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Green Infrastructure and Climate Change
Collaborating to Improve Community Resiliency

U.S. Environmental Protection Agency, Office of Wastewater Management

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Introduction

Communities across the nation already are experiencing the effects of climate change. As different parts of the country become drier, wetter or hotter, community leaders and citizens are looking to green infrastructure to improve their community's resiliency to the effects of climate change.

In 2015, EPA convened charrettes, or intensive planning sessions, in four cities: Albuquerque, Grand Rapids, Los Angeles, and New Orleans, to explore the ways in which green infrastructure could help cities become more resilient to climate change. In each city, participants were selected from a variety of disciplines, including city decision makers, climate scientists, water resource specialists, city planners, and neighborhood and environmental groups, among others. Participants considered the following concepts as they explored green infrastructure options that would help their cities be better prepared for climate change impacts:

What is green infrastructure?

Green infrastructure uses vegetation, soils, and natural processes to manage water and create healthier urban environments. Green infrastructure can range in scale from site design approaches such as rain gardens and green roofs to regional planning approaches such as conservation of large tracts of open land. In conjunction with gray infrastructure, interconnected networks of green infrastructure can enhance community resiliency by increasing water supplies, reducing flooding, combatting urban heat island effect, and improving water quality.

- Identifying the multiple benefits of green infrastructure practices.
- Collaborating across city agencies to maximize benefits.
- Unifying solutions across multiple disciplines.
- Achieving efficiencies in project implementation.

Each city's charrette focused on different issues based on the most pressing climate change impacts they were facing and their current level of green infrastructure implementation. The key goals of the charrettes are listed below – the findings of each charrette are summarized in case studies beginning on page 4.

Albuquerque

- Determine how green infrastructure can be used to meet the region's stormwater permit requirements and address flooding and water supply concerns.
- Outline the process to identify and evaluate green infrastructure opportunities.
- Identify implementation issues might arise as projects are undertaken.

Grand Rapids

- Discuss which climate resiliency concerns can be addressed by green infrastructure.
- Identify green infrastructure success stories in Grand Rapids as potential case studies.
- Determine areas of focus for future actions.

Los Angeles

- Identify transportation corridor improvements that meet multiple objectives, including heat island relief, reconnecting citizens to the Los Angeles River, and preparing for drought.
- Discuss ways to overcome potential implementation issues across multiple disciplines.

New Orleans

- Explore enhancements for public properties such as parks, playgrounds, schools, right-of-ways, and vacant lots.
- Demonstrate the benefits of green infrastructure in addressing water pollution, flooding, energy use, greenhouse gas emissions, and heat island impacts.

How Does Green Infrastructure Improve Climate Resiliency?

Green infrastructure strategies can help communities prepare for and manage climate change impacts.

Manages Flood Risk

High intensity storms are expected to become more frequent and intense as global temperatures continue to rise. As a result, the risk of flooding is likely to increase dramatically. Green infrastructure can help manage both localized and riverine floods by absorbing rainfall, preventing water from overwhelming pipe networks and pooling in streets or basements. Green infrastructure, open space preservation, and floodplain management can complement gray infrastructure approaches by reducing the volume of stormwater that flows into streams and rivers, protecting floodplain functions and reducing infrastructure and property damage.

Builds Resiliency to Drought

Fragile local water supplies are being stressed by decreased precipitation associated with climate change in some areas of the country. When a storm event does occur, rain falling on roofs, parking lots, streets, and other hard surfaces runs directly into city storm drains or water bodies. Communities are losing valuable water that could be used or stored for use when it is needed most. Prepare for drought by infiltrating water where it falls. Green infrastructure can help replenish groundwater reserves, relieving stress on local water supplies and reducing the need to import potable water.

Reduces the Urban Heat Island Effect

Urban heat islands occur when cities replace natural land cover with dense concentrations of pavement, buildings, and other surfaces that absorb and retain heat. This effect increases energy costs (e.g., for air conditioning), air pollution, and heat-related illness and mortality. Climate change will likely lead to more frequent, more severe, and longer heat waves during summer months. Extreme heat events often affect our most vulnerable populations first. Trees, green roofs, and vegetation can help reduce urban heat island effects by shading building surfaces, deflecting solar radiation, and releasing moisture into the atmosphere.

Lowers Building Energy Demands

Trees and vegetative cover can lower ambient air temperatures in urban areas through shading, windbreak, and evapotranspiration. The result is lower demand for the energy needed to provide air conditioning in summer months. Green roofs can greatly reduce the amount of energy needed to keep the temperature of a building comfortable year-round by insulating against extensive heat loss in the winter and heat absorption in the summer. A National Research Council of Canada study found that an extensive green roof reduced daily energy demand for air conditioning in the summer by over 75 percent.[1]

Improves Coastal Resiliency

Coastal areas are particularly vulnerable to the effects of climate change. Sea-level rise and heavy storms can cause erosion and flooding of sensitive coastal areas and destroy natural habitat. Climbing global temperatures will result in continued sea level rise, amplified storm surges, and more frequent and intense storms that will continue to erode the shoreline and damage property and infrastructure. Living shorelines can be created using plants, reefs, sand, and natural barriers to reduce erosion and flooding. Restoring affected wetlands can reduce wave heights and property damage.

Reduces Energy Needed to Manage Water

Communities and their residents use a lot of energy treating and moving drinking water and wastewater. They can significantly reduce municipal and domestic energy use with green infrastructure practices that will reduce rainwater flows into sewer systems, recharge aquifers, and conserve water. Cities, states, or regional entities should consider tying energy efficiency savings resulting from implementing these practices to reduced demand at power plants.

[1] Liu, K., and B. Baskaran. 2003. Thermal Performance of Green Roofs through Field Evaluation. In *Proceedings for the First North American Green Roof Infrastructure Conference*, Awards and Trade Show, Chicago, Illinois, May 29-30, 2003, pp. 1–10.

Using Green Infrastructure to Balance Water Supply, Flood Control, and Regulatory Requirements in Albuquerque, New Mexico

On August 11–12, 2015, the EPA Green Infrastructure Program and Urban Waters Partnership Program hosted a Green Infrastructure and Climate Change Resiliency Charrette. The goals of the charrette were to:

- Increase understanding of climate change effects in the Albuquerque region.
- Explore how green infrastructure can be used to help meet the region's stormwater permit requirements, address flooding, and make the community more resilient.
- Explain a screening technique for identifying potential green infrastructure sites that meet multiple community needs.
- Evaluate potential green infrastructure practices in four diverse districts of the city as examples of how green infrastructure could be used to meet multiple community needs.
- Discuss green infrastructure implementation issues as well as methods to build more green infrastructure in an arid community.

How is Albuquerque's climate predicted to change?

Weather has already become more extreme in Albuquerque. A number of recent climate studies for the region by EPA, the U.S. Geological Survey, U.S. Bureau of Reclamation, Mid-Region Council of Governments, local universities and others predict that by mid-century Albuquerque will experience:

- Continued flooding.
- Hotter temperatures.
- Longer and more severe droughts.
- Significant stream flow reductions.
- Reduced surface water allocation.

Many of these studies call for using green infrastructure to lessen the threats to water supplies, public health, property, and the environment, with the overall goal of making the City more resilient to climate change.

How can green infrastructure help?

Green infrastructure has been used in public and private development projects over the last ten years to meet multiple needs on the site, including:

- Meeting stormwater permit requirements for on-site detention and treatment.
- Supplying irrigation water.
- Reducing impacts of flooding and peak stormwater flow.
- Providing additional landscaping.
- Shading and cooling buildings, parking areas, and sidewalks.
- Increasing wildlife habitat.

Photo courtesy of Vic D'Amato, Tetra Tech
Albuquerque streetscape with street trees

Impacts of Climate Change in Albuquerque

Several agencies have studied how climate may change in the Albuquerque region over the next 30 to 40 years and beyond, and how these changes may impact the region's water resources. The charrette presented some of the major findings of these studies including:

- Snow water equivalent is projected to drop 42 percent in New Mexico and 13 percent in Colorado in the 2041–2070 period compared to the 1971–2000 period (Melillo et al. 2014).
- Regional annual average temperatures in New Mexico are projected to rise by up to 5.5 °F by the period 2041–2070 compared to the 1971–2000 period, with longer and hotter summer heat waves, decreased winter cold outbreaks, and slightly reduced winter and spring precipitation (Melillo et al. 2014).
- By mid-century, in Bernalillo County, average annual maximum and minimum temperatures are projected to increase by 7.2 °F and 6.2 °F, respectively, compared to the 1950–2005 baseline period (USGS 2014).
- No substantial change is predicted for mean annual precipitation in New Mexico, but due to the increases in heat, there will be large increases in evapotranspiration (USEPA 2013; Volpe National Transportation Systems Center 2015).
- Given climate change and urban development projections at mid-century, the Rio Grande at Albuquerque is projected to have a significant reduction in high and low flows; total volume; and nitrogen, phosphorus and sediment loading (USEPA 2013).
- Precipitation intensity and flooding risks are not projected to increase substantially (USEPA 2013; Southern Sandoval County Arroyo and Flood Control Authority 2015).
- Flows in the San Juan River, the region's surface water supply source, are projected to decrease by 25 percent by 2050–2099 compared to the baseline period 1950–1999 (Sandia National Lab and U.S. Bureau of Reclamation 2013).

Photo courtesy of Vic D'Amato, Tetra Tech
Large expanse of impervious surface in Albuquerque

Case Study: Albuquerque, New Mexico

Which green infrastructure practices are best for Albuquerque?

Presenters reviewed the current state of stormwater management and related regulations in Albuquerque and shared information on how to develop green infrastructure practices with climate change in mind. The most promising green infrastructure practices for addressing climate resiliency, flooding issues, and water rights constraints include:

- Bioretention areas/bioswales with internal water storage design features that hold water longer.
- Permeable pavement.
- Water harvesting devices such as rain barrels.
- Tree and vegetation plantings in barren areas of the city (drought tolerant plants/vegetation that will not require irrigation after the establishment period).
- Planter boxes (again, drought tolerant plants/vegetation that will not require irrigation after the establishment period).
- Other types of biological filtration systems that use plants and soils to remove pollutants.

Choosing the Best Project Sites

In addition to identifying best practices, the charrette also included the presentation of a screening process that may be used to identify good candidate sites for green infrastructure (see page 7). The process uses mapping and geographic information systems (GIS) to analyze sites and select areas best suited for green infrastructure implementation. It then sets priorities, using a prioritization matrix as a decision-making tool for the remaining parcels.

Four City districts were the focus of the charrette exercise. All have existing flooding issues, represent a wide range of land uses and socioeconomic status, and include various scales. The areas included:

South Broadway Area	100 acres urban mixed-use development
Glenrio	70 acres residential development
Mid-Valley	450 acres residential development
Ventana Dam	270 acres residential, 560 acres undeveloped

For each of these districts, EPA developed an aerial map showing the following:

- Parcels
- Buildings
- Roads
- Topography
- Hydrology
- Location of publicly owned parcels
- Storm drain network
- Existing stormwater control measures
- Existing flooding problems
- Soil infiltration categories

The group used a matrix to evaluate different green infrastructure options based on stormwater, climate resiliency, and community livability benefits.

Green Infrastructure Benefits by District

Benefit		South Broadway	Glenrio	Mid Valley	Ventana
Climate Resiliency/Stormwater	Reduces water treatment needs		✓	✓	✓
	Improves water quality	✓	✓	✓	✓
	Reduces gray infrastructure needs			✓	✓
	Reduces flooding	✓	✓	✓	✓
	Increases available water supply			✓	✓
	Increases groundwater recharge		✓	✓	✓
	Reduces energy use		✓		✓
	Improves air quality	✓	✓	✓	✓
	Reduces atmospheric CO_2	✓	✓	✓	✓
	Reduces urban heat island	✓	✓	✓	✓
Livability	Improves aesthetics	✓	✓	✓	✓
	Increases recreational opportunity	✓	✓	✓	✓
	Reduces noise pollution		✓		
	Improves community cohesion	✓	✓	✓	✓
	Urban agriculture		✓	✓	✓
Improves habitat		✓	✓	✓	✓
Offers public education opportunities		✓	✓	✓	✓

Findings and Next Steps

This case study presents the approach used and the key findings of the charrette, and includes examples of how green infrastructure can be used to meet multiple community needs in four diverse districts of the City. This approach could be used in other districts and other MS4 communities to identify best candidate sites for green infrastructure.

The charrette closed with a discussion of next steps. The group discussed the audience for the findings and recommendations of the charrette and divided the communication and outreach into three areas:

1. General education about the approach and findings of the charrette.
2. Financial/funding strategies.
3. Outreach specific to the four district areas.

Photo courtesy of Jason Wright, Tetra Tech
Bioretention in Albuquerque

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Case Study: Albuquerque, New Mexico

What are the benefits of a screening process for green infrastructure?

The first step in selecting the best potential candidate locations for implementing green infrastructure improvements and solutions is a site-selection and prioritization analysis. The analysis will begin by assessing landscape characteristics, jurisdictional attributes, water quality needs, and general site sustainability. The site screening and prioritization process systematically evaluates and prioritizes potential sites with GIS-based analyses using the best available landscape and water quality data and a reconnaissance-level aerial imagery survey.

The advantage of this prioritization process is the ability to select potential locations that are best suited for maximum cost-effectiveness, resulting in the greatest volume and pollutant load reductions per dollar. Because implementing green infrastructure concepts at any scale involves identifying and setting aside land for stormwater treatment, assessing opportunities on existing, publicly owned lands is especially important.

Green infrastructure practices often can be integrated into parks or playing fields without compromising function, so opportunities for incorporating practices in recreation areas and other public open spaces are typically prioritized and used as a first step in evaluating available sites.

Screening Process to Identify Candidate Sites for Green Infrastructure

A site selection process was used to identify, assess, and prioritize potential locations for green infrastructure practices in the City of Albuquerque. Below is an outline of a generalized screening approach that can be used by other communities to identify parcels potentially suitable for green infrastructure. The screening approach has two main steps:

1. A primary screening to eliminate unsuitable parcels based on physical and jurisdictional characteristics.
2. A site prioritization process to rank the suitability of the remaining parcels.

Primary Screening

The primary screening identifies parcels potentially suitable for green infrastructure practices based on two parameters:

- **Parcel zoning**: Parcels classified as single-family residential will not be considered in the assessment activities due to their small average size and the typically low cost/benefit ratio of implementing green infrastructure practices on single-family residential parcels. Research and experience nationally indicates that the runoff impacts of single-family parcels can be addressed more cost-effectively through outreach and education or incentives for practices such as rain barrels or downspout disconnection.

- **Slope**: Parcels with a slope greater than 10 percent will not be considered for green infrastructure practice opportunities. Slope can be determined on the basis of digital elevation model or other available topography data sets. In areas where the overall slope of the parcel is in question, slope will be verified through review of aerial imagery and field reconnaissance. Parcels where the slope exceeds 10 percent will be eliminated from consideration.

The results of the primary screening will provide a base list of parcels potentially suitable for green infrastructure practices.

Screening Process to Identify Candidate Sites for Green Infrastructure.

Site Prioritization

A GIS analysis performed on the parcels remaining identified the potential sites for LID improvements and ranked their potential suitability based on the characteristics listed below. Potential sites can be prioritized using a scoring methodology developed and refined on the basis of local preferences and priorities.

- **Public ownership**: Land costs generally are minimized by using existing public lands; therefore, a higher priority will be placed on publicly owned parcels.
- **Infiltration capacity**: The mapped hydrologic soils groups are used as an initial estimate for the infiltration rate and storage capacity of the soils. Sites where mapped hydrologic soil groups have infiltration rates suitable for infiltration BMPs receive higher priority for further investigation.
- **Contaminated sites**: Areas near contaminated sites receive lower priority due to the potential for increased costs and complications during implementation.
- **Environmentally sensitive areas**: Areas where runoff can be treated prior to draining directly to surface waters will be given a higher priority.
- **Total impervious area**: Parcels representing a larger total impervious area typically generate more runoff and greater pollutant loads and will be given a higher priority. Impervious area will be estimated using aerial imagery in areas where impervious data are not available.
- **Percent impervious**: Parcels with a higher percentage of impervious area relative to the size of the parcel also typically produce more runoff and are targeted based on the greater potential to achieve volume reduction and water quality improvements.
- **Space requirements**: To determine if sufficient space is available to implement an appropriately sized BMP, the potentially available space on a parcel will be evaluated based on the size of the parcel and the amount of existing impervious area.
- **Proximity to existing green infrastructure improvements**: To distribute treatment opportunities effectively throughout the watershed, areas in close proximity to existing or planned future green infrastructure projects are given a lower priority.
- **Proximity to parks and schools**: Areas closest to parks and schools are given a higher priority, in part to provide a greater opportunity for public outreach and education.
- **Proximity to the storm drainage network**: Areas in close proximity to the storm drain network are given a higher priority. Green infrastructure practices located on poor-draining soils require underdrain systems that tap into existing infrastructure; siting these in proximity to the storm drain network minimizes costs in these cases.
- **Parkway width**: Typically, the largest areas owned or controlled by municipalities are in the transportation corridor, making green streets, or implementation of green infrastructure practices within the right-of-way, a cost effective strategy for pollutant reduction. Areas with the most available space within the right-of-way will be given priority.
- **Multi-benefit use**: Implementation of green infrastructure concepts can achieve multiple purposes. For instance, some stormwater practices, such as grassed swales, constructed stormwater wetlands, or turfed bioretention areas, can serve a dual purpose of stormwater management and community park space. Sites that offer multi-benefit opportunities will receive higher priority in the ranking.

Green Infrastructure and Climate Resiliency in Grand Rapids, Michigan

How is Grand Rapids' climate predicted to change?

In 2013, Grand Rapids experienced a significant flooding event, which highlighted the vulnerability of the city to heavy precipitation events.

Climate change is expected to exacerbate current vulnerability, as climate models predict the following:

- Air temperature will rise.
- Average precipitation could increase.
- Extreme flood events will increase.

How can green infrastructure help?

Green infrastructure practices can be integral to climate resiliency, including the following:

- Storing rainwater for groundwater reserves.
- Harvesting rainwater onsite for irrigation or other uses.
- Using engineered green practices, such as implementing bioretention areas, to reduce localized flooding and water quality impacts.
- Using trees and living roofs to lower building energy use and reduce the urban heat island effect.

On October 6, 2015, the EPA Green Infrastructure Program and Urban Waters Partnership Program hosted a Green Infrastructure and Climate Change Resiliency Charrette in Grand Rapids, Michigan. The one-day charrette focused on exploring how green infrastructure can be better supported by new and existing requirements, and what additional actions could be beneficial. The key outcomes of the charrette were as follows:

- Identifying current resiliency concerns and green infrastructure opportunities for the City of Grand Rapids.
- Developing local case studies.
- Highlighting focus areas and discussion of potential actions.

Grand Rapids has taken a series of steps to be a national leader in resiliency efforts. The city has developed a series of community plans and actions that support resiliency efforts including:

- Grand Rapids Master Plan (City of Grand Rapids 2002).
- Green Grand Rapids (City of Grand Rapids 2012).
- Grand Rapids Climate Resiliency Report (WMEAC 2013).
- Grand Rapids Forward—Downtown and River Action Plan (City of Grand Rapids 2015a).
- Sustainability Plan (City of Grand Rapids 2015b).

Photography courtesy of Gail Gunst Heffner, Calvin College

Flooding of the Grand River in Downtown Grand Rapids, April 2013.

Impacts of Climate Change in Grand Rapids

Observed increases in total precipitation, as well as more frequent and intense storms are already impacting the Grand Rapids area. In 2013, Grand Rapids experienced a significant flood event: the Grand River was sending 37,000 cubic feet of water per second through downtown. Heavy precipitation resulted in a dramatic rise in water levels in the Grand River—almost three feet above flood stage—and caused flooding in the Grand Rapids Metropolitan area (Bunte 2014; Tunison 2013). This flood highlighted the vulnerability of the city to heavy precipitation events.

Climate change is expected to exacerbate current vulnerability, as climate models predict that air temperature will rise, average precipitation could increase, and extreme flood events will increase.

- The strongest storms have become more intense and more frequent. The amount of precipitation falling in the heaviest 1 percent of precipitation events increased by 37 percent in the Midwest and by 71 percent in the Northeast from 1958 to 2012 (GLISA undated).
- EPA's Climate Resilience Evaluation and Awareness Tool (CREAT) shows that more rain is projected for the winter and spring, and less for the summer for Grand Rapids (USEPA 2015).
- EPA's CREAT predicts the amount of rain during a 24-hour event for all return intervals is expected to increase; which means that rain events are going to become more severe in the future.
- The consensus across climate models is that average air temperature will increase over the next century. By 2084, average annual temperature is expected to have increased by about 2.9–8.0 degrees Fahrenheit (World Bank Climate Change Knowledge Portal 2015).

Photography courtesy of Gail Gunst Heffner, Calvin College

Flooding of the Grand River in in Downtown Grand Rapids, April 2013.

Case Study: Grand Rapids, Michigan

What are the issues facing the city as it addresses climate change?

Several local issues that would drive city actions were identified by representatives:

- Decreasing available amount of vacant land, reducing the potential to influence new development.
- Shrinking city resources.
- Emerald Ash Borer has affected the tree population.
- Stormwater management issues, including aging and under-performing infrastructure.
- Underutilization of Grand River, which could better enhance economic development and provide more ecosystem services.

There are several positive actions that the City can draw upon:

- Citizen awareness of tree canopy benefits.
- Requests for bike lanes.
- Local food interest.
- New economic development strategy.

Local Success Stories

The city has experienced recent success in implementing green infrastructure. These actions provide examples that can be replicated and used to educate stakeholders on green infrastructure benefits. Six case studies were identified as having lessons to draw on for future efforts:

- **Joe Taylor Park—**Joe Taylor Park was identified as an area in need of change by neighborhood residents. The city worked with local stakeholders to design, fund, and implement a stormwater retention project.
- **Grand River Restoration Project—**The Grand River restoration project seeks to provide cleaner water and increased ecological health, including more habitat for fish. The city has conducted an economic study and is working with stakeholders to achieve necessary funding needed to implement the project.
- **Mary Waters Park—**Mary Waters Park was identified as an area that could serve as a detention basin. The park is 80 acres and the goal is to detain the first 1 inch of runoff. Storage was developed for 720,000 gallons, with 11 million gallons infiltrated annually.
- **Tremont Avenue—**Grand Rapids planted a rain garden in an area prone to recurrent flooding. The city obtained a FEMA grant to purchase the homes from willing home-owners who petitioned the city to participate in the program. The city designed a 4,000 square foot rain garden with 15 plant varieties. The rain garden was planted by city staff members and volunteers.
- **Plainfield Bioretention Islands**—Using an MDOT enhancement grant, bioretention islands were designed as water quality islands for Plainfield Avenue Area businesses. Neighbors were engaged and contributed to the effort, while students conducted measurements on rainfall. This example highlights the importance of stakeholder engagement to implementation of a successful pilot.

Photography courtesy of Dan Christian, Tetra Tech

Porous concrete parking lot and bioretention at Joe Taylor Park in Grand Rapids.

Areas of Focus

Stormwater Design Standards

The City of Grand Rapids recently completed a study to understand how to better design for future precipitation events (Tetra Tech 2015). Hydrologic events are summarized through Intensity-Duration-Frequency curves, which are used to develop design standards. The study found that there is a high probability of increased risk for the city due to more intense storms and greater design volumes under future climate projections. Green infrastructure was identified as an adaptation strategy that can be used to meet projected climate change impacts.

Focus on Trees

The City of Grand Rapids has developed aggressive tree canopy goals. Participants agreed that focusing on trees would provide significant benefits for the city: reducing stormwater runoff, atmospheric CO_2, energy use, and urban heat islands; increasing groundwater recharge; and improving air quality, habitat, and community livability.

Stakeholder Engagement

Participants agreed that there are several examples in Grand Rapids that successfully show the efficacy and multiple benefits of green infrastructure. Stakeholder awareness and engagement are critical to implement and scale up green infrastructure.

Lessons Learned

Several lessons learned emerged from these and other regional efforts:

1. Stakeholder engagement and awareness are essential.
2. Networks across city departments are critical to foster planning.
3. Creativity and flexibility are important when addressing complexity.

Photography courtesy of Dan Christian, Tetra Tech

A green roof over an exhibit at the John Ball Zoo in Grand Rapids.

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Using Green Instructure along Transportation Corridors for Climate Resiliency in Los Angeles, California

How is climate change impacting Los Angeles?

The City has developed a drinking water infrastructure system that relies largely on purchased water; the City imports an average of 385,500 acre-feet of water from Northern California and the Colorado River annually (City of Los Angeles 2015). However, this system is not sustainable due to the persistent drought that has been impacting California for the last four years and climate change impacts on the Sierra snowpack. As part of the Mayor's *Sustainable City pLAn* (City of Los Angeles 2015), the City set the following three goals:

1. Reduce imported water by 50 percent by 2025.
2. Increase the percentage of water sourced locally by 50 percent by 2035 (currently the City only gets 19.6 percent of its water from local sources).
3. Reduce overall water consumption by 20 percent by 2017.

How can green infrastructure help?

The City has been exploring opportunities to use green infrastructure practices in transportation corridors to capture, treat, and store stormwater for a variety of uses and to infiltrate runoff into the aquifers for eventual use as drinking water. It will also serve to enhance recreation and create more livable spaces.

The natural services of Los Angeles River tributaries have largely been replaced by streets, curbs, and gutters, which do not allow for treatment of the stormwater runoff prior to discharge to surfaces waters. These hard surfaces prevent infiltration of storm flows that recharge the aquifers below the City. As a result, the receiving waters within the City suffer from pollution impacts, and the City's reliance on imported water to meet the population's demand is a growing concern for local policymakers.

To begin to address these concerns and move toward a more sustainable transportation and drainage network in Los Angeles, EPA's Green Infrastructure and Urban Waters Partnership Programs hosted a Green Infrastructure and Climate Change Resiliency Charrette in Los Angeles on September 24, 2015. The goal of the charrette was to identify the needs of groups of people who use or manage transportation corridors and stormwater infrastructure and reconcile those needs with ways to improve the City's climate resiliency.

The charrette built upon the principles of the One Water Los Angeles 2040 Plan and work that the City has completed to develop watershed-wide, connective stormwater greenways that restore tributary functions that balance water supply and flood control. The Greenways to Rivers Arterial Stormwater System (GRASS) tool identifies a methodology and opportunities for prioritizing multi-use transportation corridors within Los Angeles' existing regional arterial streets, and concrete tributary channels for the design of multi-benefit stormwater storage and use projects.

Concrete-lined sections of the Los Angeles River show how urbanization affects hydrology and water quality.

Resiliency Themes

To focus the charrette discussions, local expert guides explained to the charrette participants the resiliency issues challenging residents in three project areas in the city:

- **Provide relief from the urban heat island.** Vermont Avenue in South Los Angeles forms the spine of the City – providing a connective thoroughfare between Downtown and communities from the most economically and environmentally challenged areas of Los Angeles, through many other City jurisdictions, on to the Port of Los Angeles and Los Angeles Harbor. Many of the early 20th century homes along the corridor lack air conditioning, and residents depend on public transit. The corridor offers very few shade structures and street trees to protect residents as they walk to bus stops and cooling centers in extreme heat. Increased energy consumption to cope with urban heat islands also contributes to hazardous air quality conditions.
- **Restore connections to a revitalized river.** South Mission Road, a major arterial running parallel to the Los Angeles River, provides access to industrial areas along the river. South Mission Road is traversed repeatedly by railroad spurs and major utilities, including a large storm drain and two major sanitary sewer interceptors. This corridor showcases the challenges faced by planners wanting to implement green infrastructure in a highly constrained right-of-way. It also serves as a case study for using green infrastructure as a tool to restore the balance of water to the riverbed from the Mission Street terrace and Hollenbeck Park uplands. Redesign of the Mission Road cross-section also offers the potential to improve residents' access to the River by providing safe walking/biking routes.
- **Prepare for drought.** Eastern San Fernando Basin and Sylmar Basin aquifers were targeted for groundwater recharge and projects that augment local water supply and provide resilience to increasingly frequent droughts.

Photo courtesy of Los Angeles Bureau of Sanitation

This section of Vermont Avenue illustrates the lack of trees found along most of the thoroughfare.

Collaborative Problem-Solving

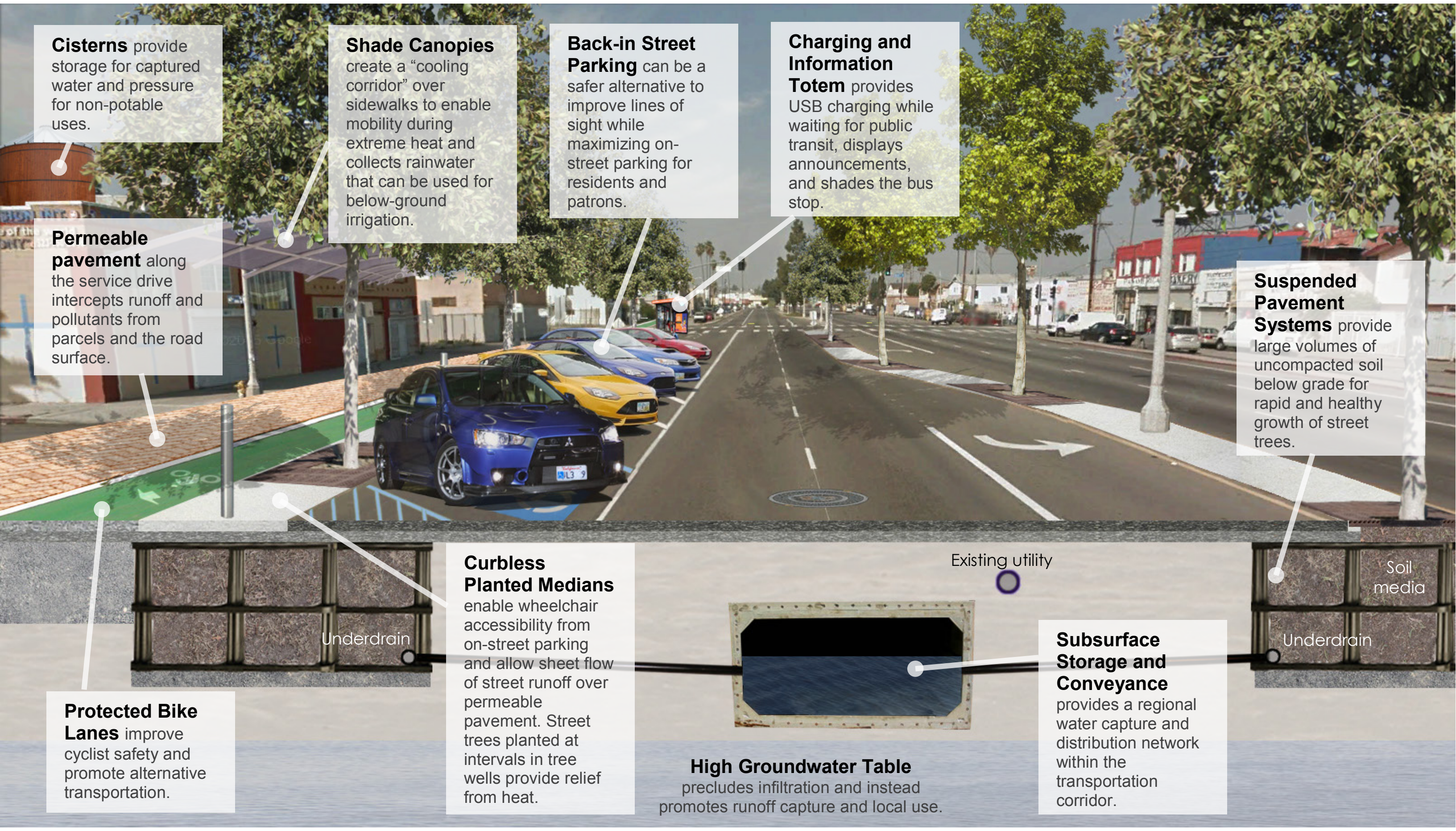
Participants formed small groups to review the challenges associated with the three resiliency themes described above. They were asked to identify and design workable green infrastructure features at the case study locations to achieve the desired goals, including the steps necessary to implement projects.

Brainstorming for Heat Island Relief along the Vermont Avenue Corridor

The group proposed creating a cooling corridor connecting the downtown area and Valley to the Los Angeles Harbor along Vermont Avenue. A suitable corridor cross-section would accommodate pedestrian traffic in heat wave emergencies. The corridor would also integrate sustainable irrigation supply standards while restoring ecosystem services and reducing pollutants in runoff.

As with all greenway network corridors, this major connector could potentially incorporate water storage silos for certain side streets. The corridor is designed to collect captured and stored water from nearby sites (including existing storm drains and contributing projects on side-streets, rooftops, graywater systems, and HVAC). Runoff sources such as air conditioning condensate could safely flow via sub-surface irrigation chambers to plant root zones for filtration and uptake.

Water quality would be enhanced via biofiltration practices that incorporate storage cells, engineered soil media, and suspended pavements; the practices would optimize the soil volumes needed for healthy street tree canopy coverage. Filtered stormwater would contribute to the subsurface storage in chambers, where it could then be recirculated back to the green infrastructure through a subsurface irrigation system.



Rendering of green infrastructure features that create a multi-benefit cooling corridor along Vermont Avenue.

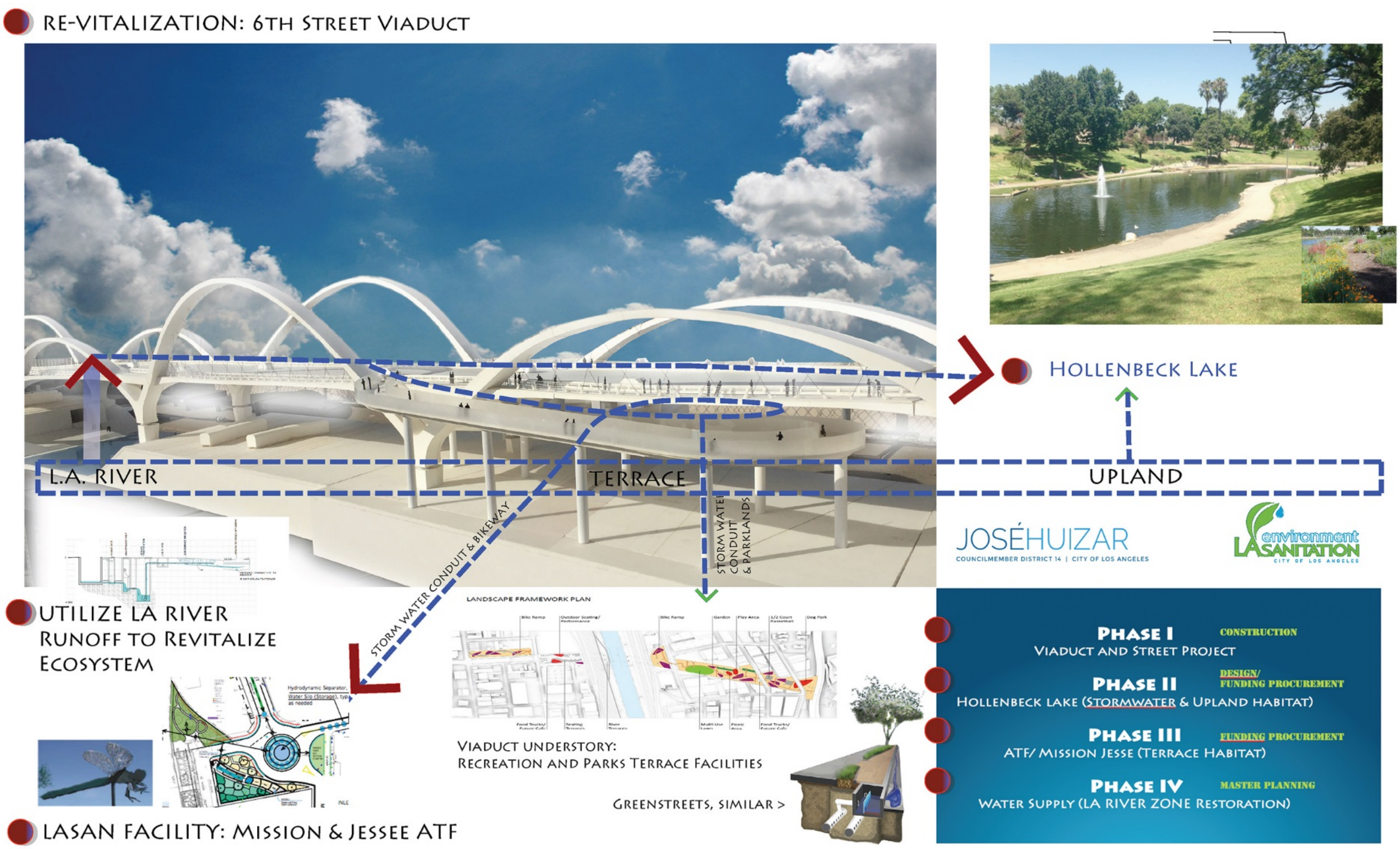
Brainstorming for Urban Connectivity and Revitalization along the South Mission Road Corridor

The South Mission Road region is characterized by multiple challenges associated with inner-city retrofit planning. It is a major arterial running parallel to the Los Angeles River and presents opportunities for using green infrastructure as a tool to implement the City and County's river revitalization goals outlined in the Los Angeles River Revitalization Master Plan.

The group was intent on not only incorporating green infrastructure into the project area, but also providing disadvantaged communities with access to the Los Angeles River. The group proposed two green streets in the area to connect surrounding communities to the Los Angeles River:

- The first, along South Mission Road, incorporated bike lanes to allow north-south bike commuting in addition to vehicular traffic.
- The second, along 6th Street, would allow residents to drive, bike, and walk safely from the residential area through the industrial area to the parks proposed for the 6th Street Viaduct project.

The group also envisioned a paseo from Hollenbeck Lake down the existing Willow Street to allow for walking and as a transport corridor for water between the lake and the planned parks and green streets. Finally, they proposed Hollenbeck Lake as a potential gravity-fed source of irrigation water for the terrace and upland tiers of green infrastructure projects proposed at Hollenbeck Park.



Rendering of green infrastructure and transportation features that revitalize the ecosystem and connect residents to the Los Angeles River.

Case Study: Los Angeles, California

Brainstorming for Drought Preparation along the Pacioma Wash/Roscoe Boulevard Corridor

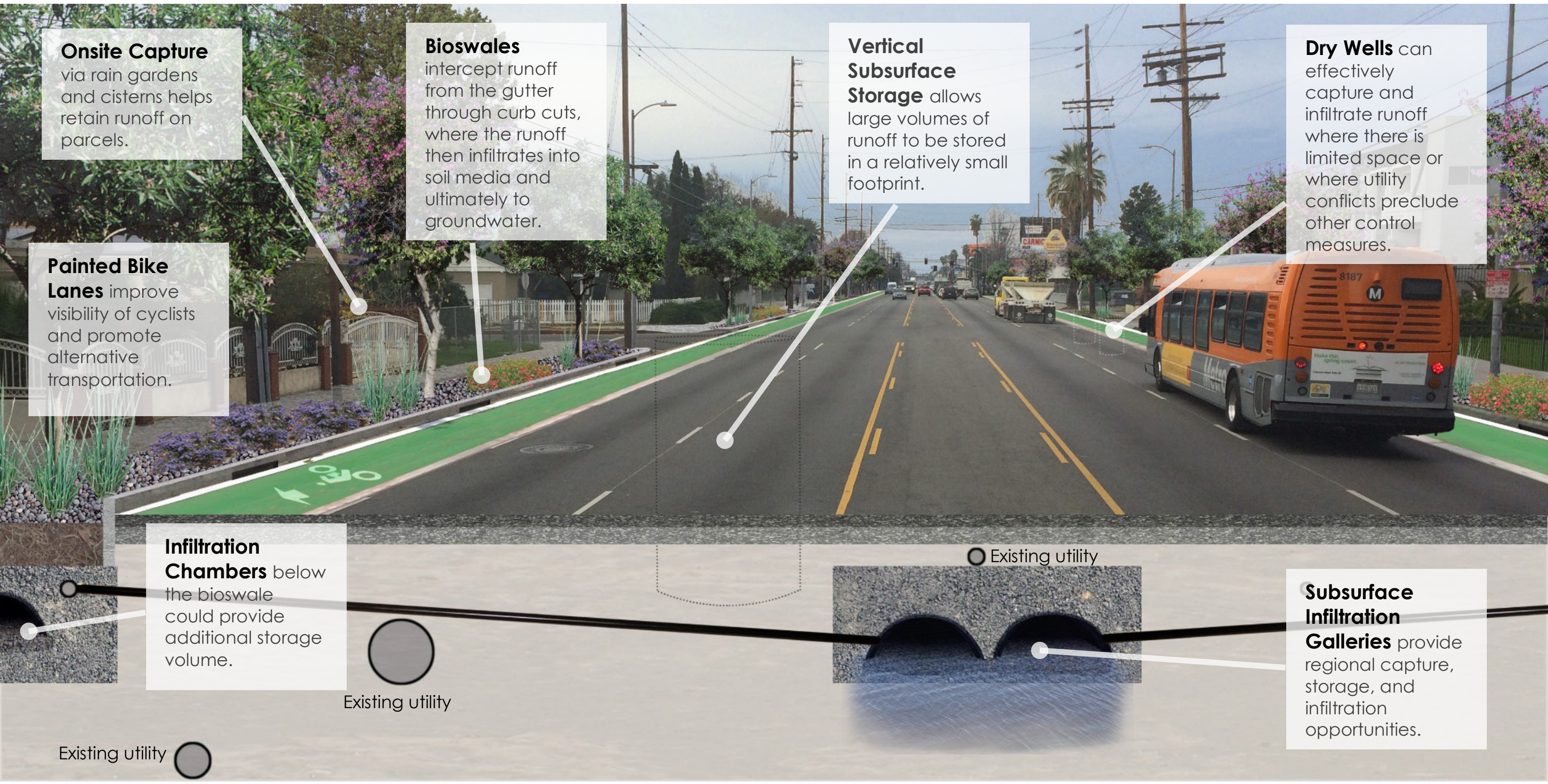
At the time of this charrette, California had experienced historic exceptional drought conditions across much of the state. Despite declaring a state of emergency in January 2014 and establishing the first statewide mandatory water restrictions in March 2015, data indicated a persistent deficit in local water supplies. The Mayor of Los Angeles set a goal to supply 50 percent of the City's water demand from local sources by 2024. The areas overlying the eastern San Fernando Basin and Sylmar Basin aquifers were targeted for groundwater recharge and projects that augment local water supply and provide resilience to increasingly frequent droughts.

The group focused on the neighborhood around the Pacoima Wash and Roscoe Boulevard to integrate the following green infrastructure approaches that would provide multiple benefits in addition to stormwater management:

- Bioretention areas in the form of parkway swales, infiltration galleries, and dry wells could later be incorporated along Roscoe Boulevard along with permeable bike lanes to reduce polluted stormwater runoff.
- Adding tree canopy in the parkway swales would provide shade for the area, reducing the heat island effect, improving air quality, and absorbing greenhouse gases.
- Bike lanes would provide a cooler and safer route for bicyclists.

The group also developed concepts for the surrounding neighborhood area:

- Stormwater storage would be integrated as widely as feasible into public areas based on landscape water demands and the volume of supply resources available.
- Stormwater from paved areas, such as parking lots, would undergo pretreatment prior to entering infiltration galleries constructed under public rights-of-way.
- Open spaces would be used more efficiently by planting taller trees with large canopies to intercept rainfall, absorb runoff, and provide shade to reduce the heat island effect.



Rendering of green infrastructure and transit streetscape improvements that would facilitate water capture.

A concept was also proposed to divert flows from the Pacoima Wash into public parcels in the area (e.g., open spaces at public schools) along the GRASS corridors so that other projects—and ultimately the aquifer—might benefit from this water resource that would otherwise be conveyed to the ocean via the concrete channel. Diverted water could be infiltrated subsurface or treated to surface irrigation standards. Ultimately, all of these projects are intended to be *off-line* and would add to the capacity of the stormwater system and controlling flooding in the original system. Thus, the proposal would provide flood mitigation, storage volume, and pollutant capture while providing a potential source for irrigation of the proposed green space.

Taken together all of these strategies support the goals of the Mayor's *Great Streets Initiative* and *Sustainable City pLAn* for local water supply as well as provide flood mitigation, storage volume, pollutant capture, and a potential source for irrigation of the proposed green space.

Big Picture and Next Steps

During the last phase of the charrette, the group synthesized lessons learned into big picture concepts and outlined a list of next steps. The following are the key needs and solutions expressed by participants:

- Ensure that stakeholders are engaged early and often during project planning, design, and implementation.
- Institutionalize green infrastructure practices in local design standards and planning processes to reduce inadequate designs and long approval times, and to increase the universe of local designers able and willing to "put their stamp" on green infrastructure projects.
- Expand the current funding partners and benefactors to include (for example) insurers, healthcare systems, private developers, and financial institutions.
- Ensure that projects incorporate multiple, community-driven benefits to expand possible funding opportunities.
- Incorporate green infrastructure into existing capital projects to meet the project permit requirements and agency/stakeholder goals.
- Conduct data-driven, high-resolution planning, and incorporate quantifiable performance metrics early in the planning phase to evaluate effectiveness and alter designs as needed.
- Humanize the metrics to incorporate goals meaningful to the community.
- Plan for adequate operation and maintenance, as well as advocate for sustainable funding resources during the design phase of projects (i.e., staff, funding).
- Maintain the energy and enthusiasm exhibited at the charrette through continued communication, collegiality, and collaboration among participants (e.g., social media) and perhaps additional charrettes that move forward with the designs generated at this charrette.
- Propose that the next phases of the effort look at the opportunities at the watershed scale (using the GRASS tool) that may have been identified at project planning level during the charrette.

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Using Resiliency and Energy to Implement Sustainable Solutions in New Orleans, Louisiana

How is climate change impacting New Orleans?

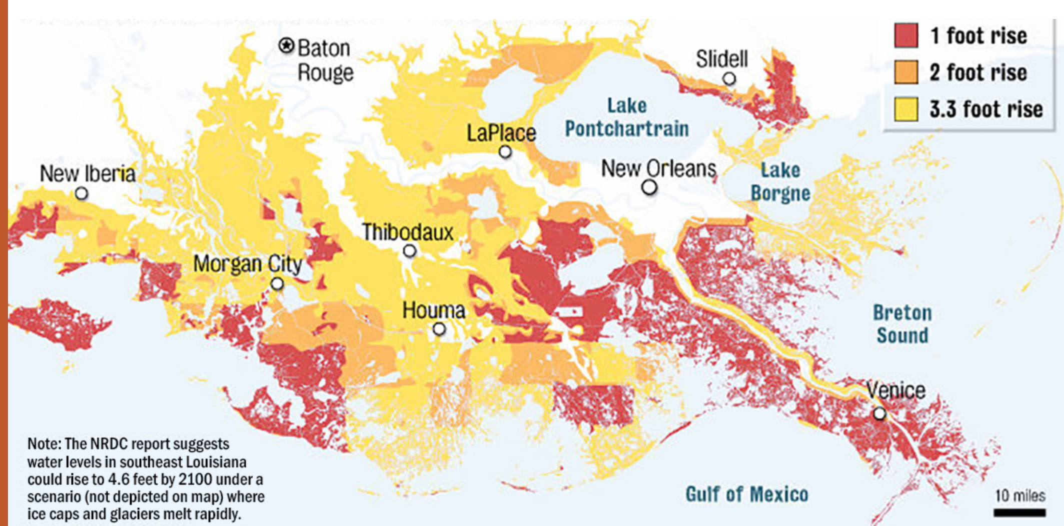
New Orleans is particularly susceptible to climate change impacts, such as sea level rise, storm surge, extreme heat, and intense precipitation. These impacts will exacerbate existing stressors, such as land subsidence and wetland loss. Climate change impacts are projected to increase in the future. Developing an understanding of climate variability and change are important to begin to plan for, and adapt to, future impacts.

Sea level rise could be particularly problematic. Louisiana has lost approximately 2,000 square miles of its coastal landscape to open water in the last 80 years (Marshall 2014). A recent study found that the rate of land subsidence in the New Orleans metro region averages 5 mm/yr, which predicts a net 1-meter decline in elevation during the next 100 years relative to present sea level (Burkett et al. 2003). The Intergovernmental Panel on Climate Change (Church et al. 2013) projects a two- to four-fold acceleration of sea-level rise over the next 100 years.

The map at right shows areas of Louisiana at risk under different sea level rise scenarios.

In August 2015, EPA's Green Infrastructure Program and Urban Waters Partnership Program hosted a Green Infrastructure and Climate Change Resiliency Charrette in New Orleans. The planning session was conducted in the pilot project area of the Lower Ninth Ward, which was one of the neighborhoods most heavily devastated by Hurricane Katrina in 2005. The session provided stakeholders with a forum to consider opportunities provided by green infrastructure on public properties, how those opportunities could be applied in their neighborhood to support resiliency goals, and how those practices could be scaled across the city. The planning session was designed to work with city stakeholders and technical advisors to achieve the following specific goals:

- Explore potential enhancements for selected properties, such as public parks and playgrounds, to engage citizenry in community resiliency.
- Demonstrate how green infrastructure practices can support urban resiliency by reducing water pollution, flood volume, energy use, greenhouse gas emissions, and urban heat island impacts.
- Support city resiliency goals and community-driven initiatives, and develop a strategy for incorporating green infrastructure specifically on:
    - Park and recreational lands.
    - Schools and other institutional sites.
    - Public right-of-way corridors.
    - City-owned vacant lots.



Source: Carbonell and Meffert 2009

Predicted Louisiana deltaic coastline comparing current extent of coast with 1 to 3.3 feet

Resiliency Goals

The group discussion identified resiliency goals green infrastructure could support:

- **Shift residents' paradigm so water is viewed as an asset, as opposed to a threat.** Although the city of New Orleans is surrounded by water, it has been constructed to close itself off from water because of flood threats. The land is rich in nutrients because of the water that flowed on top of it and underneath it. City residents should consider water as an asset, and city leaders should re-vision the city accordingly.
- **Realize the opportunity to link to new requirements and planning efforts.** A new master planning process began in 2016. This, in addition to new stormwater requirements, presents an opportunity to implement green infrastructure on a larger scale.
- **Help to focus on developing closed systems as opposed to open systems.** The city is familiar with thinking of closed and open systems as they relate to recycling versus trash. The potential exists for the City to look at water in the same way. How can water be reused closer to the source of capture while creating benefits that serve multiple purposes?
- **Use green infrastructure to enhance educational opportunities.** Embarking on a pilot project that focuses on schools can enable numerous educational opportunities. It is important that the next generation understands the concepts and practices that the City is working to implement. How to live with water will continue to increase in importance and prominence in New Orleans. An opportunity exists to address it within the context of education. It's not just a green infrastructure campaign—it is part of a larger paradigm shift.

How will the city use green infrastructure to find solutions?

There have been several planning efforts by Louisiana and New Orleans following Hurricane Katrina. *Resilient New Orleans* was released by the Mayor of New Orleans in August 2015 as "a concrete, strategic roadmap for the city of New Orleans to build urban resilience" and describes a vision of the city as a dynamic urban environment that is more closely aligned with the natural environment.

The *Greater New Orleans Urban Water Plan* (2013) was funded by Louisiana's Office of Community Development—Disaster Recovery Unit to develop a comprehensive, integrated, and sustainable water management strategy for the east banks of Orleans and Jefferson Parishes and for St. Bernard Parish.

Current conditions at the Lawless High School cluster site.

Case Study: New Orleans, Louisiana

Existing features of the Lawless High School site.

Small Groups' Conceptual Designs

Participants were asked to explore community resiliency goals that could be applicable to one of four project areas. The city developed a *Cluster Concept* and identified a school, park, vacant lots, and public rights-of-way in the Lower 9th Ward as the pilot area with greatest opportunity for impact. Participants were asked to evaluate which green infrastructure practices would best meet these goals at the cluster site (existing conditions at the site are shown on page 20 and at right). They were required to consider a hypothetical project *budget* and prioritize the practices that they would *buy*. All four of the small groups focused on the Lawless High School site. Several community resiliency goals were identified for the site, including:

- Reduce stormwater runoff and pollution.
- Integrate educational opportunities for students and community.
- Mitigate urban heat island effects.
- Maximize quality of life benefits for community.
- Maximize recreational opportunities.

Each group had a total budget for the Lawless High School site. Below is a summary of how each group chose to spend their budget. A green infrastructure concept design that applies the groups' input to the Lawless High School site is shown on page 22.

Green Infrastructure Practices Selected by Groups for Lawless High School

Green Infrastructure Practices	Group Budget			
	1	2	3	4
Wetlands	15%		8%	9%
Green roofs			75%	
Dry detention				6%
Cisterns	6%	6%	6%	9%
Rain gardens/swales		29%		30%
Bioswales	59%			
Permeable pavement		53%		25%
Impervious disconnection	3%	3%		
Tree planting	6%	6%	3%	6%
Native landscaping		3%	8%	
Soil reconditioning	11%			6%
Greenway corridors				9%

Note: bioretention and green street corridors were not chosen by any of the groups.

Groups working on green infrastructure practice selection.

Conclusions and Next Steps

The analysis conducted for this project found that green infrastructure practices integrate into public-land clusters to directly serve the social and quality-of-life needs of communities. A combination of both structural and non-structural green infrastructure practices can considerably improve flooding and water quality issues in New Orleans. The non-structural strategies, in particular, showed a considerable volume reduction relative to the structural practices and warrant further evaluation as part of the city's open space and land use planning. Hydrologic impacts were calculated for the Lower 9th Ward pilot area and scaled to the other cluster sites within the city. Although these calculations indicate significant volume control and flood mitigation potential, several next steps are necessary to better quantify the relative impact to each of the city's subbasin infrastructure:

- Extrapolate cluster site volume reduction estimates to other publicly owned parcels beyond the pilot project.
- Use modeling to quantify specific flood reduction impacts at priority drainage network locations.
- Use optimization-based modeling tools (e.g., EPA's SUSTAIN) to prioritize site locations and determine the most cost-effective green infrastructure practice volume capture targets.
- Consider additional cost-benefit analyses that quantify and value the additional social, economic and environmental benefits (including important ecosystem services to the city) provided by green infrastructure practices selected during the pilot project. Many quality of life benefits in particular (including community cohesion, public education, and recreation opportunities) were identified by participants in the Lower 9th Ward planning session.

Green infrastructure concept design for the Lawless High School site

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Conclusions

In all cases, the Green Infrastructure and Climate Change Resiliency Charrettes brought together a diverse set of stakeholders to brainstorm the best ways to integrate green infrastructure concepts into long-term planning. Common goals were to combat the effects of climate change, improve community livability, and protect water resources. The resiliency challenges and green infrastructure opportunities differed in each of the four cities, and each community arrived at a different set of next steps and guiding principles for moving forward:

- **Albuquerque, NM** – Apply the green infrastructure opportunities screening process to identify potential flood control and permit compliance projects, and educate stakeholders about the general approach, funding, and district-specific recommendations.
- **Grand Rapids, MI** – Use trees to meet multiple stormwater, climate change, and livability goals. Consider climate impacts when selecting green infrastructure design standards. Engage stakeholders by highlighting successful, local green infrastructure projects.
- **Los Angeles, CA** – Engage stakeholders early, attract novel funding partners by emphasizing multiple benefits, institutionalize green infrastructure in design standards and capital projects, establish quantifiable performance metrics, and plan for long-term maintenance.
- **New Orleans, LA** – Extrapolate pilot project benefits to other publicly owned parcels. Use models to estimate flood reduction benefits and prioritize site locations. Quantify additional social, economic, and environmental benefits of green infrastructure.

Other communities that want to examine how green infrastructure can benefit community resiliency can start by evaluating climate change projections for their region and determining the resiliency challenges they will face. The next step is to bring together a diverse mix of stakeholders: community leaders, climate change scientists, urban planners, engineers, environmental advocacy groups, and others. The stakeholders' goals are to define important outcomes, identify local constraints, prioritize next steps, and assign responsibilities. The charrettes process is a useful tool to foster this type of communication and to begin to develop an action plan, because strategies for adapting to climate change and improving resiliency need to be tailored to local conditions and preferences.

Charrette participants tour green infrastructure features of the Rapid Operations Center in Grand Rapids, Michigan.

Acknowledgments

The following are key organizers and participants in the Green Infrastructure and Climate Change Resiliency Charrettes:

Albuquerque Charrette

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Jerry Lovato, AMAFCA
Bruce Thomson, University of New Mexico
Jason Wright, Tetra Tech
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