watershed approach;**
- **better educating citizens about flood risks; and**
- **employing alternative flood mitigation strategies.**

Because flood water does not respect political boundaries, the most important qualities of effective policy solutions in these areas are communication and coordination among responsible parties. As Texas rebuilds from Hurricane Harvey, it is critical that communities realize the cumulative impacts of individual stormwater and flood risk management projects on the overall system. While it is recommended that state funding for flood management significantly increase, it should be recognized that many decisions affecting flooding are made at the neighborhood, city and county levels. To minimize the impacts of flooding, all levels of government must be more actively engaged in the strategic development and implementation of forward thinking flood risk mitigation systems.

Hurricane Harvey floodwaters approach the rims of process and treatment basins at a Houston area wastewater treatment plan. Credit: iStock photo by Karl Spencer.

GLOSSARY

EMERGENCY ACTION PLAN (EAP)
A formal document that identifies potential emergency conditions at critical infrastructure and specifies preplanned actions to be followed to minimize property damage and loss of life should those conditions occur. The EAP contains procedures and information to assist the infrastructure owners in issuing early warning and notification messages to responsible downstream emergency management authorities. It also should include inundation maps to show the emergency management authorities the critical areas for action in case of an emergency.

FLOOD
A temporary condition of partial or complete inundation of two or more acres of normally dry land area or of two or more properties from overflow of inland or tidal waters or unusual and rapid accumulation or runoff of surface waters.

FLOODPLAIN
Any land area susceptible to being inundated by floodwaters from any source.

FLOOD RISK MANAGEMENT INFRASTRUCTURE
Facilities designed to reduce the likelihood of inundation from high rainfall events. Examples include dams, levees and retention basins.

FLOOD RISK MANAGEMENT
The operation of an overall program of corrective and preventive measures for reducing flood damage, including but not limited to, emergency preparedness plans, infrastructure projects, regulations, and codes.

HAZARD
A risk to human safety, property or the environment.

HAZARD CLASSIFICATION (OF DAMS)
Defines the risk should a dam fail. A hazard classification of high indicates a probable loss of life; a hazard classification of significant indicates significant economic losses with no expected loss of life; and a hazard classification of low indicates only minor damage to normally unoccupied buildings or land with no expected loss of life if a dam fails.

INFILTRATE
To absorb into soil

LOW IMPACT DEVELOPMENT (LID)
An approach to stormwater management that seeks to control the total volume of runoff, as well as peak flowrates, by attempting to mimic the natural hydrological cycle.

NET FILL
The difference between soil or materials placed below the floodplain elevation minus that removed from below the floodplain elevation. Positive net fill increases the volume of soil in the floodplain and thus raises the one percent annual chance flood elevation.

ONE PERCENT CHANCE EVENT (100-YEAR EVENT)
A storm event that has at least a one percent chance of occurring each year, commonly referred to as a 100-year event.

RECURRENCE INTERVAL
The inverse of the probability that the event will be exceeded in any one year. For instance, a 100-year event has a one percent chance of being exceeded in a given year.

RESILIENCY
The ability of a system to recover quickly from a natural disaster.

RIVERINE FLOODING
Flooding originating from existing water bodies—such a streams, rivers and bayous—that extend beyond their banks.

STORMWATER INFRASTRUCTURE
Facilities designed to convey, hold, and route rainwater which drains or travels across the ground from and within developed areas to a natural waterbody. Examples include storm drains and LID systems.

SUSTAINABILITY
A set of economic, environmental and social conditions in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely without degrading the quantity, quality or the availability of economic, environmental and social resources. Sustainable development is the application of these resources to enhance the safety, welfare, and quality of life for all of society.

WATERSHED
An area of land that shares a common outlet for all of the water that falls on it.

Flooding in Port Arthur, Texas on August 30, 2017. Credit: Task Committee Chair Andrew Wells.

512-472-8905
TexASCE.org
office@TexASCE.org

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Flood Protection Sandbags with flooded homes in the background.
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