



Natural and Nature-Based Solutions Job Aid for Stormwater Management in Puerto Rico

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FEMA

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Collaborators: The Nature Conservancy, Protectores de Cuencas, Inc.

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1. Introduction and Background

This Job Aid is designed to equip FEMA personnel and stakeholders with the necessary knowledge and field-oriented, practical advice for effective stormwater management works in Puerto Rico through the application of Natural and Nature-Based Solutions (NNBS). This involves capturing and storing rainwater and/or promoting the infiltration of runoff, not only to reduce flood levels, but also to support stream base flows and groundwater levels, consistent with FEMA's strategic objectives for enhancing climate resilience.

Given the compounding effects that the development of impervious surfaces has caused on floodwater levels and freshwater resources in Puerto Rico, the urgency for sustainable and resilient runoff management practices is evident. Increasing water resource-related challenges associated with climate change makes this aim more necessary than ever.

1.1. Objectives of This Job Aid

- To increase understanding and awareness of NNBS and their role in stormwater management.
- To provide technical guidance on the implementation of bioretention, permeable pavement, and rainwater harvesting systems.
- To illustrate the benefits and effectiveness of NNBS in urban environments for a variety of infrastructure types.
- To facilitate informed decision-making in selecting and applying NNBS in various urban contexts, with the primary overarching goal of flood reduction, and ancillary benefits in support of maintaining stream base flows and improving groundwater recharge

1.2. Background on Stormwater Management in Puerto Rico

Puerto Rico's stormwater runoff is conditioned by the island's climate, topography, and land cover. Annual rainfall varies from less than 1,000 millimeters (mm) to over 4,000 mm (40 to 157 inches).[1] Its largely mountainous watersheds are characterized by relatively steep slopes. Stream valleys are usually well-incised and narrow, and major storms tend to be intense but brief; hence, flooding is rapid with peak discharges several orders of magnitude above base discharge.

All of Puerto Rico's watersheds have experienced significant alterations due to historical land use changes and deforestation, which were initially driven by timber harvesting, agriculture, and cattle ranching. Once intensive industrial agricultural practices subsided after the 1950s—mostly associated with sugar cane plantations—many areas reverted to forest cover, but others were further modified for urban development. Many hills have been flattened, floodplains filled, and later paved to make way for the construction of streets, highways, parking lots, and other residential, commercial, and industrial development. More than 11% of the island is composed of developed

[1] US Department of Commerce, NOAA. (2024). "PR and USVI Normals." National Weather Service. NOAA's National Weather Service. https://www.weather.gov/sju/climo_pr_usvi_normals.

surfaces, reaching up to 40% in regions such as the San Juan Metropolitan Area.[2] These changes have significantly modified stormwater drainage patterns and downstream floodwater levels.

Paved surfaces severely limit the infiltration of rainwater. This not only increases the volume of runoff that moves initially as sheet flow over land, but also its velocity. Storm drains can easily become overwhelmed by the resulting augmented flows. In addition, stormwater flowing over paved surfaces reaches streams and rivers much faster, overwhelming the capacity of these water bodies to receive and manage a greater volume of water within their existing channel configurations, which could lead to more frequent and higher flood levels along adjoining lands. Moreover, contaminants from both point and non-point sources of pollution are more likely to reach surface water bodies when transported by runoff over paved surfaces instead of being partially or totally degraded by vegetated soils.

Higher flows also have a greater capacity to remove and transport soil and other loose materials from streambanks and riverbeds, facilitating erosion and scouring. Paradoxically, river flows become lower between rain events after urbanization. Paved surfaces act as a barrier that isolate the soil, preventing the infiltration of rainwater that otherwise would have gradually discharged from the ground and into streams days later, a process that is critical for maintaining base flows for riparian fish and wildlife species, but also to sustain public water supply.

In response, various hard infrastructure measures (flood control pump stations, curved side gutters, concrete trapezoidal channels, etc.) have been widely adopted across the island to address stormwater runoff related flooding with minimal consideration to ecological, social, cultural, or aesthetic impacts. These practices often involve significant operation and maintenance costs, and in many instances, could even promote erosion, scouring, and water quality impairments farther downstream and in other receiving water bodies.

Taking advantage of the ecological services that green areas and other sustainable practices offer to manage runoff flows and improve water quality is more vital than ever before to safeguard the wellbeing of communities, especially against the increasing water-related impacts associated with climate change in Puerto Rico. These climate change-induced impacts include very intense or extreme rain events with significant dry spells or droughts in between, compounded by a reduction of the annual average precipitation between 13% and 22% for the whole island by the year 2050 compared to that recorded for the period between 1986 and 2005.[3]

[2] Martinuzzi, Sebastián, William A. Gould, and Olga M. Ramos González. (2007). “Land Development, Land Use, and Urban Sprawl in Puerto Rico Integrating Remote Sensing and Population Census Data.” https://doi.org/10.1016/j.landurbplan.2006.02.014.

[3] Climate Change Council Puerto Rico. (2022). “Puerto Rico State of the Climate 2014-2021.” https://www.drna.pr.gov/wp-content/uploads/2022/10/PR_StateOfTheClimate_2014-2021_PRCCC-09-2022.pdf.

1.3. The Role of Natural and Nature-Based Solutions in Stormwater Management

NNBS offers a myriad of benefits in stormwater management, aiming to slow down and reduce runoff before it reaches overloaded stormwater systems, creeks, streams, rivers, and coastal waters. This can be achieved by enhancing evapotranspiration and infiltration through plant coverage and improved soil performance, reducing impermeable surfaces, capturing, and storing rainwater in localized areas to enhance on-site drainage, and increasing flow paths and storage capacity of stormwater systems. These practices, akin to traditional stormwater management, reduce peak flows and downstream water levels during heavy rain events, as well as resulting erosion and scour impacts on streambanks, fostering safer, more resilient communities.

In Puerto Rico, the diverse and expansive natural environment is integral to its social and cultural fabric. Green stormwater infrastructure and NNBS provide numerous environmental benefits to safeguard these resources. Urban wetlands, for instance, can act as natural buffers, absorbing excess nutrients and contaminants, thereby enhancing water clarity and quality. Rainwater harvesting systems can reduce pollution of surface water with fertilizers, pesticides, metals, and other sediments. Green infrastructure elements such as permeable pavements and bioswales help to slow down and infiltrate stormwater, preventing overflow into stormwater systems and alleviating pressure on urban infrastructure. This restoration of natural hydrological processes not only fosters habitat creation and biodiversity but also contributes to the overall health of ecosystems, supporting native flora and fauna populations, reducing the "urban heat island effect," and enhancing ecosystem resilience to climate change impacts, including the expected increase in the severity of tropical storms and droughts.[4] These strategies not only bolster resilience to frequent rain events but also promote groundwater recharge, fostering sustainable stormwater practices within urban environments.

Stormwater NNBS can also reduce stormwater management costs compared to conventional gray infrastructure approaches. By promoting on-site infiltration in small parcels or land surfaces, more runoff is managed locally, thus reducing the burden on overloaded stormwater conveyance systems. In Puerto Rico, where degradation of stormwater infrastructure is not uncommon, the adoption of more localized solutions would be particularly valuable for many municipalities. Additionally, the incorporation of green spaces and vegetation in urban landscapes offer recreational and aesthetic benefits to communities and may lead to increased property values.[5]

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[4] Program, U. S. Global Change Research. (2023). "Fifth National Climate Assessment US Caribbean." https://nca2023.globalchange.gov/chapter/23/.

[5] FEMA. (2021). "Building Community Resilience with Nature-Based Solutions." https://www.fema.gov/sites/default/files/documents/fema_riskmap-nature-based-solutions-guide_2021.pdf.

2. Natural and Nature-Based Solutions Conceptual Methodologies

This section discusses methodologies for three types of green stormwater infrastructure: (1) bioretention, (2) permeable pavements, and (3) rainwater harvesting systems. While a single project incorporating one of these systems will not completely eradicate flooding for an entire municipality, especially for structures located within floodplains, municipalities and developers should aim to integrate these systems at the site scale, prioritizing public infrastructure improvements (e.g., plazas, recreational areas, parking lots, roads), new developments, and redevelopments (e.g., residential communities, commercial buildings, shopping center parking lots). By increasing on-site infiltration and reducing runoff, communities can alleviate stress on overloaded stormwater conveyance systems and streams. These small changes can cumulatively make a significant difference in reducing the flood risk for a community and improving water quality, the latter by making use of natural processes leading to the breakdown of nutrient loadings and other pollutants. Figure 2-2 provides an example illustration of how these features can be seamlessly integrated into a community's existing stormwater infrastructure, without losing the function of these spaces.

In some areas of Puerto Rico, river systems or smaller channels can quickly fill up even during ordinary rain events. Encouraging site-level infiltration and minimizing the impact of rapid runoff on downstream channels can reduce flood risk. Furthermore, combining these site-scale techniques with more regional methodologies discussed in the FEMA Puerto Rico Joint Recovery Office Streambank and/or Coastal Job Aid reports can establish a healthier and more resilient system.

Figure 2-1: Example of how stormwater NNBS features can be incorporated into a community across various infrastructure types.

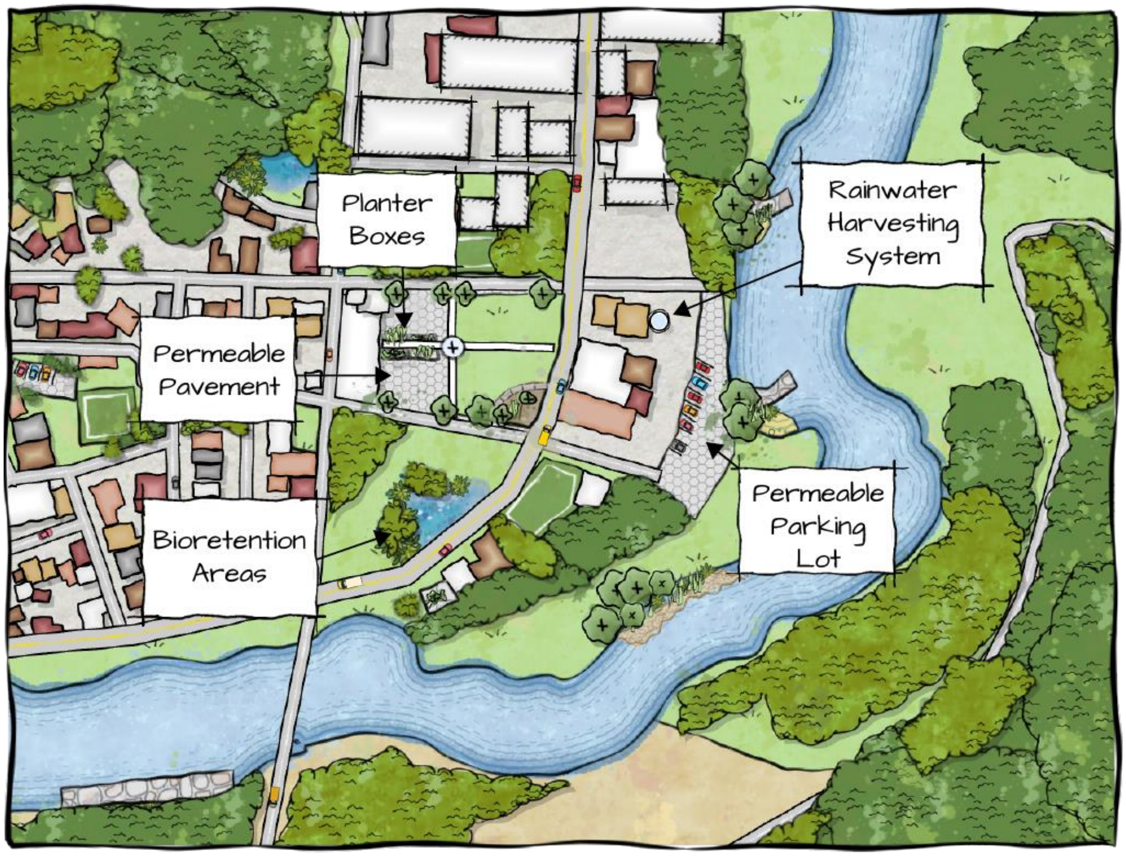

Figure 2-2: Example of how stormwater NNBS features can be incorporated into a community across various infrastructure types.

This Job Aid details information for the development of bioretention systems, permeable pavements, and rainwater harvesting systems, summarized in Table 2-1. There are many different types of green stormwater techniques or applications that have been successfully implemented under different site-specific conditions that are not discussed in this document. Additional publications and/or guidelines on other common types of green stormwater infrastructure techniques have been included as Resources at the end of this document.

Table 2-1: Green Stormwater Techniques and Applications Included in This Job Aid

Type	Definition	Application Examples
Bioretention Systems	The term "bioretention systems" is used for a variety of facilities that manage stormwater. In order of scale and amount of storage provided, this includes planter boxes, rain gardens, bioswales, and bioretention cells. Full details on this methodology are included in Section 2.1.	Residential sites Commercial sites Parking lots Plazas Roadways Parks

Type	Definition	Application Examples
Permeable Pavements	Permeable pavements allow more rainfall to soak into the ground. Common types include pervious concrete, porous asphalt, and interlocking pavers. Full details on this methodology are included in Section 1.2.	Parking lots Plazas
Rainwater Harvesting	Rainwater harvesting collects and stores rainwater for future use. It can vary in scale from a backyard rain barrel to a large cistern. Full details on this methodology are included in Section 1.3.	Residential sites Commercial sites

2.1. Bioretention Systems

2.1.1. DESCRIPTION OF SOLUTIONS AND OBJECTIVES

Figure 2-3. Bioretention planter boxes at the GSA federal facility in the municipality of Guaynabo during an afternoon rain

Figure 2-4. Bioretention planter boxes at the GSA federal facility in the municipality of Guaynabo during an afternoon rain

The term "bioretention systems" encompasses a wide variety of drainage systems designed to manage stormwater runoff. These solutions vary in scale and runoff storage capacity, including planter boxes, rain gardens, bioswales, bioretention cells, and constructed artificial wetlands. **Planter boxes** typically consist of concrete structures filled with planting media, sand, and gravel layers to facilitate infiltration (Figure 2-2). **Rain gardens** are shallow vegetated basins that collect and absorb runoff from impervious surfaces like rooftops and sidewalks (Figure 2-3). **Bioswales**, or vegetated swales, are channels lined with plants or mulch that treat and absorb stormwater as it travels downgradient. Unlike rain gardens, bioswales incorporate an underdrain system and are often used in areas where space is limited, directing excess water to existing drainage systems. **Bioretention cells** or "biocells" function similarly to bioswales but are not linear and occupy specific areas, such as buffer zones between parking lots and water bodies, often featuring deeper engineered soils and trees. **Constructed artificial wetlands** are typically larger systems that are designed to retain/store water, whereas the other types are dry systems. However constructed wetlands are not optimal in urban settings because they provided habitat for species that are not desirable in such settings (mosquitos, frogs, etc.).

All types of bioretention systems offer numerous benefits, including increased infiltration, reduced runoff, improved water quality, habitat creation for native wildlife, and aesthetic enhancements. Depending on the design of the system, on-site stormwater runoff volumes can be reduced as much as 56 to 89% for a storm event.[6] Pollutant removal performance is more variable, but research has indicated that bioretention can aid with reductions in the amount of total metals, bacteria, total suspended solids, and total nitrogen in stormwater runoff.[6] Although there are differences in design and considerations for the different types of bioretention systems, the core components are largely similar for all types.

1.1.1. SUITABLE ENVIRONMENTS FOR SUCCESSFUL IMPLEMENTATION

Bioretention systems are well suited to any site size because of the flexibility in the scale of the system. Key design considerations include drainage area, slope, soil conditions, groundwater table depth, and the incorporation of features to optimize performance and minimize maintenance. Ideal sites include parking lots and residential landscapes with gentle slopes around 5% to ensure sufficient elevation difference for proper water flow through the filtering media within a specified timeframe.[6] Bioretention within the right-of-way should accommodate vehicle use and parking demands.

A field infiltration test should be performed to confirm suitability of the soil at the proposed NNBS stormwater practice, as soil type considerations are critical. Most Puerto Rican soils have sufficient infiltration rates to support these systems, but in areas with poor infiltration, underdrains can be added if needed, to ensure adequate drawdown time for plant survivability. The bottom layer of the system should be a minimum of 2 feet above the groundwater table.[6]

[6] Environmental Protection Agency. (2021). "Stormwater Best Management Practice, Bioretention (Rain Gardens)." https://www.epa.gov/system/files/documents/2021-11/bmp-bioretention-rain-gardens.pdf .

Figure 2-5. Rain garden in Culebra, PR (Left photo: Puerto Rico Department of Natural and Environmental Resources, Right photo: Protectores de Cuencas, 2023)

When selecting vegetation, it is important to consider the microclimate of the area (shading, wind exposure, proximity to buildings), in addition to the macro climate of Puerto Rico (well-drained karst region, humid north, drier south regions, etc.). Potted plants from nurseries can be planted in selection based on available space or area. Selected plant species availability may be a temporary limiting factor for project development, since large quantities or certain species may not be readily available for sale at local plant nurseries. Therefore, it is important to plan to either set aside existing stock or harvest and develop seeds and/or saplings so that vegetation is available when needed during the planting phase of the project. As such, it is critical to coordinate with local suppliers to understand what vegetation can be provided, its annual availability, or if there is an extended lead time on procurement. Ensuring that plant material is available when the project is under construction is crucial to expedite the timeline and reduce costs.

Irrigation of newly established grasses, shrubs, and trees is advised to increase the chances of transplant survival over the first few weeks. Planting during the rainy season (April to November) can also support this effort and result in lower costs associated with irrigation. Additionally, mulching around plants can help the soil retain more moisture that is beneficial for the plants' initial survival. It is normal to experience some mortality among individual plants, due to dehydration, temperature shock, wind desiccation, or insect damage. However, it is important to account for these losses and to plan for the replacement of dead plants, both in terms of logistics and total project costs.

The paper *Recommended Species for Rain Gardens, Bioswales, and Bioretention Cells in Puerto Rico and the Caribbean Islands* provides a comprehensive list of recommended bioretention vegetation specific to Puerto Rico.[7] The most recommended plant habits include herbaceous species

[7] Terrasa-Soler, J.J. (2016). "Recommended Species for Rain Gardens, Bioswales, and Bioretention Cells in Puerto Rico and the Caribbean Islands." https://jterrasa.wordpress.com/wp-content/uploads/2016/02/recommended-species-for-rain-gardens-bioswales-bioretention-cells-in-puerto-rico-and-caribbean-islands_jose-j-terrasa-soler_2016.pdf.

like forbs and graminoids, as well as shrubs, and trees. Examples of native recommended species for bioretention for these habits is included in **Table 2-2** below.

Table 2-2: Example Recommended Species for Bioretention

Plant Habit	Example Native Species (*Scientific Name* / Common Name(s))	Notes
Forb	*Commelina diffusa* / Climbing dayflower, Cohítre	Blue flower. Recommended 4" pot fully rooted with 12" spacing. Best planted in partial or full sun.
	Buchnera americana / American bluehearts	Perennial wildflower with purple or blue coloring. Recommended 4" pot fully rooted with 12" spacing. Best planted in full sun, highly drought tolerant.
	Sphagneticola trilobata (Wedelia trilobata) / Creeping oxeye, Wedelia, Manzanilla	Caribbean native plant. Attractive overflowing yellow flowers with dense groundcover adapted to many spaces. Recommended 4" overflowing pot fully rooted with 12" spacing. Best planted in partial shade and can survive moderate droughts.
Graminoid	*Cladium mariscus* ssp. Jamaicense / Jamaica swamp sawgrass, Cortadera de ciénaga	Recommended 3-gallon plant of 24" height with a minimum of 5 stems with 36" spacing. Best planted in partial to full sun in a regularly inundated area.
	Cyperus polystachyos / Manyspike flat sedge	Recommended 3-gallon plant of 24" height with a minimum of 5 stems with 36" spacing. Best planted in partial or full sun. Commonly found in moist and grassy areas at lower elevations.
	Fimbristylis spp. / Fimbry, Junquito	Recommended 3-gallon plant of 24" height with a minimum of 5 stems with 36" spacing. Best planted in partial or full sun. Well tolerant of regular inundation.
Shrub	*Lantana camara* / Hedgeflower, Cariaquillo	Recommended 4" overflowing pot fully rooted with 18" spacing. Best planted in full sun. Drought tolerant.
	Chrysobalanus icaco / Coco plum, Icaco	Recommended 3-gallon plant of 24" height with a minimum of 5 stems with 36" spacing. Best planted in partial or full shade. Well tolerant of both dry and wet conditions.
Tree	*Bucida buceras* / Gregorywood, Gregre, Úcar	Recommended 15-gallon plant of 8' height. Best planted in direct sun. Requires regular watering and well suited to regularly inundated areas.
	Ficus citrifolia / Wild Banyantree, Shortleaf fig, Jagüeíllo	Recommended 7-gallon plant of 6' height. Best planted in indirect sun. Requires well drained soil.

1.1.2. CONSTRUCTION MATERIALS AND EQUIPMENT

Bioretention design will be site-specific and depend on the type of bioretention facility selected. Key elements, considerations, and their applicability are included in **Table 2-3** below, summarized from the Environmental Protection Agency's (EPA's) Bioretention Design Handbook,[8] with added considerations for the local conditions of Puerto Rico. During construction, temporary sediment control measures such as compost logs, check dams, and sediment basins can be used to prevent clogging in the system. Low-impact earth-moving equipment, such as wide-track or marsh track equipment, or light equipment with turf-type tires, should be utilized to reduce pressure and compaction on the soil. Drivable mats can be employed for backfilling and grading. Excavating during dry conditions is recommended to prevent soil smearing, and raking the soil with the teeth of the bucket is advised to loosen any compaction.

Table 2-3: Bioretention Design Elements

Design Element	Description	Materials	Applicability
Inlet / Runoff Capture	Inflow can enter a bioretention facility as sheet or concentrated flow, or for larger systems, engineered inlet structures can be used to direct water into the system.	Materials are dependent on the type of inlet selected. Common types include covered inlets, trench drain, pipe, curb extension inlet, depressed drains, and inlet slumps.	Engineered inlets are recommended for bioswales and bioretention cells, and optional for smaller rain gardens and planter boxes.
Pretreatment	Pretreatment measures, such as vegetated filters, should be used to dissipate energy and minimize erosion. This filters out coarse material that can clog the soil and reduce infiltration efficiency.	Materials are dependent on the type of pretreatment selected. Common sheet flow pretreatments include vegetated filter strips, and gravel diaphragms. Common inlet pretreatments include forebays, splash blocks, catch basin, catch basins, filter guards, or screens.	Applicable for all types of bioretention with a contributing drainage area of 1/2 acre. Commonly used when inflow is entering as concentrated flow (curbs, pipes) but can also be used for sheet flow.

[8] Environmental Protection Agency. (2021). "Bioretention Design Handbook: Designing Holistic Bioretention for Performance and Longevity." https://www.epa.gov/system/files/documents/2023-11/bioretentiondesignhandbook_plainnov2023.pdf.

Design Element	Description	Materials	Applicability
Vegetation	Native, non-invasive, low-maintenance vegetation is the optimal selection for bioretention systems. Systems are intended to drain completely in 24–36 hours (i.e., not become a wetland); therefore, selected plant species should be tolerant of short periods of inundation and longer dry periods.	The paper Recommended Species for Rain Gardens, Bioswales, and Bioretention Cells in Puerto Rico and the Caribbean Islands provides a comprehensive list of recommended bioretention vegetation specific to Puerto Rico.[8]	Applicable to all types of bioretention systems. Scale of vegetation and number of selected plants will vary with the size of the system. For example, bioretention cells are large enough to accommodate trees, while planter boxes typically cannot.
Mulch	Mulch is typically used over the Bioretention Soil Media (BSM) layer (1–2 inches) as a filter bed cover to retain and filter water and provide a suitable environment for vegetation at the surface.	Wood mulch	Applicable to all bioretention system types. Gravel/shale/rock can be used as a more resilient alternative if the system will be exposed to intense storms and winds.
Bioretention Soil Media (BSM)	Filter media, or bioretention soil media, can be existing soil if conditions are appropriate or it can include engineered soil to improve infiltration rates. Descriptions of how to perform infiltration tests to determine the suitability of the soil can be found at Bioretention Cell Design Guidance for Oklahoma.[9] This layer is typically between 2 and 4 feet.	Existing soil can be used if infiltration rates are suitable. Engineered BSM is typically composed of 4 parts sand, 2 parts compost, and 1 part topsoil, or regionally appropriate mix, with 80% relative compaction.[6] BSM amendments to increase infiltration include biochar and coconut coir.	Applicable to all bioretention systems. Engineered soil is recommended if soil surveys show poor infiltration rates. If water quality is a key outcome, media enhancements (biochar, wastewater treatment residuals) can be added for this purpose. The depth of this layer varies with the desired storage capacity of the system.

[9] Oklahoma State University. (2017). “Bioretention Cell Design Guidance for Oklahoma.” https://extension.okstate.edu/fact-sheets/print-publications/bae/bioretention-cell-design-guidance-for-oklahoma-bae-1536.pdf.

Design Element	Description	Materials	Applicability
Choker Layer or Liner	Choker layers or liners can be used to separate the filter bed from the drainage layer and limit the migration of materials.	Choker layers are generally 2 to 4 inches of sand or gravel (1/4 inch to 1 inch in diameter). Burlap coffee bags can be used as a permeable liner. Impermeable liners include till liners, clay layers, geomembrane liners, and concrete liners.	The use of chokers and liners is typically limited to bioretention cells. Liners can be appropriate when there are contaminated areas in the underlying soil. They should not be used in areas with clay soils, as this can clog the systems.
Drainage Layer	A coarser-grade stone layer beneath the BSM to promote drainage. This layer is typically between 1 and 2 feet.	Recommended stone aggregate materials for this layer are approximately 3/4-inch to 2.5-inch diameter (AASHTO stone numbers 2, 3, 56, 57, and 67).	Appropriate for planter boxes or constrained systems when it's not possible to store total water volume on the surface or for any bioretention systems where minimizing surface storage is desired.
Underdrains and Outlets	Water can leave the bioretention system through exfiltration, evapotranspiration, and outflow. Underdrains are used to control outflow on the subsurface. Outlets are used to control outflow on the surface.	Underdrains are typically a 4- to 6-inch diameter PVC or HDPE pipe with equally spaced holes; 6-inch is recommended to minimize clogging. Outlet material varies depending on the type of outlet selected (curb cuts, orifices, weirs, risers).	Underdrains and outlets are appropriate when the site has poor exfiltration, poor infiltration (below 0.2 inches per hour, not common in PR), when an impermeable liner is used, or there is a high-water table.

1.1.3. CONSTRUCTION CONSIDERATIONS

Proper installation is important to avoid over-compaction, which can reduce the effectiveness and storage capacity of the system and have long-term impacts on the effectiveness of the system. Having sufficient material quantities available on site is recommended for efficient installation and stabilization of exposed areas. The drainage stone used should be sprayed down or washed free of fine particles to avoid clogging. Failure of the system can also occur when the vegetation is dead or dying upon planting. Proper grading of the site and inlet construction (if applicable) cannot be overlooked, and it is critical that grades and the direction of flow are clearly planned out in the design and communicated. Designing simple shapes is often the simplest way to minimize excavation and simplify construction. Recommended checks to complete during construction include: (1) Inspecting the BSM to ensure stones have been washed of fines, (2) ensuring the sub-grade and the BSM are not compacted after installation; infiltration rates can be tested after each layer is added, and (3) inspecting plants for health before and after planting. After construction, recommended checks include: (1) confirming that water is draining into the system as designed, and (2) inspecting water after a rainfall event (no ponding should be visible after 24 to 48 hours). If bioretention is part of a larger project, it should be scheduled to be constructed toward the end of the construction sequence to prevent clogging by sediment and/or heavy loading of construction equipment.[10]

1.1.4. TYPICAL SECTIONS

The features described in Section 1.1.2 are shown below in a typical bioretention cross-section in Figure 2-6.

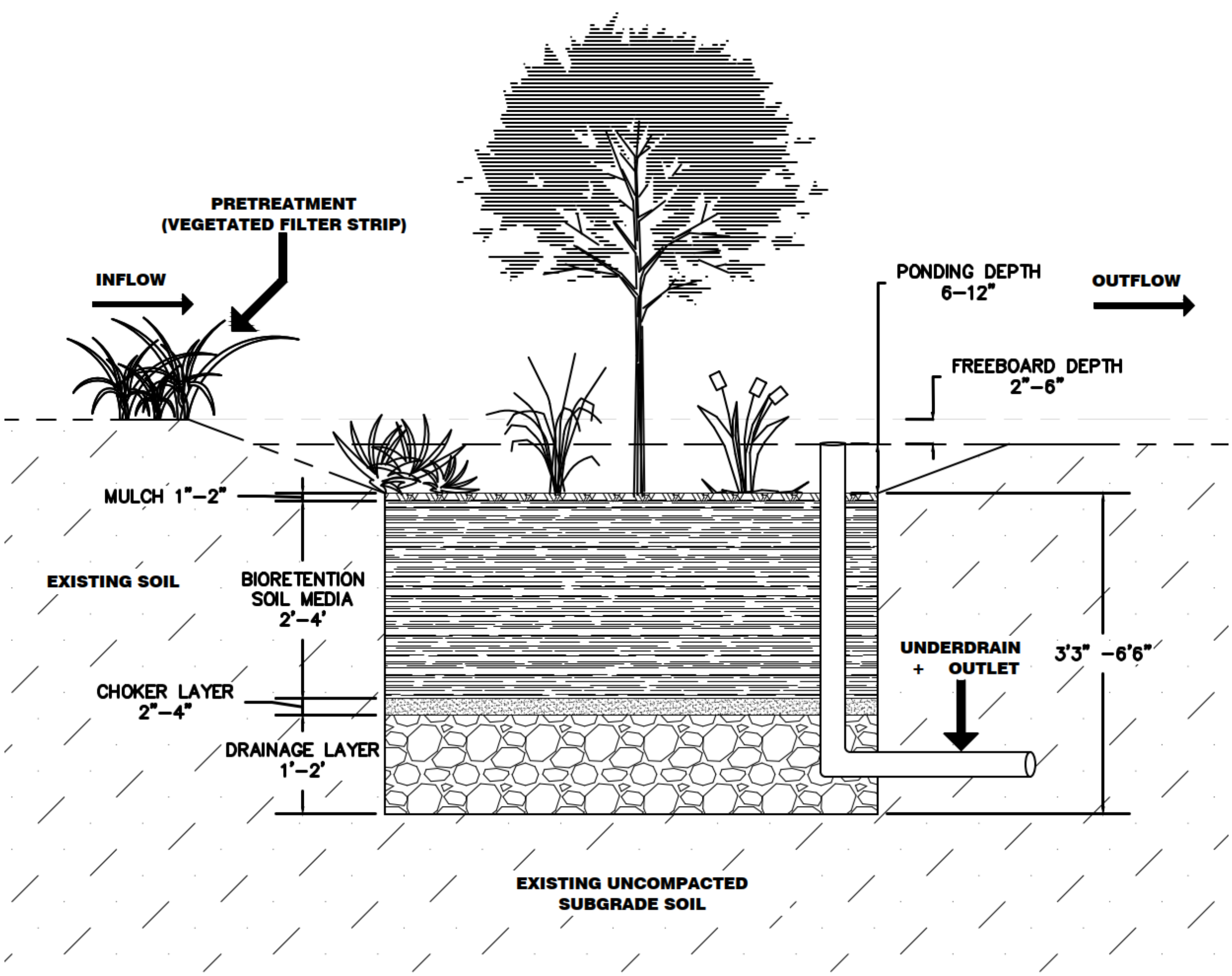

Figure 2-6. Example of a typical bioretention section

[10] Minnesota Pollution Control Agency. (2024). “Construction Specifications for Bioretention - Minnesota Stormwater Manual.” https://stormwater.pca.state.mn.us/index.php/Construction_specifications_for_bioretention.

1.1.5. MONITORING AND ADAPTIVE MANAGEMENT

Routine inspections and clearing of unwanted materials (sediment, trash, dead plant material, etc.) are important for maintaining the health of the bioretention system. Inlets and outlets should be inspected for sediment buildup and cleaned when the structure is greater than 50% full. Street sweeping is often a useful pretreatment tool in preventing trash and debris from entering the system. Inspections are recommended on a quarterly basis and can include checking for signs of erosion, settlement, or over-compaction. Ponding after 48 hours following a rain event is a sign that clogging has occurred in the system. Commonly, clogging occurs within the top 3 to 6 inches of the BSM layer, so excavation and cleaning of material may be needed if this occurs. The mulch layer can be removed and reapplied by hand every 2 to 3 years or as needed. Vegetation should be treated as assets. Regardless of the scale of the system, bioretention is a community benefit because of the aesthetic benefits, so maintenance, including weeding, should be performed year-round, like any well-manicured landscaped area. In dry periods, watering may be needed. Vegetation health should be inspected to see if any has overgrown or needs to be replanted. If needed, vegetation can be removed and replaced with minimal to no impact on the overall system.[8]

Local communities and environmental/community groups can become critical partners for project development, monitoring, and maintenance, especially with projects that are to be built in public spaces. These partnerships can be advantageous for lowering operation and maintenance costs, in addition to fostering a sense of ownership and stewardship among nearby residents and citizens.

1.1.6. ESTIMATED COSTS

Bioretention areas in Puerto Rico average $25 to $35 per square foot. More details are included in the attached cost estimation spreadsheet.

1.2. Permeable Pavement

1.2.1. DESCRIPTION OF SOLUTIONS AND OBJECTIVES

Permeable pavement reduces runoff from an otherwise impervious surface by increasing evaporation, detention, filtration, and infiltration at a site (Figures 2-5 and 2-6). Through small openings and permeable joints made up of small-sized aggregates, stormwater can more easily infiltrate the soil below than with traditional pavement. This reduction in impervious area in an urban landscape improves localized drainage without sacrificing the functionality of a paved surface. By increasing on-site infiltration, issues such as local flooding and ponding are minimized, especially during smaller, more frequent rain events. With proper installation under the right soil conditions, permeable pavement can serve as a durable, cost-efficient, and suitable replacement for traditional impermeable cover.

Figure 2-7. Permeable parking lot at the GSA Guaynabo Center after an afternoon rain, showing the water slowly infiltrating into the pavement, recharging the groundwater and reducing runoff at the site. Wet area corresponds to standard pavement placed to sustain more intense traffic, while the remaining parking lot was covered with permeable pavement.

1.2.2. SUITABLE ENVIRONMENTS FOR SUCCESSFUL IMPLEMENTATION

Soil conditions, slope, land use, and degree of usage are important considerations when determining if permeable pavement will be successful for a site. Due to the small openings and aggregate in permeable pavement, the surface is more abrasive and can deteriorate more quickly than conventional coverings; therefore, high-speed or high-traffic roadways are not appropriate candidates. Additionally, high-traffic roadways are high sediment loading areas, which can clog the pores and severely limit infiltration.[11] However, permeable pavement can be effectively used in low-speed roadways, emergency lanes, parking areas, sidewalks, or within portions of a larger impervious areas. In Puerto Rico, many municipalities also have town plazas or town squares that could also be good candidates for permeable pavement.

[11] Environmental Protection Agency. (2021). "Stormwater Best Management Practice: Permeable Pavements." https://www.epa.gov/system/files/documents/2021-11/bmp-permeable-pavements.pdf.

For permeable pavement placement, the minimum acceptable infiltration rate in soil is 0.5 inches per hour.[12] Most of Puerto Rico's soil coverage is comfortably above this threshold. Puerto Rico's three most common soil orders, accounting for 65% of Puerto Rico's land mass are Inceptisols, Ultisols, and Mollisols soils.[13] Eight-hour infiltration rates for Inceptisols, covering 30% of Puerto Rico's land mass, range from 1.1 to 5.31 inches per hour.[14] Rates for Ultisols, 20% of Puerto Rico's land mass, range from 2.96 to 9.47 inches per hour; and Mollisols, 15% of Puerto Rico's land mass, range from 3.3 to 7.8 inches per hour.[14] A field infiltration test should be performed in the preliminary stages of design to ensure suitability of the soil and select the optimal locations. If a soil has poor infiltration, designers can compensate by increasing the depth of the subbase or adding underdrains. Site surveys should also check for groundwater table elevation and presence of shallow bedrock, which can limit the depth of infiltration.

Site slope should ideally be under 2%, but slopes over 2% can be accommodated by adding terracing or lined trenches with underdrains along the slope. Steeply sloped lands (greater than 15%) are not suitable, as slopes this steep can lead to durability and erosion challenges.

Figure 2-8. Permeable parking lot in Rincon, PR (Protectores de Cuencas, 2024)

[12] Tennessee Stormwater Management. (n.d.). "Tennessee Permanent Stormwater Management and Design Guidance Manual- Chapter 5.48 Permeable Pavement." https://tnpermanentstormwater.org/manual/17%20Chapter%205.4.8%20Permeable%20Pavement.pdf#:~:text=In%20addition%2C%20permeable%20pavement%20should%20never%20be,infiltration%20rate%20of%200.5%20inches%20per%20hour.

[13] University of Puerto Rico. (2018). "Taxonomic Classification of Soils in Puerto Rico,2017." https://www.uprm.edu/tamuk/wp-content/uploads/sites/299/2019/06/Taxonomic_classification_soils_PR_2018_reduced.pdf.

[14] López, M. A. Lugo, J. Juárez, and J. A. Bonnet. (1968). "Relative Infiltration Rate of Puerto Rican Soils." The Journal of Agriculture of the University of Puerto Rico. https://doi.org/10.46429/jaupr.v52i3.11510.

1.2.3. CONSTRUCTION MATERIALS AND EQUIPMENT

Typical design elements for permeable pavement, summarized from the EPA's Stormwater Best Management Practice: Permeable Pavements,[11] the Minnesota Stormwater Manual[15] and Toronto's Sustainable Technologies Evaluation Program Permeable Pavement Guide,[16] with added consideration for the local conditions of Puerto Rico, are included in **Table 2-4** below. Note that there are many similarities between the materials needed for bioretention and permeable pavements.

Besides equipment for the transportation of materials, the main construction equipment needed is a vibrating compaction roller. It is important to not over-compact the soil, and no more than three passes total are expected during construction. In general, much of the same equipment and installation process for conventional concrete is used, but with different handling and installation requirements.[16]

Table 2-4: Permeable Pavement Design Elements

Design Element	Description	Materials	Applicability
Pretreatment	Pretreatment, such as vegetated filters, should be used to dissipate energy and minimize erosion. This filters out coarse material that can clog the soil and reduce infiltration efficiency of the pavement.	Permeable pavement systems manage direct precipitation or runoff from sheet flow. Common sheet flow pretreatments include vegetated filter strips and gravel diaphragms.	Applicable for permeable pavement with a contributing drainage area greater than 1/2 acre.
Bedding Course	The bedding course provides a level and stable surface for the permeable surface layer.	This layer is typically 1 to 2 inches thick composed of small, uniform aggregate (AASHTO no. 8; 3/8 inch to 1/2 inch).	Key component of all permeable pavement systems.
Filter Course (Base Reservoir)	The base reservoir serves as a high-infiltration-rate transition layer between the bedding and subbase layers.	This layer is typically 3 to 4 inches thick and is composed of uniformly sized crushed stone of an intermediate size (AASHTO No. 57 stone; 3/4 to 3/16 inch). The sizing should be between the bedding and subbase aggregate.	Key component of all permeable pavement systems.

[15] Minnesota Pollution Control Agency. (2024). "Design Criteria for Permeable Pavement - Minnesota Stormwater Manual." https://stormwater.pca.state.mn.us/index.php/Design_criteria_for_permeable_pavement.
[16] Sustainable Technologies Evaluation Program. (2012). "Low Impact Planning and Design Fact Sheet: Permeable Pavement." https://wiki.sustainabletechnologies.ca/images/7/7e/Permeable_Pavement_Factsheet.pdf.

Design Element	Description	Materials	Applicability
Drainage Layer (Subbase Reservoir)	This layer is the main water storage and support layer.	Recommended stone aggregate materials for this layer are approximately 3/4-inch to 2.5-inch diameter in size (AASHTO stone numbers 2, 3, 56, 57, and 67). This layer is typically between 1 and 2 feet.	For pedestrian application, for well-drained soils, a subbase layer may not be required.
Choker Layer or Liner	A choker layer or liner can be used to separate the filter bed from the drainage layer to limit the migration of materials.	Choker layers are generally 2 to 4 inches of sand or gravel (1/4 inch to 1 inch in diameter). Burlap coffee bags can be used as a permeable liner. Impermeable liners include till liners, clay layers, geomembrane liners, and concrete liners.	The use of chokers and liners is appropriate when there are contaminated areas in the underlying soil. They should not be used in areas with clay soils, as this can clog the systems.
Underdrains and Outlets	Underdrains are used when the underlying soil has poor infiltration rates to facilitate water drainage from the base and subbase layers. Like bioretention systems, the underdrain piping would drain to an outlet structure.	Underdrains are typically a 4- to 6-inch diameter PVC or HDPE pipe with equally spaced holes; 6-inch is recommended to minimize clogging. Outlet material varies depending on the type of outlet selected (curb cuts, orifices, weirs, risers).	Underdrains are appropriate when the site has poor exfiltration, poor infiltration (below 0.2 inches per hour), when an impermeable liner is used, or there is a high-water table elevation.

1.2.4. CONSTRUCTION CONSIDERATIONS

Proper installation is crucial for the long-term effectiveness of permeable pavement. While construction crews can generally utilize similar equipment for both permeable and conventional versions of asphalt and concrete, the mixtures differ slightly and have distinct handling and installation requirements. During the compaction of porous asphalt, minimal pressure should be applied to avoid closing pore space, and vehicular traffic should be avoided for 48 hours post-installation.[15] Pervious concrete, having a lower water content than traditional concrete, significantly reduces handling time, necessitating pouring within 1 hour of mixing unless admixtures are used to extend handling time. When leveling pervious concrete with a screed, set ½ inch above the finished height; floating and troweling should be avoided to prevent surface pore closure.[15] Consolidation of concrete, typically with a vibrating steel roller, occurs within 15 minutes of placement.[15] To protect permeable pavements from high sediment loads, designers should implement pretreatment measures such as filter strips and swales for large contributing areas, ensuring a high infiltration rate by preventing sediment from entering the base during construction. Stormwater flow from disturbed areas should be diverted away from permeable pavement until stabilization is complete, which may take up to a week for concrete systems. If permeable pavement is part of a larger project, installation should be scheduled toward the end of the construction sequence to prevent problems with sedimentation or heavy loading of construction equipment.

1.2.5. TYPICAL SECTIONS

The features described in Section 1.2.4 are shown in Figure 2-9 below in a typical permeable pavement cross-section.

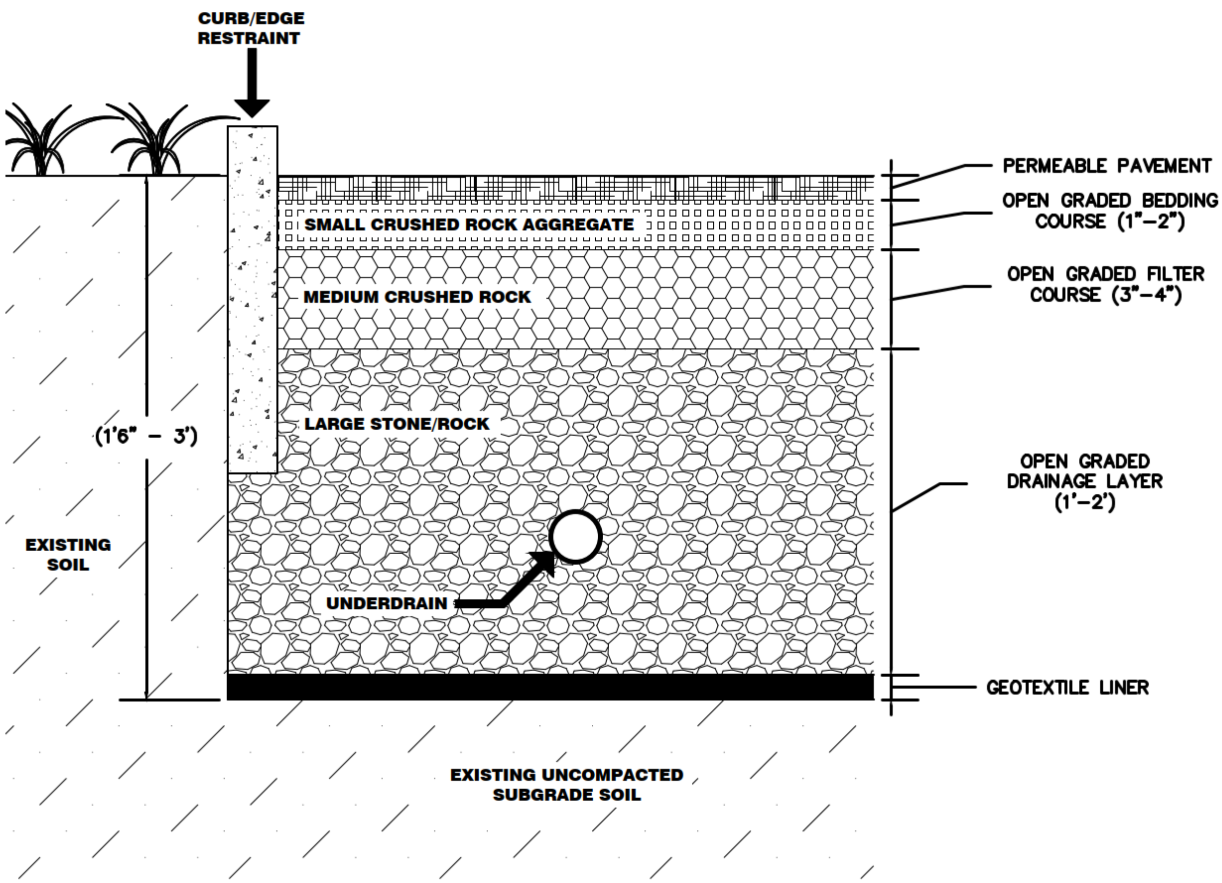

Figure 2-9. Example of a typical permeable pavement section

1.2.6. MONITORING AND ADAPTIVE MANAGEMENT

Monitoring and maintenance are critical since the clogging of pavement pores is the number one concern for permeable pavements, and age and usage can accelerate these concerns. Sediments and other fine particles from vehicles or other sources can clog openings and reduce the degree of infiltration. The larger the area draining to the site and the more frequently it is used, the more that this issue becomes relevant. Site vacuuming and pressure washing are the most common maintenance methods to remove the accumulated sediment and restore permeability. Monitoring is recommended every 6 months for the first 2 years and annually thereafter to test infiltration rates. Sweeping of debris is recommended monthly, and vacuuming or pressure washing should be performed on an as-needed basis, when infiltration rates fall below a predetermined threshold, or no less than once every 18 months.[17]

1.2.7. ESTIMATED COSTS

Permeable pavements in Puerto Rico average $8 to $12 per square foot. More details are included in the cost estimation spreadsheet.

1.3. Rainwater Harvesting

1.3.1. DESCRIPTION OF SOLUTIONS AND OBJECTIVES

Rainwater harvesting (RWH) systems collect, divert, and store rainwater for future use. These systems can greatly vary in scale, from a backyard rain barrel that stores under 50 gallons to a large storage tank or cistern that stores thousands of gallons. Stored water can be used for irrigation, drinking, or general domestic use. By capturing and diverting rainwater, the total runoff for a site is reduced, which reduces the flooding risk for downstream areas. This flood reduction benefit can be maximized by ensuring the storage tank is emptied prior to a heavy rain event so that more water can be captured and diverted.

In addition to runoff reduction, rainwater harvesting is also a cost-effective and sustainable resilience measure to diversify the water supply in Puerto Rico. There are also valuable applications of rainwater harvesting in the agricultural sector. In times of crisis, having access to rainwater harvesting systems can be the difference between life and death. Recent hurricanes and severe tropical storms in Puerto Rico have left some communities without electricity and/or water, for up to months at a time in some instances such as that with Hurricane Maria. Trends in annual mean rainfall are not significantly different from the mean for the period 1925 to 2020. However, heavy rainfall events (> 3 inches in a day) are increasing in frequency as are periods of drought, indicating that while annual rainfall may not be changing, severe rainfall and drought events may be increasing.[3] Therefore, adopting measures to capture and store rainfall can support runoff management measures targeting localized flooding while providing a human water supply.

Although this section focuses on the design and costs for a residential RWH system connected to the home's interior plumbing, small-scale backyard rain barrels (*drones* in Spanish) can also play a useful role in this space. These types of rain barrels or buckets can be used to water vegetation, grass, or even vegetable gardens for homeowners. These are already commonly used in Puerto Rico, especially in more rural communities.

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[17] City of Melbourne. (2019). "Permeable Pavements Maintenance and Monitoring Outcomes." https://urbanwater.melbourne.vic.gov.au/wp-content/uploads/2021/07/Permeable-pavements-maintenance-and-monitoring-outcomes_20191219_Final-Introduction.pdf.

1.3.2. SUITABLE ENVIRONMENTS FOR SUCCESSFUL IMPLEMENTATION

In the U.S. Virgin Islands, all new construction is required to have a self-sustaining water supply system such as a rainwater collection system.[18] This is due to limited groundwater or watersheds lacking a sizeable river. RWH systems are an excellent and sometimes the only option for isolated, rural areas with these challenges. The Caribbean Environmental Health Institute and the United Nations Environment Program have been instrumental in developing guidance for small-scale rainwater harvesting systems that are well adapted for Caribbean environments and advocating for policy and attitude changes surrounding RWH.

How much water can a roof capture?

Supply = rainfall (mm/year) x roof area (m^2) x runoff coefficient x 0.22 = gallons per year

Runoff Coefficients for Common Roof Types:
Tile: 0.8–0.9
Corrugated Metal: 0.7–0.9
Concrete: 0.6–0.8

Despite successes in other parts of the Caribbean, RWH in Puerto Rico is limited; however, the interest is growing. The organization Ridge to Reefs[19] is a pioneer in the space, and they have helped support small farms with direct assistance to RWH and filtration systems. Additionally, the nonprofit organization Plenitud PR[20] has a program to help fund and install community and home RWH systems in the municipality of Las Marías. The local government of Canóvanas received federal funding through the American Rescue Plan Act (ARPA) to install residential rainwater cisterns through the “Llevar agua al campo” program.[21] Similarly, the local government of Carolina also received ARPA funding to install 400-gallon cisterns for qualifying residents in the municipality.[22] It would be beneficial for more municipalities and homeowners to consider establishing RWH programs or practices as a cost-effective and effective way to support communities that have historically been at risk of losing access to water following severe events.

1.3.3. CONSTRUCTION MATERIALS AND EQUIPMENT

Despite the scale or complexity of the system, complete rainwater harvesting systems connected to the interior plumbing of a home include six basic components, described in **Table 2-5** below. The information in this table is summarized from the Texas Manual on Rainwater Harvesting,[23] with

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[18] Environmental Protection Agency. (2022). “US Virgin Islands Environmental Protection Handbook.” https://dpnr.vi.gov/wp-content/uploads/2023/08/2022-VI-Environmental-Protection-Handbook_Full.pdf.
[19] Ridge to Reefs. (2024). “Hurricane & Earthquake Relief- Resilience Development for Puerto Rico.” https://www.ridgetoreefs.org/relief-for-puerto-rico.
[20] Plenitud PR. (2023). “Water Security in Puerto Rico.” https://www.plenitudpr.org/watersecurity.
[21] Metro Puerto Rico. (2021). “Llevarán e Instalarán Cisternas En Comunidades de Canóvanas.” https://www.metro.pr/pr/noticias/2021/11/01/llevaran-e-instalaran-cisternas-en-comunidades-de-canovanas.html.
[22] Municipio Carolina. (n.d.). “Alcalde Aponte Inspecciona Proyectos de Instalación de Cisternas.” https://www.municipiocarolina.com/alcalde-aponte-inspecciona-proyectos-de-instalacion-de-cisternas/.
[23] Texas Water Development Board. (2005).“The Texas Manual on Rainwater Harvesting.” https://www.twdb.texas.gov/publications/brochures/conservation/doc/RainwaterHarvestingManual_3rdedition.pdf.

added considerations for the local conditions of Puerto Rico, and the Handbook for Rainwater Harvesting for the Caribbean.[24]

Table 2-5: Six Basic Components of a Rainwater Harvesting System

Basic Components	Description	Materials
Catchment Surface	The catchment surface is the collection surface from which rainfall runs off, typically the roof of a building or a house.	The two most common roof types in Puerto Rico are metal and concrete roofs. Metal roofs pair well with rainwater harvesting systems due to the smooth, flat surface. Concrete or clay roofs are porous in nature, so there will be some inefficiency in the system. To reduce water loss, roofs can be coated with a sealant, which also prevents bacterial growth.
Gutters and Downspouts	Gutters are used to capture rainwater running off the eaves of a building.	Gutters should be installed with a slope (at minimum 1/8 inch per foot) toward the downspout. Depending on the size of the gutters, roof area, and rainfall intensity, spillage or overrunning can occur. Attention to the number of downspouts is important, and a long roof distance between spouts should be avoided. Gutter maintenance is important for systems of all scale.
Screens, Diverters, and Washers	Filters are needed to remove large debris that gathers on the roof, reduce clogging of the system, and ensure water quality. A first-flush diverter can be used to route the first flow (which generally has the most debris and particles) away from the storage tank. It can be diverted to a planted area below the system. Washers are placed ahead of the storage tank to filter small debris for potable (drinkable) systems.	Coarse leaf screens capture debris from the catchment surface for areas with overhanging trees. Types of leaf screens include leaf guards (1/4-inch mesh), strainer baskets, a cylinder of rolled screen inserted into the outlet, filter socks of nylon mesh installed on the PVC pipe, or a funnel-type downspout filter made of PVC or steel cut into the downspout pipe. In tropical regions, fine insect-proof screens are also useful to install at the inlet and outlet of the tank. The simplest first-flush diverter is a 6- to 8-inch PVC standpipe that drains via a pinhole or loose screen. A ball valve is a variation of the standpipe, and as the chamber fills, the ball floats up and seals the seat, effectively cutting off the first flush of water and routing the remainder to the storage tank. A box roof washer is a commercially available 30- to 50-gallon tank with leaf strainers and one or two 30-micron filters. It is placed on a stand beside the storage tank and must be easily accessible for cleaning.

[24] Caribbean Environmental Health Institute and United Nations Environment Programme. (2009). "Handbook for Rainwater Harvesting for the Caribbean." https://carpha.org/saintlucia/Rain/Rainwater%20Harvesting%20Toolbox/Media/Print/RWH_handbook.pdf.

Basic Components	Description	Materials
Storage Tanks / Cisterns	The storage tank (above ground) or cistern (below ground) stores the water for usage.	The size of the storage tank varies depending on the scale and intended use of the system. Tanks must be opaque (can be achieved by painting) to prevent algal growth. The common PVC above-ground storage tank has emerged as the preferred option for Caribbean RWH systems due to the lower cost and lower maintenance needs required for this type of tank. The tank can be covered with vents screened to discourage mosquito breeding and should be easily accessible for cleaning. A guidance document for estimating the storage requirements and recommended storage tank or cistern size based on demand, rainfall amount, and roof size was developed by Caribbean Environmental Health Institute and the United Nations Environment Programme.[25] Typical tank sizes used for residential RWH systems in Caribbean areas range from 400 to 2,000 gallons for a one- to a four-person household.[24]
Delivery System	Pressure tanks or pumps can be used between the storage tank and the home or end use.	To achieve high enough water pressure, the water tank would have to be ~90 feet above the home using gravity alone. This is usually not achievable, which is why pumps are needed to achieve sufficient pressure. The typical pump-and-pressure tank arrangement consists of a ¾- to 1-horsepower pump (shallow well jet pump or multistage centrifugal pump), the check valve, and pressure switch. Alternatively, “on-demand” pumps eliminate the need for a pressure tank. These combine all the components in a single unit.
Treatment / Purification	For a non-potable (non-drinkable) system, the leaf screens and roof washers can be sufficient, and this step is not needed. For potable systems, treatment is critical to remove disease-causing pathogens.	The most common types of disinfection systems include cartridge filters and ultraviolet (UV) light, ozone, chlorination, and membrane filtration. A simple boiling method (3 minutes at 100°C) is a low-cost alternative for killing bacteria without chemical additives.

[25] Caribbean Environmental Health Institute and United Nations Environment Programme. (n.d.). “Rainwater Harvesting in the Caribbean: Estimating Storage Requirements.” https://carpha.org/saintlucia/Rain/Rainwater%20Harvesting%20Toolbox/Media/Print/Techsheet-3A_B.pdf.

1.3.4. CONSTRUCTION CONSIDERATIONS

The main consideration for construction in the planning stages is how large the system needs to be and what the water will be used for. A guidance document for estimating the storage requirements and recommended storage tank or cistern size based on demand, rainfall amount, and roof size was developed by Caribbean Environmental Health Institute and the United Nations Environment Programme for residential applications.[25] If the water is being used solely for irrigation, the filtration and disinfecting step is not needed, but it is critical for water intended for potable use. It should also be noted that home systems can be set up to not disinfect 100% of the water. Water used for toilets, cleaning, washing clothes, gardening, etc. does not need to be disinfected. If the plumbing is set up in such a way to allow for this, the lifespan of disinfection systems can increase significantly.

No matter the scale or use of the system, cleaning and maintenance are critical for rainwater harvesting; therefore, every component should be easy to access. Screens, diverters, and washers are the components the get clogged most of the time since these tend to trap larger debris.

1.3.5. TYPICAL SECTIONS

The features described in Section 1.3.3 are shown in **Figure 2-8** below in a typical rainwater harvesting system.

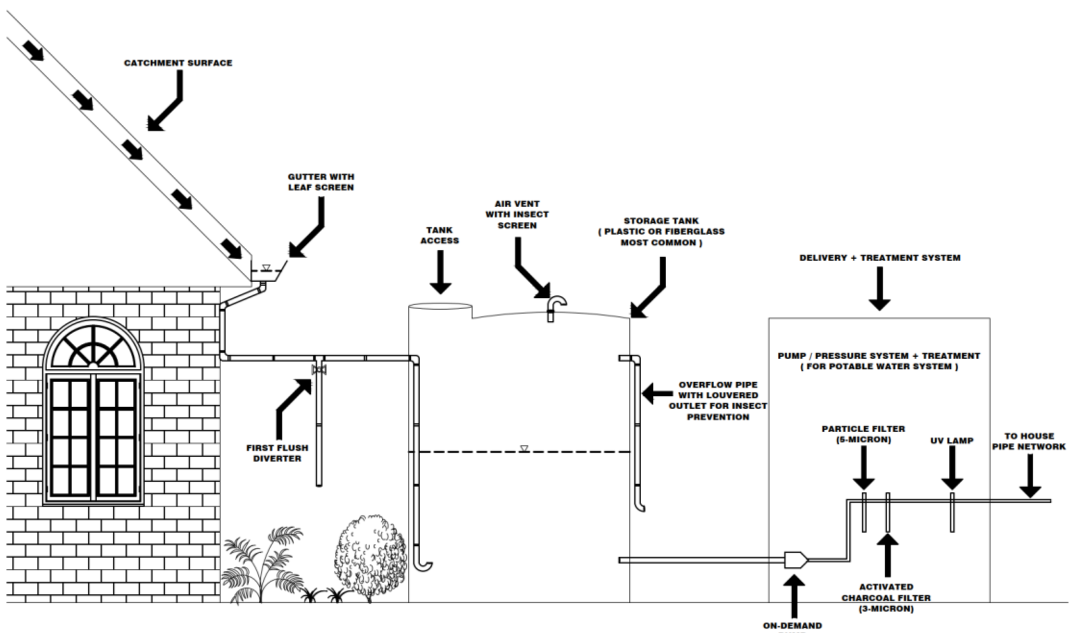

Figure 2-10. Example of a typical residential rainwater harvesting system

1.3.6. MONITORING AND ADAPTIVE MANAGEMENT

Maintenance is important for rainwater harvesting systems of any scale. Regular cleaning of all parts of the system is needed to avoid clogging and system failure. Components like gutters, downspouts, and screens need monthly cleaning in most cases. Debris such as leaves and twigs can accumulate easily after rainfall events and ultimately impact the water quality of the system. Tanks require less frequent service, and in most cases, servicing every 2 years is sufficient if the other parts of the system are kept in good condition. For potable systems, treatment filters will need replacement, but the frequency will depend on the type that is used. UV light systems are designed with a wiper unit, and manual cleaning is not recommended. The particle and activated carbon filters often need regular replacement, with the frequency specified by the manufacturer of the filters selected. If any odor or taste is detected in the system, the user should immediately cease potable use.

1.3.7. ESTIMATED COSTS

A typical potable RWH system for a single-family home (family of four using a 2,000-gallon system) in Puerto Rico ranges from $10,000 to $16,000. For a single-person household, costs for a 500-gallon system range from $4,000 to $6,000. More details are included in the cost estimation spreadsheet. For a smaller-scale, 200-gallon RWH system intended for non-potable use (irrigation, gardening, cleaning, washing clothes, etc.) costs range from $3,000 to $5,000.

It should also be noted that the Puerto Rico Aqueduct and Sewer Authority may require a water meter to be set up at the end of the sanitary sewer pipeline exiting a household or building that is partially or totally supplied by rainwater in order to measure the volume that will be discharged into the sanitary system and treated at one of its sewage treatment facilities, both to manage and bill for the service.

2. Regulatory Management Considerations

Puerto Rico's stormwater infrastructure exhibits a high degree of decentralization; consequently, there is currently no comprehensive inventory of stormwater infrastructure assets available for Puerto Rico. According to the EPA, as of 2018, there were 85 authorized municipal separate storm sewer systems (MS4) across the Archipelago.[26] These systems fall under the jurisdiction of various municipalities, institutions, and/or governmental agencies. For instance, within the municipality of San Juan, multiple public entities, including the Department of Natural and Environmental Resources (DNER), the Department of Transportation and Public Works (DTOP, by its Spanish acronym), along with the municipality itself, oversee distinct segments of the stormwater infrastructure.26 This division of managerial responsibility presents obstacles to achieving a comprehensive understanding of these assets, while at the same time underscoring opportunities to enhance collaboration among local stakeholders. Overall, municipalities across Puerto Rico have varying degrees of organization of stormwater infrastructure information, but comprehensive geospatial information is highly limited, even in San Juan.

Stormwater management functions are predominantly the responsibility of municipalities, which apply for permits administered by the EPA to discharge stormwater into waterways. However, the Puerto Rico Aqueducts and Sewers Authority (PRASA) manages runoff in those urban areas where it maintains a series of combined sewer systems that convey both wastewater and stormwater. Stormwater is also managed by the Puerto Rico Department of Transportation and Public Works and the Puerto Rico Highway and Transportation Authority, in those areas where it drains from state roads and highways.[26] In an effort to standardize storm sewer system practices, the Puerto Rico Planning Board published the document "Regulation for the Design, Operation, and Maintenance of Storm Sewer Systems in Puerto Rico" in April 2023.[27] This document includes guidance in Spanish on the design of low impact development stormwater management practices including bioretention ponds, rain gardens, permeable pavement, green roofs, and vegetated ditches.

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[26] Preston, B.L, et. al. (2020). Beyond Recovery: Transforming Puerto Rico's Water Sector in the Wake of Hurricanes Irma and Maria. Homeland Security Operational Analysis Center operated by the RAND Corporation. https://www.rand.org/pubs/research_reports/RR2608.html.

[27] Junta de Planificación. (2023). "Reglamento para el Diseño, Criterios de Operación y Mantenimiento de Sistemas de Alcantarillados Pluviales en Puerto Rico." https://jp.pr.gov/wp-content/uploads/2023/05/JP-RP-40-Reglamento-de-Planificacion-Num.-40-Sello-Estado-1.pdf.

3. Case Studies

3.1. U.S. General Services Administration Guaynabo Center

The U.S. General Services Administration (GSA) Center facilities in Guaynabo serves as a successful example of multiple types of stormwater NNBS features. The project was implemented between 2019 and 2023 and incorporated several of the NNBS features discussed in this job aid (**Figure 2-2** and **Figure 2-5**). The primary objective of incorporating NNBS features at this site was to strategically mitigate stormwater runoff, reducing its impact on the overloaded city stormwater system during intense rainfall. Beyond its immediate benefits, this project stands as an exemplary model for effectively integrating NNBS features within the constraints of an urban landscape, offering valuable insights for similar projects.

Key enhancements include engineered bioretention areas adorned with native vegetation, such as tall grasses, trees, and other low-maintenance plants. These zones serve the dual purpose of retention and natural filtration, while efficiently trapping sediments and pollutants. Porous pavement was added within low-traffic areas of the parking lot to reduce runoff and increase groundwater recharge. The grass-lined detention basin is a notable feature in the rear parking lot of the facility, offering an aesthetically pleasing experience for employees and visitors walking to and from their cars, while managing runoff and facilitating nutrient absorption by vegetation. Surrounding the building, planters contribute to stormwater treatment and infiltration while creating green spaces that elevate the site's aesthetic and bolster sustainability. By adopting these NNBS features, the

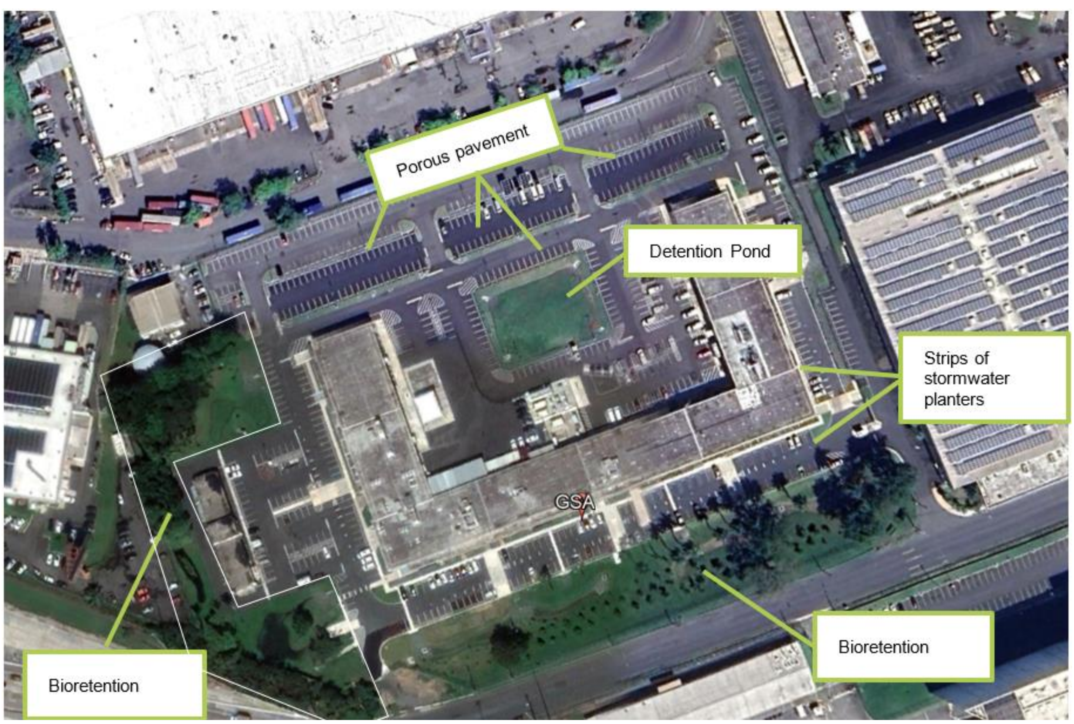

Figure 3-1. GSA federal facility NNBS aerial view

project not only addresses stormwater challenges at the site but also enhances the overall environmental quality and resilience of the GSA government facility, setting a precedent for sustainable urban development in Puerto Rico. A plan-view layout of these features is shown in Figure 3-1.

As this recently constructed project evolves, regular maintenance and monitoring are important in the short term to ensure the NNBS features perform optimally. Regular inspections will be crucial to ensure the bioretention cells, planter boxes, and other integrated elements effectively mitigate stormwater runoff. Vigilance against invasive species will be imperative, necessitating periodic assessments to identify and address any potential threats to the native species that were planted. Furthermore, proactive measures, including the inspection and cleaning of drainage inlets for the detention basin and ponding areas at the front of the facility, are essential. Preventing sediment buildup in these critical components is vital for sustaining their functionality and minimizing the risk of impeding runoff.

To enhance the impact of the project, the incorporation of educational materials, such as signage explaining the purpose and benefits of each NNBS feature, throughout the site is recommended as a future enhancement (Figure 4-2). Providing clear information can foster a deeper understanding of the project's environmental significance and encourage responsible use and appreciation of NNBS. The success of the project hinges on a proactive and adaptive approach to maintenance, ensuring the longevity and continued efficacy of the implemented NNBS features.

Figure 3-2. A recommended future enhancement for the GSA site is the incorporation of educational signage, such as the ones seen in this rain garden in City of Omaha, NE (EPA, 2023)

3.2. Conceptual Design of a Community Plaza

Community plazas hold immense significance in Puerto Rico, serving as vibrant hubs of social interaction, cultural expression, and community cohesion. Nearly all of Puerto Rico's municipalities have a plaza at the town center where neighbors can come together to celebrate, mourn, or simply connect, reinforcing the bonds that tie communities together and enriching the fabric of Puerto Rican society. As important as these spaces are to the 78 municipalities across Puerto Rico, they also present a unique opportunity to incorporate NNBS elements into a prominent space in the community that is otherwise typically fully impervious. Adding additional NNBS features within the plaza, such as permeable pavement and stormwater planters with native vegetation, would be positive steps to further increase infiltration and reduce the overall volume of runoff in the area. More importantly, given the social nature of plazas, they serve as ideal locations for educational initiatives by adding signage that effectively communicates the benefits of NNBS and serves as an example for other NNBS for the municipality. Community plazas are a great first step municipalities can take to explore NNBS for stormwater management, while increasing vegetation cover and reducing heat-island effects within densely urbanized surroundings.

Figure 4-3 shows a conceptual design of a typical Puerto Rican plaza. To increase infiltration and reduce runoff on the site, surface paving would be replaced with a combination of permeable pavement and grassy areas. One important consideration is that plazas are pedestrian-only spaces, so paved sidewalks would be needed for ease of walking through the site. Bioretention cells or planter boxes are good candidates for a plaza area and have the dual benefit of beautifying the space. In addition to the actual NNBS features, adding signage to communicate the purpose of the feature to educate the community is strongly recommended. Incorporation of trees on the outer edges of the plaza and next to benches is recommended for maintaining the open feel of the space, providing shade for pedestrians, lower ambient temperatures, and creating an aesthetic appeal for travelers along the adjacent streets.

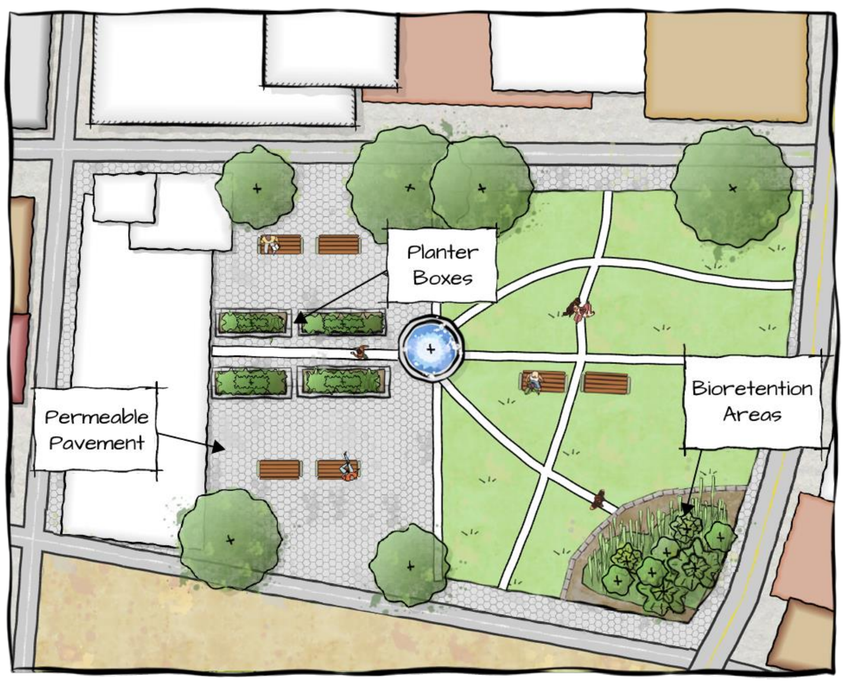

Figure 3-3. Conceptual community plaza design

4. References

Caribbean Environmental Health Institute and United Nations Environment Programme (2009). "Handbook for Rainwater Harvesting for the Caribbean." https://carpha.org/saintlucia/Rain/Rainwater%20Harvesting%20Toolbox/Media/Print/RWH_handbook.pdf .

Caribbean Environmental Health Institute and United Nations Environment Programme (n.d.). "Rainwater Harvesting in the Caribbean: Estimating Storage Requirements." https://carpha.org/saintlucia/Rain/Rainwater%20Harvesting%20Toolbox/Media/Print/Techsheet-3A_B.pdf.

City of Melbourne (2019). "Permeable Pavements Maintenance and Monitoring Outcomes." https://urbanwater.melbourne.vic.gov.au/wp-content/uploads/2021/07/Permeable-pavements-maintenance-and-monitoring-outcomes_20191219_Final-Introduction.pdf .

Climate Change Council Puerto Rico (2022). "Puerto Rico State of the Climate 2014-2021." https://www.drna.pr.gov/wp-content/uploads/2022/10/PR_StateOfTheClimate_2014-2021_PRCCC-09-2022.pdf.

Environmental Protection Agency (2021). "Bioretention Design Handbook: Designing Holistic Bioretention for Performance and Longevity." https://www.epa.gov/system/files/documents/2023-11/bioretentiondesignhandbook_plainnov2023.pdf.

Environmental Protection Agency (2021). "Stormwater Best Management Practice, Bioretention (Rain Gardens)." https://www.epa.gov/system/files/documents/2021-11/bmp-bioretention-rain-gardens.pdf.

Environmental Protection Agency (2021). "Stormwater Best Management Practice: Permeable Pavements." https://www.epa.gov/system/files/documents/2021-11/bmp-permeable-pavements.pdf.

Environmental Protection Agency (2022). "US Virgin Islands Environmental Protection Handbook." https://dpnr.vi.gov/wp-content/uploads/2023/08/2022-VI-Environmental-Protection-Handbook_Full.pdf.

FEMA (2021). "Building Community Resilience with Nature-Based Solutions." https://www.fema.gov/sites/default/files/documents/fema_riskmap-nature-based-solutions-guide_2021.pdf.

Junta de Planificación (2023). "Reglamento para el Diseño, Criterios de Operación y Mantenimiento de Sistemas de Alcantarillados Pluviales en Puerto Rico." https://jp.pr.gov/wp-content/uploads/2023/05/JP-RP-40-Reglamento-de-Planificacion-Num.-40-Sello-Estado-1.pdf.

López, M. A. Lugo, J. Juárez, and J. A. Bonnet (1968). "Relative Infiltration Rate of Puerto Rican Soils." The Journal of Agriculture of the University of Puerto Rico. https://doi.org/10.46429/jaupr.v52i3.11510.

Martinuzzi, Sebastián, William A. Gould, and Olga M. Ramos González. (2007). "Land Development, Land Use, and Urban Sprawl in Puerto Rico Integrating Remote Sensing and Population Census Data." https://doi.org/10.1016/j.landurbplan.2006.02.014.

Metro Puerto Rico (2021). "Llevarán e Instalarán Cisternas En Comunidades de Canóvanas." https://www.metro.pr/pr/noticias/2021/11/01/llevaran-e-instalaran-cisternas-en-comunidades-de-canovanas.html.

Minnesota Pollution Control Agency (2024). "Construction Specifications for Bioretention - Minnesota Stormwater Manual." https://stormwater.pca.state.mn.us/index.php/Construction_specifications_for_bioretention

Minnesota Pollution Control Agency (2024). "Design Criteria for Permeable Pavement - Minnesota Stormwater Manual." https://stormwater.pca.state.mn.us/index.php/Design_criteria_for_permeable_pavement.

Municipio Carolina (n.d.). "Alcalde Aponte Inspecciona Proyectos de Instalación de Cisternas." https://www.municipiocarolina.com/alcalde-aponte-inspecciona-proyectos-de-instalacion-de-cisternas/.

Oklahoma State University (2017). "Bioretention Cell Design Guidance for Oklahoma." https://extension.okstate.edu/fact-sheets/print-publications/bae/bioretention-cell-design-guidance-for-oklahoma-bae-1536.pdf.

Plenitud PR. (2023). "Water Security in Puerto Rico." https://www.plenitudpr.org/watersecurity.

Preston, B.L, et. al. (2020). Beyond Recovery: Transforming Puerto Rico's Water Sector in the Wake of Hurricanes Irma and Maria. Homeland Security Operational Analysis Center operated by the RAND Corporation. https://www.rand.org/pubs/research_reports/RR2608.html.

Program, U. S. Global Change Research (2023). "Fifth National Climate Assessment US Caribbean." https://nca2023.globalchange.gov/chapter/23/.

Ridge to Reefs (2024). "Hurricane & Earthquake Relief- Resilience Development for Puerto Rico." https://www.ridgetoreefs.org/relief-for-puerto-rico.

Sustainable Technologies Evaluation Program (2012). "Low Impact Planning and Design Fact Sheet-Permeable Pavement." https://wiki.sustainabletechnologies.ca/images/7/7e/Permeable_Pavement_Factsheet.pdf.

Tennessee Stormwater Management (n.d.). "Tennessee Permanent Stormwater Management and Design Guidance Manual- Chapter 5.48 Permeable Pavement." https://tnpermanentstormwater.org/manual/17%20Chapter%205.4.8%20Permeable%20Pavement.pdf#:~:text=In%20addition%2C%20permeable%20pavement%20should%20never%20be,infiltration%20rate%20of%200.5%20inches%20per%20hour.

Terrasa-Soler, J.J. (2016). "Recommended Species for Rain Gardens, Bioswales, and Bioretention Cells in Puerto Rico and the Caribbean Islands." https://jterrasa.wordpress.com/wp-content/uploads/2016/02/recommended-species-for-rain-gardens-bioswales-bioretention-cells-in-puerto-rico-and-caribbean-islands_jose-j-terrasa-soler_2016.pdf.

Texas Water Development Board (2005)."The Texas Manual on Rainwater Harvesting." https://www.twdb.texas.gov/publications/brochures/conservation/doc/RainwaterHarvestingManual_3rdedition.pdf.

University of Puerto Rico. (2018). "Taxonomic Classification of Soils in Puerto Rico, 2017." https://www.uprm.edu/tamuk/wp-content/uploads/sites/299/2019/06/Taxonomic_classification_soils_PR_2018_reduced.pdf.

US Department of Commerce, NOAA. (2024). "PR and USVI Normals." National Weather Service. NOAA's National Weather Service. https://www.weather.gov/sju/climo_pr_usvi_normals.

5. Resources

Delta Institute, Environmental Consulting & Technology, Inc. (2021). A Design Guide for Green Stormwater Infrastructure Best Management Practices. https://www.risc.solutions/wp-content/uploads/2021/08/Design-Guide-for-Green-Infrastructure-BMPs-RISC-Report-August-2021.pdf.

DRNA, USFS, NRCS, USFWS & Envirosurvey, Inc. (2022). Guía de árboles nativos para prácticas de conservación en Puerto Rico e Islas Vírgenes. https://guiadearboles.org/.

Environmental Protection Agency (2021). Stormwater Best Management Practice Infiltration Trench. https://www.epa.gov/system/files/documents/2021-11/bmp-infiltration-trench.pdf.

FEMA (2021). Building Communities Resilience with Nature Based Solutions – A Guide for Local Communities: https://www.fema.gov/sites/default/files/documents/fema_riskmap-nature-based-solutions-guide_2021.pdf.

FEMA (2023). Building Community Resilience with Nature-based Solutions – Strategies for Success: https://www.fema.gov/sites/default/files/documents/fema_nature-based-solutions-guide-2-strategies-success_2023.pdf.

Metropolitan Area Planning Council (2018). Designing Parks and Playgrounds as Green Infrastructure for Stormwater and Climate Resilience. https://www.mapc.org/wp-content/uploads/2018/07/FINAL.Designing-Parks-and-Playgrounds-as-Green-Infrastructure.Chelsea.6.29.18.pdf.

Para La Naturaleza. (n.d.). Guía digital de árboles nativos de Puerto Rico/Guidebook to native trees of Puerto Rico. https://www.paralanaturaleza.org/para-la-naturaleza-presenta-nueva-guia-digital-de-arboles-nativos-de-puerto-rico/.

Penkova, I.F.G., Zimmerman, J.K., González, G. (2020). Green roofs in the tropics: design considerations and vegetation dynamics. https://doi.org/10.1016/j.heliyon.2020.e04712.

Universidad de Puerto Rico – Servicio de Extensión Agrícola (2018). Manual de forestación urbana para Puerto Rico y las Islas Vírgenes Americanas. /Guidebook for urban forestation in Puerto Rico and the US Virgin Islands. https://www.uprm.edu/sea/manual-de-forestacion-urbana-de-puerto-rico/.