Catching the Rain

How Green Infrastructure Can Reduce Flooding and Improve Water Quality in Texas

Environment Texas Research & Policy Center

Frontier Group

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Cover photo: A 700 gallon rain harvesting tank designed by Concordia and Asakura Robinson at the Baker Ripley Neighborhood Center in Houston. Image courtesy of Asakura Robinson.

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Executive Summary

Flooding has brought significant damage to Texas in recent years. Unfortunately, continued development across the state, along with the growing threat of climate change, suggests that the challenge posed by flooding is unlikely to decrease. However, we can adapt to it.

Historically, as forests, prairies and wetlands were replaced with development, people built "gray" infrastructure – sewage pipes, drainage tunnels and water treatment plants – to take over the job of water management. However, these systems are expensive to build and maintain, and their construction can produce harmful environmental impacts.

Green stormwater infrastructure, however, can help mitigate flooding and protect water quality, at less economic and environmental cost than gray infrastructure. While green stormwater infrastructure cannot fully prevent flooding, it can limit property damage and water pollution, making these systems worthy of public investment.

Flooding is a serious concern in Texas and around the country.

- In 2015, 176 people across the U.S. were killed by floods.
- Texas has suffered more flooding fatalities than any other state in 11 out of the last 21 years.
- Flooding damages across the state totaled more than $3 billion in 2015.

The risk of flooding is increasing across Texas.

- The National Academy of Sciences found that global warming is increasing the frequency of extreme rainfall and other weather-related disasters across the country. This trend is particularly evident in the Texas cities of McAllen, Houston, Austin and El Paso, which are all among the 50 U.S. cities that have experienced the largest increase in heavy rains since 1950.
- The spread of development and paved surfaces, which are impermeable to stormwater, has increased rapidly across the state. Recent satellite data shows that by 2011, 31 percent of Harris County was fully covered by impermeable material. The total area of impervious surfaces in surrounding counties has also increased by 17 to 53 percent since 2001.

Green stormwater infrastructure (GSI) can help limit the property damage and water pollution caused by flooding.

- GSI systems come in many sizes and varieties, and are designed for residential, commercial and public use. Common components include:
  - **Rain gardens** – planted areas that absorb rainwater where it falls.
  - **Bioswales** – shallow, vegetation-lined drainage channels.
  - **Permeable pavement** – a road or surface made out of material that allows water to seep through.

- **Green roofs and walls** – vegetated roofs or walls that capture rainfall on the building itself.
- **Rain barrels** – storage containers that collect rainwater from roofs.

- Most types of green stormwater infrastructure can absorb between 50 and 90 percent of rainfall.

Green stormwater infrastructure can be a more cost-effective investment than gray infrastructure.

- For projects with similar water management impacts, construction costs for green stormwater infrastructure are 5 to 30 percent lower than the expense of building new gray infrastructure.
- Maintenance costs, particularly for residential scale GSI, are minimal. Additionally, these systems collect water that can be used for cleaning and gardening, which can reduce water bills.

Green stormwater infrastructure offers positive impacts in addition to flood protection. Additional benefits of green stormwater infrastructure include:

- **Restoring the water table.** In northern Texas, water levels in the Ogallala Aquifer have dropped nine feet since 2004. Increasing the amount of permeable cover can replenish groundwater.
- **Improving water quality.** Studies have shown that stormwater systems can trap between 45 and 99 percent of solid pollutants in stormwater.
- **Beautifying the landscape.** Many green stormwater management installations can be incorporated into new or existing public parks, further benefiting the community.
- **Removing greenhouse gases from the atmosphere.** Trees and green roofs can capture hundreds of pounds of carbon over their lifetimes.

Investment in green stormwater infrastructure in Texas will require work and support from local and state policymakers. Some important actions include:

- Encouraging new developments to limit impermeable cover and incorporate aspects of green stormwater infrastructure.
- Requiring cities to design green infrastructure programs.
- Preserving nature lands.
- Restructuring local agencies to integrate the management of all water resources.

Introduction

Houston's "Tax Day" flood in April 2016, which killed eight people, and the 2015 Memorial Day flood in Wimberley, which killed 12 people, have renewed the longstanding conversation about how the state can best prevent or mitigate the impacts of deadly flooding.[1] Texas has lost more lives to floods than any other state over the last 20 years.[2]

It is tempting to meet the rise in flood risk with resignation. As Houston Mayor Sylvester Turner even said after the Tax Day flood: "There's nothing I can say that's going to ease your frustration. We certainly can't control the weather."[3]

But while we can't control the weather, or prevent all flooding, there are specific steps we can take to limit the damage.

Green stormwater infrastructure – installations that mimic the natural environment and absorb rainfall – has the potential to help address flooding, improve water quality and add beauty to local neighborhoods. By replacing traditional roofs with green ones, traditional paved roads with permeable ones, and portions of mowed lawns with rain gardens, just to give three examples, flooding can be reduced and mitigated. Furthermore, these green projects can be more cost effective than traditional and often environmentally harmful infrastructure.

Texas cities currently have unique opportunities to implement new policies to require and encourage the use of green infrastructure for stormwater management. The ReBuild Houston program, approved by voters in 2010, has allowed the Houston Department of Public Works and Engineering to improve more than 900 miles of roads and will enable the city to completely rebuild its street and drainage infrastructure over the coming decades.[4] Houston will also upgrade its sewage system due to a consent decree that the city is presently negotiating with the U.S. EPA. Additionally, the city has a new "flood czar," who is charged with coordinating policies and programs among the many agencies and entities responsible for stormwater and flood management.[5] These recent changes provide Houston with the opportunity to create new green infrastructure in the city.

Similarly, Austin has an opening to implement better stormwater management policies through CodeNEXT, a new city initiative that will lead to a massive overhaul of the city's development code. The city previously set some worthwhile goals for stormwater management in the Imagine Austin Comprehensive Plan, adopted in 2012. The CodeNEXT process aims to update these goals to be adopted in 2018. Already, CodeNEXT has written a prescription paper proposing ways to adapt development to address flooding and preserve water.[6]

Over the next few months, it will be crucial to turn these recommendations into policy, both in Austin and throughout the state, that will require and encourage the greater use of green stormwater infrastructure. This white paper will explore the dangers posed by flooding and stormwater, both across the country and in Texas specifically, and the ways in which green stormwater infrastructure can help to address it. This paper will also look at successful green infrastructure installed across the state and propose ways that policymakers can work to spread these systems further.

Flooding Is a Serious Concern in Texas

Flooding – resulting from rainfall, breached dams, seawater or melting ice saturating land more quickly than the water can be absorbed – is a frequent problem across the United States.[7] In Texas, this danger has been apparent both through the visible impact of recent large-scale floods and the increasing frequency of smaller ones. These weather-related disasters can threaten lives, cause billions of dollars of destruction, and have lasting impacts on local water quality.

Flooding Causes Death and Destruction

In the United States, floods are both common and dangerous. In 2015, 176 people across the country were killed by floods.[8] On average, there are approximately 16 floods nationwide each year that are large enough to create at least $1 billion in damage, in addition to the many smaller storms that have severe impacts on a more local scale.[9]

Figure 1. Yearly Flooding Fatalities in the United States and Texas since 1995[10]

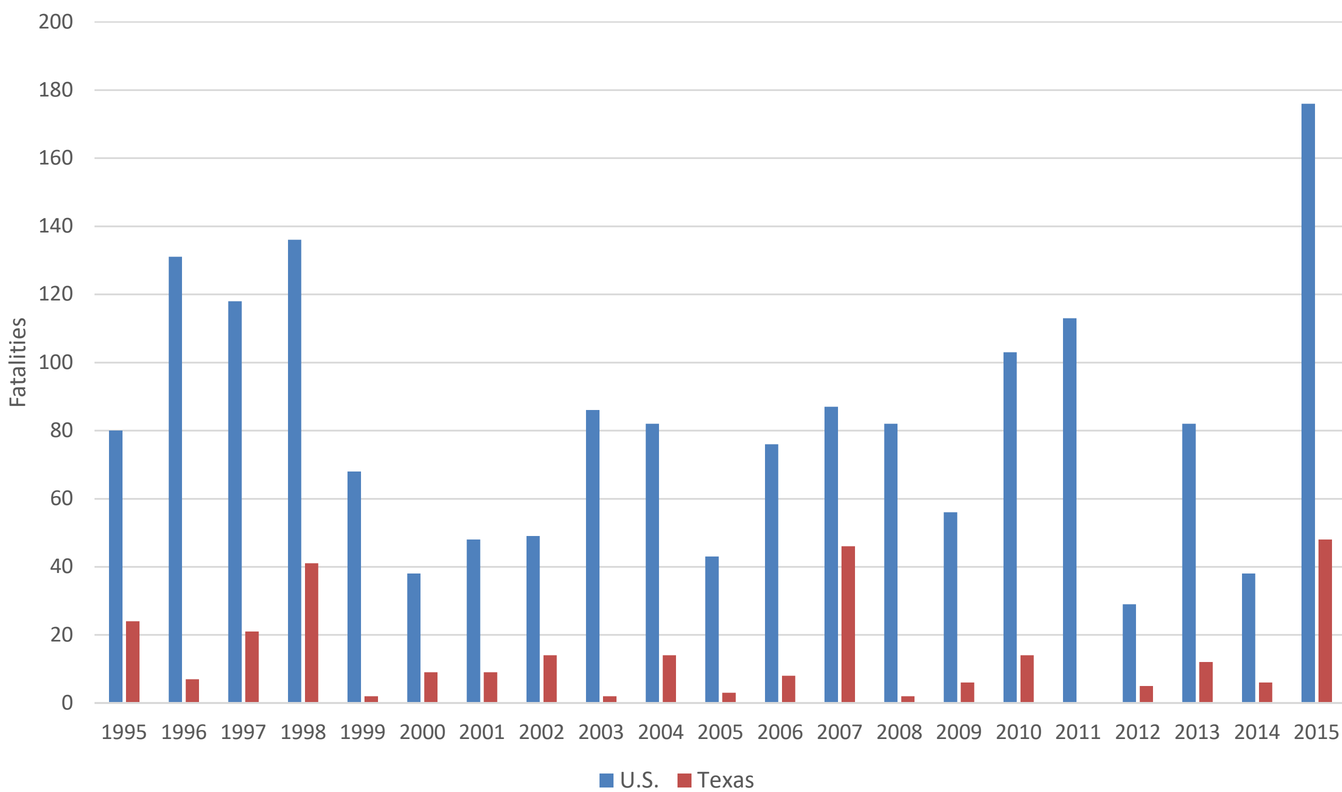

Photo: Brian Zabcik

Stormwater mixed with automotive fluids at a service station during the 2015 Memorial Day flood in Austin.

In recent years, Texas has been particularly impacted by flooding. In 2015, 48 people across the state were killed by floods, and Texas has been the state with the highest number of flooding-related deaths 11 times in the last 21 years.[11] (Figure 1.) Damages from flooding totaled more than $3 billion in Texas in 2015, the most expensive year on record.[12]

Stormwater Runoff Worsens Water Quality

Even when flooding isn't an issue, stormwater brings pollutants into the water supply, creating longer-term health impacts. The Texas Commission on Environmental Quality (TCEQ) found that in 2008 more than 430 miles of rivers and streams across the state were impacted by stormwater runoff.[13] On its city government website, Austin warns local residents to "refrain from swimming after flooding or heavy rains" because stormwater has been known to transport manure and hazardous waste to local streams.[14]

The Houston-Galveston area faces similar concerns. In its 2015 *Galveston Bay Report Card*, the Galveston Bay Foundation gave the current pollution situation in the Bay a "D" grade, indicating a need for action.[15] Stormwater was specifically mentioned as a cause of human and animal waste pollution in the bay. Additional reports have found that swimming and fishing are too dangerous in 80 percent of all major waterways across the greater Houston area due to pollution concerns, a situation made worse by stormwater.[16]

The Risk of Flooding Is Increasing

Global warming is increasing the frequency of heavy precipitation that can exacerbate flooding, as well as other extreme weather events across the country, according to the National Academy of Sciences.[17] This trend has been particularly evident in Texas. Two Texas cities – McAllen and Houston – are among the 10 U.S. cities that experienced the sharpest increase in heavy rain since 1950.[18] Austin and El Paso are also among the 50 cities with the most severe uptick in heavy rains, experiencing 67 percent and 40 percent increases, respectively, over the last 65 years.[19]

In addition to the growing frequency of heavy rain, flooding has become a common danger in Texas because of the increased surface coverage that pre-

Photo: Brian Zabcik

Impermeable surfaces, like parking lots and roads, contribute to flooding.

vents stormwater from being absorbed into the ground. Most rooftops, paved roads and parking lots are made of impervious materials. When stormwater cannot be absorbed or collected, it overwhelms sewer systems, streams and bayous, which leads to flooding.

As more land is blanketed with impervious cover, runoff is likely to increase. While just 5 percent of rainfall in forested regions becomes runoff, more than half of rainfall in the most heavily urban areas can become stormwater runoff.[20] Much of Texas is heading in this direction; recent satellite data shows that 337,000 acres of Harris County, out of 1.1 million total, were fully covered by impermeable material by 2011.[21] Furthermore, coverage by impervious surfaces in more suburban neighboring counties is increasing at a rapid rate, including a 53 percent increase in Fort Bend County since 2001.[22]

Green Stormwater Infrastructure Is a Tool for Flood Management

Flooding is a complex problem that has been addressed in a variety of ways. The traditional option for flood management is through "gray" infrastructure: systems of concrete-lined drainage channels, sewage mains, tunnels and wastewater treatment plants that collect, convey and treat stormwater. Current proposals to address flooding focus primarily on expanding this gray infrastructure system, but these methods are expensive and can have harmful impacts on the environment.

Alternatively, flooding and poor water quality can be addressed with green stormwater infrastructure (GSI), which are man-made systems that absorb runoff and filter pollutants in ways that either incorporate or replicate nature.

The original "green infrastructure" was, and still is, the natural environment. Forests, wetlands and prairies are vital components of the water cycle, responsible for absorbing significant amounts of rainwater. The EPA has found that wetlands, for example, can store a million gallons of water per acre.[23] Because many of these natural ecosystems have been lost to development, Texas has become more vulnerable to flooding.

Replacing some of the rainwater capacity that natural lands had provided requires implementing green infrastructure projects like rain gardens, rain barrels, green roofs and walls, permeable pavements, constructed wetlands and bioswales, among many others. All of these systems retain rainwater on site where it falls, and some of them also function as filters.[24] Some of these systems are constructed primarily on residential property, others are better suited for commercial structures, and some can be widely installed in public spaces. Combined, they offer broad coverage that can mitigate flooding and improve water quality while saving money.

Stormwater Infrastructure Mitigates Flooding and Improves Water Quality

While green stormwater infrastructure alone cannot prevent flooding, these systems can be the difference between minor and major flooding. For example, a 1,000-square foot paved driveway can produce more

Permeable pavement allows water to soak through.

than 600 gallons of stormwater runoff in a 1-inch rainfall.[25] If the pavement were instead permeable, more than 80 percent of this runoff could be prevented.[26]

Permeable pavement is far from the only GSI project that limits flooding. The EPA predicts that if GSI initiatives are adopted across the country starting in 2020, by 2040 they could prevent up to $2.3 billion in flooding damages.[27] Numerous studies have found that GSI systems can absorb between 50 and 90 percent of rainfall on site, with much higher effectiveness during less severe storms, including the potential to fully prevent flooding.[28]

Beyond reducing flood flows, GSI can reduce stormwater pollutants such as litter, plant or animal matter, and sewage. More than a dozen studies over the last 15 years have found that bioswales and other grass strips situated alongside roads can trap between 45 and 99 percent of the solid particles that are contained in stormwater.[29] While estimates of the ability of GSI to reduce levels of other water pollutants vary, the sheer volume of water that can be contained by green stormwater infrastructure certainly prevents a significant amount of these pollutants from reaching our rivers and lakes.[30]

Green Stormwater Infrastructure Can Reduce the Cost of Flood Control

Between the lower cost of installing GSI systems and the costs saved by limiting flood damage and reducing pollution, GSI is an efficient and cost-effective approach to managing runoff in comparison to gray infrastructure. Construction costs for GSI are 5 to 30 percent lower than the expense of building new gray infrastructure, and maintenance expenses over these systems' lifetimes are 25 percent lower.[31] Given that estimates of the expense of improving Houston's infrastructure after the 2016 Tax Day Flood were as high as $26 billion, the financial savings of greener solutions can be significant.[32]

Side-by-side comparisons of green and gray infrastructure have consistently shown investments in green infrastructure to be more cost effective. The World Resources Institute found that green efforts to preserve water quality in Maine's Sebago Lake watershed could cost up to 76 percent less than similarly effective investments in gray infrastructure, even before considering the millions of dollars in climate benefits that the green infrastructure option would produce through carbon sequestration.[33] More locally, when the Union Carbide Corporation needed a way to treat wastewater in Seadrift, Texas, it decided to use a constructed wetland instead of a building an industrial water treatment facility. In addition to being significantly less energy-intensive and environmentally harmful than a treatment plant, the engineered wetland took half as long and cost 30 times less to build.[34]

Smaller-scale GSI systems for residential use are similarly affordable. Price estimates vary widely across the country, but green roofs cost less than $20 per square foot, rain gardens cost between $3 and $20 per square foot, rain barrels costs less than $1 per gallon per year, and all of these systems require minimal maintenance expenses.[35] Beyond limiting stormwater runoff, some of these tools store water that can be used for landscape irrigation, which can lower water bills and further reduce their cost.[36]

Another factor in the cost-effectiveness of GSI is the value of the flood damages they prevent. The Conservation Fund calculates that wetlands in the Houston-Galveston region prevent up to $8,000 in damages per acre annually.[37] While GSI operates at a smaller scale, the impressive cost-saving potential of wetlands hint at the value provided by some green stormwater infrastructure that is designed to mimic wetlands' ability to absorb stormwater.

Photo: Alisha Goldstein, EPA

Beyond absorbing and filtering stormwater, rain gardens add natural beauty to developed areas.

Other Benefits of Green Stormwater Infrastructure

While their primary function is to offer extra protection against the threat of flooding and the resulting water quality concerns, green stormwater infrastructure installations offer additional benefits to their surrounding area.

Because rain gardens, bioswales and green pavement are permeable, unlike most paved areas, they allow rainwater to replenish the water table. Approximately one-quarter of the rainwater absorbed into the soil by permeable surfaces is eventually restored to groundwater reserves, while just 5 percent of water on impervious surfaces will infiltrate that deeply underground.[38] Drought and groundwater depletion are urgent concerns across Texas and particularly in the northwest region of the state, where the water levels in the Ogallala Aquifer have dropped almost nine feet since 2004.[39] Restoring permeable lands could help prevent further aquifer depletion.

Because GSI systems replicate natural features in man-made developments, they have been praised for beautifying the landscape. In its guide to the benefits of green infrastructure, the Center for Neighborhood Technology identifies three stormwater management strategies that "improve aesthetics" of the local community - green roofs, tree planting and bioretention and infiltration. The Center specifically notes that green roofs "increase community interest in green infrastructure through their aesthetic appeal, which provides a great opportunity for public education."[40] Green stormwater infrastructure can be designed to also function as public parks, further showing the community benefit that GSI can provide.[41]

Additionally, green stormwater infrastructure can benefit the climate. GSI systems that involve planting trees or shrubs remove carbon dioxide from the atmosphere. A 5,000 square foot green roof, for example, would remove between 166 and 172 pounds of carbon from the atmosphere each year.[42] A single tree planted to increase floodwater absorption can capture between 200 and 900 pounds of carbon dioxide over a 40-year period, depending on the tree's size and location.[43]

Models for Green Stormwater Infrastructure Policies and Projects

While there are many ways in which green stormwater infrastructure can and should be expanded throughout the state, some successful GSI programs have already been implemented in Texas and nationwide.

In Texas:

- Austin has developed a master plan called "Water Forward" that includes water-demand strategies for the city's next 100 years. Austin also offers rebates of up to $500 for installing stormwater management systems – including permeable pavement, rain gardens and bioswales – in homes or schools.[44]

- In July 2016, a green roof was set up at the Dell Medical School in Austin. The roof features native plants that can grow without irrigation.[45]

- Just outside Houston, Birnamwood Drive became the first road in Harris County to use green infrastructure when it was built in 2012. The road's traffic lanes are separated by a wide, depressed median that uses native plants, gravel and buried rain tanks to collect and filter excessive runoff.[46]

- Houston recently built a new firehouse, Station 90, which incorporates a variety of green infrastructure installations and other techniques to minimize outdoor water use. The station was able to reduce the high cost and environmental impact of excessive irrigation by using native plants in its landscaping and harvesting rainwater from its roof.[47]

- The San Antonio River Authority offers $22,000 grants to public schools in any of four counties – Bexar, Wilson, Karnes and Goliad – that want to educate students about flooding and water pollution and build rain gardens, bioswales or rain cisterns on their campuses.[48]

Around the country:

- Seattle has adopted a plan to increase the amount of stormwater managed by green infrastructure citywide from 100 to 700 million gallons. Its plan also calls for reducing the amount of stormwater runoff from downtown by 50 percent. To achieve these goals, Seattle offers generous rebates for homes and businesses to install green infrastructure components.[49]

- Philadelphia pays up to 100 percent of the cost of installing green infrastructure on homeowner properties.[50]

- Chicago has allocated $50 million to build new green stormwater infrastructure, an investment that is projected to reduce 250 million gallons of runoff annually.[51]

- Denver has integrated its water management functions by creating a Wastewater Management Division in the Department of Public Works. Combining all water responsibilities in one department makes it easier for the city to combat stormwater runoff and flooding.[52]

Obstacles to Expanding Green Stormwater Infrastructure

Despite the many benefits of GSI and the successful models that new developments can draw from, a number of obstacles still limit the expansion of green stormwater infrastructure. Many homeowners' associations (HOAs), for example, restrict or forbid the installation of rain barrels, rain gardens or other stormwater management systems. Almost 20 percent of U.S. homes are governed by HOAs, and given the difficulty of revising many of these associations' bylaws, their regulations can make it much harder for homeowners to mitigate damage from stormwater.[53] Even though a Texas law passed in 2013 banned HOAs from prohibiting residential rainwater collection, homeowners associations are still allowed to regulate the methods used.[54]

Additionally, developers and homeowners may fear the upfront cost of many GSI systems and choose not to incorporate them into their projects. Unlike gray infrastructure, which is largely a public cost, GSI expenses are generally private. A survey of engineers, architects and developers in New York State found that cost was the most commonly cited reason for not using green infrastructure in their projects, cited by 30 percent of respondents.[55] However, the Water Environment Federation points out that many of these concerns disappear after considering maintenance costs over a development's lifetime.[56]

In addition to funding and regulatory concerns, a lack of knowledge about options for stormwater management has limited the spread of GSI. One study of the barriers to green infrastructure in Michigan's Huron River watershed identified limited training and knowledge among engineers, developers and residents as key obstacles.[57] The New York State survey similarly indicated that insufficient knowledge was the second largest barrier to GSI expansion, after cost.[58] Even though both research and experience have demonstrated the many benefits offered by GSI, these techniques will not be more widely used without increased awareness.

Policy Recommendations

While a few Texas cities have adopted some green infrastructure programs and practices, there's ample room for cities and the state to do much more. Because climate change will continue to impact Texas, it is crucial to take action now to mitigate future flooding and reduce the risks of fatalities, property damage and water pollution caused by excessive runoff. Green stormwater infrastructure can significantly lessen these problems. There are a number of specific steps that Texas cities and the state can take to reduce flooding and improve water quality:

- Adopt a comprehensive green infrastructure plan in order to conduct an inventory of the amount of stormwater handled by existing green infrastructure, set a realistic but ambitious target for increasing the amount of stormwater managed by new green infrastructure, and implement the policies necessary to reach this goal.
- Integrate all aspects of water management – drinking water, wastewater, stormwater and natural water sources – by changing government structures in order to bring these related responsibilities together under one roof.
- Require all new developments and encourage existing ones to retain and manage stormwater onsite with green infrastructure elements such as permeable paving, rain gardens, retention ponds, bioswales, green roofs and walls, disconnected downspouts and rain harvesting.
- Require new developments and redevelopments to discharge no more stormwater runoff than was discharged from their sites prior to development whenever possible. This requirement can be adjusted when unique site conditions are met.
- Require all new or rebuilt roads to use permeable pavement and vegetation. This would allow stormwater to be absorbed and filtered by the soil, greatly reducing runoff volume.
- Identify obstacles to the expansion of green infrastructure by reviewing, revising and updating their building codes and zoning ordinances.
- Provide funding for green infrastructure plans through adequate appropriations in city and state budgets, bond issues for larger projects, and awards and settlements from environmental litigation.
- Incentivize homeowners and business by offering substantial rebates or tax credits to cover the cost of installing GSI.

Notes

1. Tax Day: Associated Press, "Death Toll Reaches 8 from Houston-area Storms, Flooding," *KXAN*, 20 April 2016, archived at web.archive.org/web/20161223161713/http://kxan.com/2016/04/20/death-toll-reaches-8-from-houston-area-storms-flooding/; Wimberley: Jamie Thompson, "When the River Rises," *Texas Monthly*, May 2016, archived at web.archive.org/web/20161223155501/http://features.texasmonthly.com/editorial/wimberley-floods-memorial-day-weekend-2015/.

2. National Weather Service, *Flood Fatalities by State and Location* (dataset), 1995-2015, available at www.nws.noaa.gov/om/hazstats.

3. CBS News and Associated Press, "Houston Mayor Says There's No Solution to Flooding There," *CBS*, 19 April 2016, archived at web.archive.org/web/20161111225032/http://www.cbsnews.com/news/houston-mayor-says-theres-no-solution-to-flooding-there/.

4. Houston Department of Public Works and Engineering, *Rebuild Houston: Look Back/Look Forward Report 2016*, March 2016.

5. Florian Martin, "What Ideas Does Houston's New Flood Czar Have to Address Flooding?," *Houston Public Media*, 12 May 2016, archived at web.archive.org/web/20161230164326/https://www.houstonpublicmedia.org/articles/news/2016/05/12/150083/houstons-appointed-flood-czar-was-surprised-to-be-named/.

6. Code Next, *Natural and Built Environment Code Prescription*, March 2016.

7. The National Severe Storms Laboratory, National Oceanic and Atmospheric Administration, *Severe Weather 101: Flood Basics*, accessed 8 November 2016, archived at web.archive.org/web/20161108163524/http://www.nssl.noaa.gov/education/svrwx101/floods/.

8. National Weather Service, *Weather Fatalities*, 6 April 2016, archived at web.archive.org/web/20161111212755/http://www.nws.noaa.gov/om/hazstats.shtml.

9. Adam B. Smith and Richard W. Katz, "US Billion-Dollar Weather and Climate Disasters: Data Sources, Trends, Accuracy and Biases," *Natural Hazards*, 67(2):387-410, doi:10.1007/s11069-013-0566-5, June 2013.

10. See note 2.

11. See note 2.

12. Dylan Baddour, "Texas Flood Damage Could Top $3 Billion for 2015," *Houston Chronicle*, 28 October 2015, archived at web.archive.org/web/20170109205347/http://www.chron.com/news/houston-texas/texas/article/texas-flood-damage-cost-climate-change-el-ni-o-6594008.php.

13. Texas Commission on Environmental Quality, *Texas Nonpoint Source Management Program*, May 2012, archived at web.archive.org/web/20170109211244/https://www.tsswcb.texas.gov/files/docs/nps-319/npsmgmtplans/2012mgmtprogram.pdf, 2.

14. Austin-Travis County, *Swim Safety Tips for Pools, Rivers and Lakes*, 24 June 2015, archived at web.archive.org/web/20161111221456/http://www.austintexas.gov/blog/swim-safety-tips-pools-rivers-and-lakes.

15. Galveston Bay Foundation, *Galveston Bay Report Card 2015*, accessed 9 January 2017, archived at web.archive.org/web/20170109211439/http://www.galvbaygrade.org/wp-content/uploads/2015/07/Galveston_Bay_Full_Report_updweb.pdf.

16. Luke Metzger and Sara Smith, Save Buffalo Bayou, *Valuable Insight about Stormwater Pollution of Our Bayous*, 20 November 2015, archived at web.archive.org/web/20161111223526/http://www.savebuffalobayou.org/?m=201511.

17. Doyle Rice, "National Academy of Sciences Report Links Extreme Weather to Climate Change," *USA Today*, 11 March 2016, archived at web.archive.org/web/20161112224253/http://www.usatoday.com/story/weather/2016/03/11/extreme-weather-attribution-climate-change/81639624/.

18. Climate Central, *Across U.S., Heaviest Downpours on the Rise*, 27 May 2015, archived at web.archive.org/web/20161112225056/http://www.climatecentral.org/news/across-us-heaviest-downpours-on-the-rise-18989.

19. Ibid.

20. Lance Frazer, "Paving Paradise: The Peril of Impervious Surfaces," *Environmental Health Perspectives*, 113(7): A456–A462, July 2005.

21. Kim McGuire, "Houston's Development Boom and Reduction of Wetlands Leave Region Flood Prone," *Houston Chronicle*, 25 July 2016, archived at web.archive.org/web/20161113005500/http://www.houstonchronicle.com/news/houston-texas/houston/article/Houston-s-development-boom-and-reduction-of-8403838.php.

22. Ibid.

23. Environmental Protection Agency, *Wetlands: Protecting Life and Property from Flooding* (factsheet), May 2006, archived at web.archive.org/web/20170109212024/hps://www.epa.gov/sites/production/files/2016-02/documents/flooding.pdf.

24. Environmental Protection Agency, *What Is Green Infrastructure?*, 23 September 2016, archived at web.archive.org/web/20161110180535/https://www.epa.gov/green-infrastructure/what-green-infrastructure.

25. URS Group Inc., *Water: Too Much or Too Little? Or a Little of Both?* (slides), 2010 ASFPM National Conference, May 2010.

26. Center for Neighborhood Technology, *The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits*, 2010, archived at web.archive.org/web/20170110225856/http://www.cnt.org/sites/default/files/publications/CNT_Value-of-Green-Infrastructure.pdf, 19.

27. Environmental Protection Agency, *Flood Loss Avoidance Benefits of Green Infrastructure for Stormwater Management*, December 2015, archived at web.archive.org/web/20170110230004/https://www.epa.gov/sites/production/files/2016-05/documents/flood-avoidance-green-infrastructure-12-14-2015.pdf, 8-13.

28. William J. Taylor, Taylor Aquatic Science and Policy, *White Paper for Stormwater Management Program Effectiveness Literature Review: Low Impact Development Techniques*, April 2013, archived at web.archive.org/web/20170110230133/http://www.ecy.wa.gov/programs/wq/psmonitoring/ps_monitoring_docs/SWworkgroupDOCS/LIDWhitePaperFinalApril2013.pdf.

29. Ibid., 22.

30. Ibid.

31. Claudia Copeland, Congressional Research Service, *Green Infrastructure and Issues in Managing Urban Stormwater*, 2 May 2016, archived at web.archive.org/web/20170110230231/https://fas.org/sgp/crs/misc/R43131.pdf, 2.

32. Mary Anne Piacentini, Jaime González and Deborah January-Bevers, "How to Fight Houston Flooding with Plants," *Houston Chronicle*, 19 August 2016, archived at web.archive.org/web/20170110230314/http://www.houstonchronicle.com/local/gray-matters/article/Want-to-fight-flooding-Make-nature-an-ally-9171041.php.

33. John Talberth et al., World Resources Institute, *Insights from the Field: Forests for Water*, February 2012, archived at web.archive.org/web/20170110230434/http://www.wri.org/sites/default/files/pdf/insights_from_the_field_forests_for_water.pdf.

34. The Nature Conservancy et al., *The Case for Green Infrastructure: Joint-Industry White Paper*, June 2013, archived at web.archive.org/web/20170110230517/https://www.nature.org/about-us/the-case-for-green-infrastructure.pdf.

35. Center for Neighborhood Technology, *National Green Values™ Calculator Methodology*, 30 June 2009, archived at web.archive.org/web/20170110230603/http://greenvalues.cnt.org/national/downloads/methodology.pdf

36. Julia Fiala, World Wildlife Fund, *Saving Water and Money with Rain Barrels*, 16 December 2013, archived at web.archive.org/web/20161111182056/http://www.worldwildlife.org/blogs/on-balance/posts/saving-water-and-money-with-rain-barrels.

37. The Conservation Fund, *Houston-Galveston: Green Infrastructure and Ecosystem Services Assessment*, 2013, archived at web.archive.org/web/20170110230702/http://www.conservationfund.org/images/projects/files/Houston_Galveston_Report.pdf, 10.

38. See note 31.

39. Sandra Postel, "Drought Hastens Groundwater Depletion in the Texas Panhandle," *National Geographic*, 24 July 2014, archived at web.archive.org/web/20170110230745/http://voices.nationalgeographic.com/2014/07/24/drought-hastens-groundwater-depletion-in-the-texas-panhandle/.

40. See note 26.

41. American Planning Association, *How Cities Use Parks for… Green Infrastructure*, 2003, available at www.planning.org/cityparks/briefingpapers/.

42. See note 26.

43. Ibid.

44. Austin Water, *Waterwise Rainscape Rebate*, accessed 13 November 2016, archived at web.archive.org/web/20161113211136/http://www.austintexas.gov/department/waterwise-rainscape-rebate.

45. Lady Bird Johnson Wildflower Center, *Dell Medical School Green Roof*, accessed 12 January 2017, archived at web.archive.org/web/20170112171517/http://www.wildflower.org/project/dell-medical-school-green-roof

46. Bryan Kirk, "Birnamwood Drive Project Serves a Model for Managing Drainage," *Houston Chronicle*, 7 January 2015, archived at web.archive.org/web/20170111204823/http://www.chron.com/neighborhood/spring/news/article/Birnamwood-Drive-project-serves-a-model-for-5999493.php

47. Asakura Robinson, *Fire Station 90*, accessed 13 November 2016, archived at web.archive.org/web/20161113205259/http://www.asakurarobinson.net/portfolio-view/fire-station-90/.

48. San Antonio River Authority, *Watershed Wise: Grant*, accessed 13 November 2016, archived at web.archive.org/web/20161113205757/https://www.sara-tx.org/lid-sustainability/green-infrastructure/.

49. 700 Million Gallons, *How the Rebate Works*, accessed 11 January 2017, archived at http://web.archive.org/web/20170111204543/http://www.700milliongallons.org/rainwise/.

50. Philadelphia Water, *Learn More*, accessed 11 January 2017, archived at web.archive.org/web/20170111204207/http://www.phillywatersheds.org/whats_in_it_for_you/residents/raincheck/gettingstarted.

51. City of Chicago, *Green Stormwater Infrastructure Strategy*, April 2014.

52. Denver Department of Public Works, *Public Works Services*, accessed 13 November 2016, archived at web.archive.org/web/20161113213942/https://www.denvergov.org/content/denvergov/en/denver-department-of-public-works/about-us/our-divisions.html.

53. Kaid Benfield, “The Tyranny of Homeowners Associations,” *CityLab,* 19 February 2013, web.archive.org/web/20161230173216/http://www.citylab.com/housing/2013/02/tyranny-homeowners-associations/4731/.

54. Karel Holloway, “New Texas Law Forbids HOAs to Ban Some Water Conservation Methods,” *The Dallas Morning News*, August 2013, archived at web.archive.org/web/20161230174004/http://www.dallasnews.com/life/life/2013/08/28/new-texas-law-forbids-hoas-to-ban-some-water-conservation-methods.

55. Emily Vail and Andrew Meyer, Hudson River Estuary Program, *Barriers to Green Infrastructure in the Hudson Valley: an Electronic Survey of Implementers,* 2012.

56. Water Environment Federation, *The Real Cost of Green Infrastructure*, 2 December 2015, archived at web.archive.org/web/20161230183431/http://stormwater.wef.org/2015/12/real-cost-green-infrastructure/

57. Huron River Watershed Council, *Barriers Preventing Implementation of Green Infrastructure in Washtenaw County, Michigan,* February 2014.

58. See note 54.