



GREEN INFRASTRUCTURE AND POST-DISASTER RECOVERY

At the regional scale, green infrastructure is a network of natural areas and open spaces that provide multiple benefits for people and wildlife, such as regional parks and nature preserves, river corridors and greenways, and wetlands (Benedict and McMahon 2006). At the neighborhood and site scales, the U.S. Environmental Protection Agency (EPA) refers to green infrastructure as stormwater management practices that mimic natural processes by absorbing water, such as green streets, green roofs, rain gardens, and pervious pavement. Trees are a type of green infrastructure that spans these scales, from regional woodlands to the urban forest to street and other tree plantings.

Green infrastructure plays an important role in preparation for and recovery from natural disasters. Climate change scenarios project that precipitation and temperature extremes, storm frequency and intensity, and sea-level rise will accelerate in the coming century. By incorporating green infrastructure into post-disaster recovery, communities can become more resilient to future disasters.

KEY POINT #1

Green infrastructure reduces damage from storm surge and flooding and plays a role in other types of disasters.

KEY POINT #2

Resilience to natural disasters is one of a broad array of benefits provided by green infrastructure.

KEY POINT #3

Particularly in urban contexts, green infrastructure must be combined with gray infrastructure to effectively reduce damage from natural disasters.

KEY POINT #4

Green infrastructure resources can suffer severe damage from disasters, which in the absence of preplanning can be exacerbated in short-term recovery response.



For the purposes of the [Hurricane Sandy] Rebuilding Strategy, green infrastructure is defined as the integration of natural systems and processes, or engineered systems that mimic natural systems and processes, into investments in resilient infrastructure. Green infrastructure takes advantage of the services and natural defenses provided by land and water systems such as wetlands, natural areas, vegetated sand dunes, and forests, while contributing to the health and quality of America's communities.

Source: Hurricane Sandy Rebuilding Task Force 2013

KEYPOINT #1:

Green infrastructure reduces damage from storm surge and flooding and plays a role in other types of disasters.

Damage from flooding in inland areas, and from storm surge and flooding in coastal environments, is significantly reduced when natural wetland, riparian, and floodplain areas and the ecosystem services they provide are protected. Buildings, roads, and other supporting infrastructure are particularly vulnerable to storm damage

when constructed in these areas, and loss of natural functions such as flood storage capacity can increase damage to development on adjacent, less sensitive lands. Thus a particularly effective use of green infrastructure to reduce damage from natural disasters is to conserve environmentally sensitive areas through strategies such as acquisition of land or easements, natural resource protection ordinances, and other regulatory controls and incentives.

In many urban areas, natural resources such as streams, floodplains, and wetlands have been replaced by development and natural hydrological processes have been disrupted by fill and impervious surfaces. The conventional stormwater management approach in such areas has been to collect the high volumes of runoff generated during storms and convey them via pipes to nearby waterways. This approach can exacerbate flooding from major storms and degrade water quality, for example from combined sewer overflow (CSO) in older cities with connected storm and sanitary

sewer systems. Green infrastructure is an alternative approach that retains stormwater near where it is generated through infiltration (rain gardens, stormwater planters, pervious surfaces, etc.) and evapotranspiration from trees and other vegetation. While green stormwater infrastructure is most commonly used at the site scale to manage runoff from smaller storms, when deployed at a watershed scale it can reduce flooding from larger disasters such as the benchmark 100-year storm (Medina, Monfilis, and Baccala 2011). The New York City Department of Parks & Recreation manages approximately 2,500 green streets, many of which performed well during Hurricane Sandy. *A Stronger, More Resilient New York*, former Mayor Bloomberg's post-Sandy plan to address future climate risk, recommends expansion of the city's green streets program as part of a strategy to mitigate the impacts of extreme weather events (New York City 2013).

Green infrastructure—and how it is managed—plays a role in other types of natural disasters. For example, intense urban heat waves such as those experienced by Chicago (approximately 700 fatalities in 1995) and Europe (more than 70,000 fatalities during the summer of 2003) will likely become more common in the future as a result of climate change and the global trend of increasing urbanization. Green infrastructure such as trees, parks, and green roofs can ameliorate the so-called urban heat island effect. One study found that adding 10 percent green cover in high-density residential areas in Manchester, United Kingdom, will keep maximum surface temperatures at or below 1961–1990 baseline levels in the 2080s, contrasting with a projected 1.7° C to 3.7° C increase due to climate change with no increase in greening (Gill et al. 2007).

Drought is a type of natural disaster that can adversely impact green infrastructure by weakening natural ecosystems, making them more susceptible to invasive species, disease, and pests, and causing the loss of urban trees and other vegetation (Schwab 2013). The Manchester study notes that the potential of green cover to moderate surface temperatures is adversely impacted by drought, when grass dries out and loses its evaporative cooling function (Gill et al. 2007). Mature trees retain this cooling function longer than grass, and the study recommends that adequate water be provided to vegetation during droughts (which may, however, conflict with

the need to restrict water usage). Such issues are particularly important in arid regions such as the southwestern United States, highlighting the need to conserve native ecosystems that are adapted to the climate and to specify low-maintenance, drought-resistant plant species.

Wildfires are another type of disaster with implications for green infrastructure in drier climates. For example, low-intensity wildfire is a natural occurrence that maintains the health of southwestern Ponderosa Pine forests, but fire suppression has resulted in dense, overcrowded tree stands that threaten development with destructive and costly wildfires. To combat this risk, Flagstaff (ranked as Arizona's most at-risk wildfire community) developed a comprehensive fire management program with five core areas: public preparedness, strategic development, response, land-use management, and hazard mitigation (Schwab 2009). Land-use planning focuses on creating and maintaining fire-adapted neighborhoods (www.fireadapted.org), while hazard mitigation involves managing forest conditions and fuel regimes to reduce the likelihood of destructive wildfires.

KEYPOINT #2:

Resilience to natural disasters is one of multiple benefits provided by green infrastructure.

Green infrastructure can mitigate the direct effects of natural disasters through services such as reducing stormwater runoff, buffering against storm surge in coastal environments, and reducing surface temperatures during heat waves, while also providing a broad array of other community benefits.

Often framed in terms of the triple bottom line of environmental, economic, and social return on investment, these additional benefits include (Rouse and Bunster-Ossa 2013):

Environmental

- Improved air and water quality
- Natural habitat preservation
- Climate change mitigation (from reduced fossil fuel emissions, reduced energy consumption, and carbon sequestration)

Economic

- Creation of job and business opportunities
- Increased tourism, retail sales, and other economic activity
- Increased property values
- Reduced energy, health care, and gray infrastructure costs
- Provision of locally produced resources (food, fiber, and water)

Social

- Promotion of healthy lifestyles through walking, biking, and outdoor recreation
- Improved public health outcomes (e.g., by connecting people to nature)
- Increased environmental justice, equity, and access for underserved populations
- Enhanced community identity through public art, culture, and places for people to gather

While many of the above benefits do not directly relate to post-disaster recovery, they can contribute to increased community resilience and, in doing so, reduce vulnerability to natural disasters. A park designed to accommodate flooding during storms while providing benefits such as recreation, social interaction, and increased commerce is an example of using green infrastructure to leverage multiple benefits beyond mitigating the direct impacts of a disaster. The triple-bottom-line analysis conducted for *Green City, Clean Waters*, the EPA-approved plan prepared by the Philadelphia Water Department to address the CSO problem, found that \$1 million in green infrastructure investments would yield a \$2.2 million return on investment over a 40-year period (Philadelphia 2009). Monetary return was calculated for eight different factors, such as green jobs generated, additional recreational user-days, reduced energy consumption, and fewer heat-related deaths.

Green infrastructure can be of particular value for poor and disadvantaged neighborhoods that too often suffer a disproportionate share of the impacts of a natural disaster. Incorporating green infrastructure into planning for post-disaster recovery can provide multiple environmental, economic, and social benefits for these neighborhoods, which frequently have fewer trees and green spaces than more advantaged communities.

KEYPOINT #3:

Particularly in urban contexts, green infrastructure must be combined with gray infrastructure to effectively reduce damage from natural disasters.

According to a recent study by the Natural Capital Project and the Nature Conservancy, 16 percent of the U.S. coastline, inhabited by 1.3 million people and representing \$300 billion in residential property value, is located in high-hazard areas (Arkema et al. 2013). Sixty-seven percent of these areas are protected by natural green infrastructure (intact reefs, sand

dunes, marshes, and other coastal vegetation), and the number of people and total property value exposed to hazards would double if this habitat were lost. These findings underscore the effectiveness of preserving and restoring natural habitat areas, as well as mimicking the services provided by such areas through “nature-based” approaches (e.g., artificial oyster reefs and living shorelines), to increase resilience to natural disasters. However, in many populated areas at risk from flooding, natural ecosystems have been extensively altered or replaced by development. Moreover, barrier beaches, dunes, riverine floodplains and the like are dynamic systems that move in response to natural processes such as erosion and sea-level rise, with implications for adjacent developed properties. Green infrastructure can reduce damage but may be insufficient to protect against catastrophic events such as the storm surge experienced by New York during Hurricane Sandy.

Traditional structural protection measures (often referred to as gray infrastructure) include, among others, seawalls, bulkheads, breakwaters, and jetties to protect against erosion and storm surge in coastal areas and levees, dams, embankment walls, and channelization to protect against flooding and erosion in inland areas. Such measures can be effectively deployed to protect urban and other areas with extensive investment in buildings and infrastructure. Considerations regarding the use of gray infrastructure include cost relative to benefits provided (it is typically more expensive than green infrastructure), unintended consequences caused by interruption to natural processes, and the possibility of inadequate protection or even failure during

catastrophic events (e.g., levee failure in New Orleans during Hurricane Katrina). Examples of unintended consequences include barriers that displace flooding from one area to another or groins (coastal erosion structures typically constructed perpendicular to the shoreline to trap sand) that cause beach erosion along the “down-drift” shoreline.

Integrated approaches to planning for future disasters combine green and gray infrastructure strategies. For example, a study of Howard Beach, a neighborhood in Queens that was flooded by Hurricane Sandy, concluded that a combination of natural and structural defenses would provide the most cost-effective protection against future storms (Nature Conservancy 2013). These “hybrid” strategies include restored marsh, mussel beds, rock groins, removable flood walls, and flood gates. At a larger scale, *A Stronger, More Resilient New York* combines nature-based (e.g., beach, dune, and marsh restoration) and structural (e.g., floodwalls and storm-surge barriers) measures to protect against the effects of climate change (New York City 2013).

Louisiana’s *Coastal Protection Master Plan* proposes a combination of restoration, nonstructural, and targeted structural measures to provide increased flood protection for all communities (Louisiana 2012). If current trends continue, Louisiana’s coastline is projected to lose 1,750 square miles over 50 years from multiple causes, including alteration of natural ecosystems, land subsidence, storms, and sea-level rise. Annual damages from coastal flooding are projected to increase almost ten-fold (from \$2.4 billion to \$23.4 billion in 2061). The plan proposes nine project types, ranging from marsh creation, barrier island restoration, and oyster barrier reefs to bank stabilization and structural protection (levees, flood walls, and pumps). The largest proportion of the proposed \$50 billion investment is allocated for marsh creation (\$20 billion).

While the above discussion addresses protection against flooding and storm surge, similar concepts can be applied to other types of natural disasters. One example is to combine green infrastructure (trees, green roofs, etc.) with building technology (e.g., active and passive cooling systems) to reduce the heat island effect that exacerbates urban heat waves. Another is to preserve active fault systems, unstable soils (prone to earth shaking, liquefaction, or mudslides), and low-lying

coastal areas (subject to tsunamis) as green space while implementing state-of-the-art building codes to reduce risk of damage from earthquakes.

KEYPOINT #4:

Green infrastructure resources can suffer severe damage from disasters, which in the absence of preplanning can be exacerbated in short-term recovery response.

The largest structural component of green infrastructure in urban areas, the urban forest takes years to grow and cultivate, but can be devastated in a single disaster. The Federal Emergency Management Agency's Public Assistance guidance, National Response Framework, and National Recovery Framework primarily address trees as debris (standing or on the ground),

and during the immediate recovery phase they are too often viewed as a problem that slows response efforts. If handled poorly, the community can be faced with years of expensive restoration to bring back a mature urban forest and the multiple benefits it provides.

Post-storm surveys have shown that most trees and branches that fail during storm events have pre-existing structural defects that could have been prevented through proper planting and pruning practices. Furthermore, these defects could have been detected and corrected if the trees had been inspected prior to the storm. Thus the most effective way for a community to improve preparedness and reduce damage to its urban forest from a major storm is to develop a tree risk management program that includes periodic inspections and corrective actions (Pokorny 2003). To facilitate recovery, response plans should be developed during preplanning to specify contractual arrangements, involvement of licensed and qualified arborists, damage assessment protocols, staging areas, opportunities for use of woody debris, etc.

Dunes, marshes, and wetlands are adapted to withstand storm damage if natural processes such as overwash (the landward transport of beach sediments across a dune system) are retained. Other types of

coastal vegetation can sustain significant damage from saltwater flooding, storm surge, and high winds; in 1989, approximately 4.45 million acres of forest were damaged by wind and water when Hurricane Hugo struck South Carolina (www.seesouthernforests.org/case-studies/climate). Inland flooding can cause significant damage to riparian forests, particularly if trees and shrubs are inundated for a period of weeks during the growing season. Foresters estimate that 36,546 acres of riparian and community forests were impacted by flooding along the Missouri and Mouse Rivers in June 2011, and thousands of dead and toppled trees were inventoried on public lands (Kangas 2013).

While the effects of a severe storm can be devastating, the long-term recovery phase provides the opportunity to "regrow" healthy forests—and other forms of green infrastructure—that provide enhanced community benefits while being more resilient to future disasters. Recommended strategies include replanting with low-maintenance, low-risk, and long-lived species; maximizing below- and above-ground growing space and minimizing infrastructure conflicts; preparing and maintaining baseline tree inventories; and implementing regular structural pruning, inspection, and maintenance programs.

CONCLUSION

The potential of green infrastructure to reduce damage from natural disasters has risen to the forefront in recent years in the aftermath of catastrophic events such as Hurricanes Katrina and Sandy. Preservation and restoration of marsh, dune, floodplains, and other natural systems; creation of living shorelines, oyster reefs, and other nature-based solutions; and integration of green resources (trees, green streets, green roofs, etc.) into the urban environment can increase community resilience while providing multiple environmental, economic, and social benefits. Planning for post-disaster recovery should use green infrastructure in combination with appropriate structural protection measures to reduce potential risks; specify how short-term recovery will address trees and other green resources; and set the framework for incorporating green infrastructure into long-term recovery. The result will be healthier communities that are more resilient to future disasters.

RESOURCES

American Planning Association. 2014. *Hazardous Tree Management and Post-Disaster Recovery*. Available at <https://www.planning.org/research/treemanagement>.

Arkema, Katie K., Greg Guannel, Gregory Vertutes, Spencer A. Wood, Anne Guerry, Mary Ruckelshaus, Peter Kareiva, Martin Lacayo, and Jessica M. Silver. 2013. *Coastal Habitats Shield People and Property from Sea-Level Rise and Storms*. The Natural Capital Project, Stanford University and The Nature Conservancy. Published in *Nature Climate Change* 3, pp. 913–918. Available at <http://www.nature.com/nclimate/journal/v3/n10/full/nclimate1944.html>.

Benedict, Mark, and Ed McMahon. 2006. *Green Infrastructure: Linking Landscapes and Communities*. Washington, D.C.: Island Press.

Gill, S.E., J.F. Handley, A.R. Ennos, and S. Pauleit. 2007. *Adapting Cities for Climate Change: The Role of the Green Infrastructure*. *Built Environment* Vol. 33 No. 1, pp. 115–133. Available at http://urbanspace.rec.org/files/Article_Gill_Adapting_Cities_for_CC.pdf.

Hurricane Sandy Rebuilding Task Force. 2013. *Hurricane Sandy Rebuilding Strategy*. Available at <http://portal.hud.gov/hudportal/documents/huddoc?id=hsrebuildingstrategy.pdf>.

Kangas, Michael. 2013. *Flood Recovery Guide for Green Infrastructure in Communities*. North Dakota Forest Service. Available at <http://www.ag.ndsu.edu/pubs/plantsci/landscap/f1696.pdf>.

Louisiana, State of. 2012. *Louisiana's Comprehensive Master Plan for A Sustainable Coast*. Coastal Protection Master Plan available at <http://coastal.la.gov/a-common-vision/2012-coastal-master-plan>.

Medina, Daniel E., Jacquelyn Monfils, and Zachary Baccata. 2011. "Green Infrastructure Benefits for Floodplain Management: A Case Study." *Stormwater*, November–December issue. Available at http://www.stormh2o.com/SW/Articles/Green_Infrastructure_Benefits_for_Floodplain_Manag_15593.aspx.

Nature Conservancy. 2013. *Integrating Natural Infrastructure into Urban Coastal Resilience: Howard Beach, Queens*. Available at <http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/newyork/natural-infrastructure-study-at-howard-beach.xml>

New York, City of. 2013. *A Stronger, More Resilient New York*. Available at <http://www.nyc.gov/html/sirr/html/report/report.shtml>.

Philadelphia, City of. 2009. *Philadelphia Combined Sewer Overflow Long Term Control Plan Update, sup. Vol. 2: Triple Bottom Line Analysis*. Available at http://www.phillywatersheds.org/ltcpu/Vol02_TBL.pdf.

Pokorny, Jill D., coordinating author. 2013. *Urban Tree Risk Management: A Community Guide to Program Design and Implementation*. U.S. Forest Service. Available at <http://www.na.fs.fed.us/spfo/pubs/uf/utrm>.

Rouse, David C., AICP, and Ignacio F. Bunster-Ossa. 2013. *Green Infrastructure: A Landscape Approach*. PAS Report no. 571. Chicago: American Planning Association.

Schwab, James, AICP, ed. 2009. *Planning the Urban Forest: Ecology, Economy, and Community Development*. PAS Report no. 555. Chicago: American Planning Association.

Schwab, James, AICP, ed. 2013. *Planning and Drought*. PAS Report no. 574. Chicago: American Planning Association.

U.S. Environmental Protection Agency. 2014. *What is Green Infrastructure?* Available at http://water.epa.gov/infrastructure/greeninfrastructure/gi_what.cfm.

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