Built Environments
17. Urban Stormwater and Runoff Management

DEFINITION

Urban areas have large areas of impervious surfaces, which cause water to run off during storms (rather than retaining water or allowing it to infiltrate into the ground). This creates issues with stormwater flooding and, in cities with combined sewer systems, can also lead to sewer overflows following rainfall. Nature-based solutions (NBS) strategies for urban stormwater and runoff management such as rain gardens, stormwater parks, permeable pavement, and bioswales are intended to reduce these issues by promoting water retention, infiltration, and evapotranspiration instead of runoff (Palermo et al. 2023).

TECHNICAL APPROACH

Technical specifics vary for different types of urban stormwater NBS, but the general approach is similar and can be summarized in the following steps:

1. **Identify the most critical stormwater issues within the area of interest and select appropriate locations and techniques to address them (FEMA 2021):** The Minnesota Stormwater Manual includes additional broadly relevant guidance on selecting NBS stormwater techniques (Minnesota Pollution Control Agency 2023a).

2. **Design the system components:**

    - **Rain gardens, bioswales, tree trenches, and stormwater parks:** This includes the dimensions and depth of the basin or ditch, structure and location of inflows and outflows, soil or other media, and vegetation selection (Scott et al. 2013). Stormwater parks often include built wetlands; see the built wetlands summary for more information on the design of those components.

    - **Permeable pavement:** This includes whether an underdrain is needed (depending on soil infiltration rates), slope and overflow structures to prevent flooding in severe storms, and pavement type (based on anticipated traffic load and environmental factors such as freezing temperatures; options include permeable pavers, pervious concrete, and porous asphalt) (Minnesota Pollution Control Agency 2022).

    - **Rainwater harvesting:** This includes the size of the storage tank (based on roof size and local precipitation rates) and its location, a gutter system to direct water from the roof into the storage tank, and a treatment system to achieve standards required for the intended use of the harvested water (Hunt 2021).

Table 17.1 NBS stormwater techniques and considerations

Technique	Description	Location Considerations
Rain garden	Vegetated depression that collects rainwater (from streets, driveways, roofs, etc.) and promotes infiltration (EPA 2023; Figure 1)	Must be able to direct runoff to rain garden location
Bioswale	Vegetated ditch similar to a rain garden but designed to capture larger volumes of runoff from impervious surfaces like parking lots and streets (Scott et al. 2013; Figure 2)	Often installed along streets/ sidewalks
Tree trenches	Trench with trees planted in depressions to collect stormwater runoff for uptake by trees (Minnesota Pollution Control Agency 2023b)	Often installed along streets/ sidewalks
Stormwater park	Recreational areas designed to flood during storms to reduce downstream peak flows; often include built wetlands (Puget Sound Regional Council 2022; Figure 3)	Requires larger area and inflow of stormwater (usually from conveyance infrastructure)
Permeable pavement	Alternative pavement materials that allow water to infiltrate rather than running off (Minnesota Pollution Control Agency 2022; Figure 4)	Easiest to install during new construction or renovation that requires replacing existing pavement
Rainwater harvesting	System to collect rainwater from roofs in a storage tank for later use (for irrigation, ponds/fountains, toilet flushing, etc.) (FEMP n.d.)	Site should have one or more uses for the collected water

Figure 17.1 Rain garden at Arlington National Cemetery

Photo courtesy Arlington National Cemetery

Figure 17.2 Bioswale at Arlington National Cemetery

Photo courtesy Arlington National Cemetery

Figure 17.3 Stormwater park in Milwaukee, WI

Photo courtesy Aaron Volkening

Figure 17.4 Permeable pavement in a Mississippi high school parking lot

Note: There is also a tree trench in the background.
Photo courtesy Mississippi Watershed Management Organization

3. **Install the system according to the design:**
   - **Rain gardens, bioswales, and tree trenches:** The general process is to (1) install temporary erosion and sediment controls and divert water from the site until the project is complete; (2) excavate the site to the appropriate depth and dimensions, including inlet and outlet locations and elevations; (3) install underdrain if required; (4) add soil or other media to fill the excavated area to the desired elevation; (5) plant vegetation and add surface cover (e.g., mulch, stone, grass); and (6) remove erosion and sediment controls and allow water flow into the project site (Scott et al. 2013).
   - **Permeable pavement:** The general process is to (1) install temporary erosion and sediment controls; (2) excavate the site, till, and grade the soil; (3) install underdrain (sloping toward outlet) if needed; (4) spread 4 to 6 in. of base stone; and (5) install paving material according to manufacturer specifications (Minnesota Pollution Control Agency 2022). Care is needed to not to over-compact porous asphalt or pervious concrete to avoid reducing infiltration capacity.
   - **Rainwater harvesting:** The general process is to (1) install the storage tank (tanks can be installed underground or aboveground), (2) install a filtration and treatment system, and (3) direct rainwater into the tank by modifying the existing gutter system or adding new gutters (Hunt 2021).

4. **Monitor vegetated systems:** It is important to regularly monitor the site as the vegetation becomes established and water plants (if conditions require), remove and replace dead plants, remove sediment accumulation, and repair erosion issues (Scott et al. 2013). Once vegetation cover is adequate, these tasks will need to be performed less regularly (see operations and maintenance section).

OPERATIONS AND MAINTENANCE

Rain gardens, bioswales, tree trenches, stormwater parks: Inspect at least twice during the growing season. Based on inspection, common maintenance includes mowing grass cover (if present), removing debris and sediment from inlets, weeding and removing invasive plants, and addressing any erosion issues (Scott et al. 2013).

Permeable pavement: Avoid surface clogging by vacuuming at least twice annually (more frequently if there is high sediment deposition), maintaining surrounding landscaping to reduce soil erosion onto the pavement, and minimizing use of sand for winter traction (Minnesota Pollution Control Agency 2022).

Rainwater harvesting: Clear debris and clean filter as needed, remove sediment from tank annually, ensure mechanical components (pump, treatment system, etc.) are functioning properly (FEMP n.d.). If water is used for drinking (rare), regular water testing is required.

FACTORS INFLUENCING SITE SUITABILITY

Rain Gardens, Bioswales, Tree Trenches, Stormwater Parks

- ✓ **Low tree cover:** Communities with limited canopy cover can use these strategies with planted trees to enhance tree cover as well as address stormwater issues.
- ✓ **Older communities with extensive existing development:** Tree trenches, bioswales, and rain gardens have relatively small footprints and are easier to add to existing developed areas.
- ✓ **Public view or access:** These strategies are aesthetically pleasing and larger sites, particularly stormwater parks, can provide recreational opportunities if there is public access.
- ✗ **Steep slope:** Rain gardens need to be installed in areas with low slopes so the bottom of the garden is flat.

Permeable Pavement

- ✓ **Highly urbanized areas:** Permeable pavement reduces the need for separate water retention facilities in urban areas where space is at a premium (Minnesota Pollution Control Agency 2022).
- ✓ **Low traffic:** Areas with pedestrian access or low-volume, low-speed roads and parking lots are suitable for permeable pavement (Minnesota Pollution Control Agency 2022).

- ✗ **Shallow water table:** Shallow depth to groundwater prevents permeable pavement from draining completely. Vertical separation of at least 1 ft is recommended for permeable pavement with an impermeable liner at the bottom, and at least 3 ft for permeable pavement without a liner (Minnesota Pollution Control Agency 2022).
- ✗ **High pollutant loading:** Areas that receive high volumes of debris, sediment, chemicals, or fuels are not good candidates for permeable pavement because of the potential for clogging or water contamination (Minnesota Pollution Control Agency 2022).

Rainwater Harvesting

- ✓ **Adequate rainfall:** The site should receive enough precipitation to supply water for its intended use (FEMP n.d.).
- ✓ **Large, shallow roofs:** These capture more rainfall than smaller or steeper roofs (FEMP, n.d.).

TOOLS, TRAINING, AND RESOURCES FOR PLANNING AND IMPLEMENTATION

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Bioretention Illustrated: A Visual Guide for Constructing, Inspecting, Maintaining and Verifying the Bioretention Practice	Guidebook	2013	Chesapeake Stormwater Network	Written for the Chesapeake Bay Watershed but much of the information is broadly relevant	Introduction to principles of bioretention systems (rain gardens, bioswales) and overview of design and construction. Focuses on visual indicators to assess performance and maintenance needs. Also includes visual indicators for other urban stormwater management practices, including permeable pavement and filter strips.	✓	—	✓	—
EPA System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN)	Software	2014	US Environmental Protection Agency (EPA)	National	Decision support tool to select optimal stormwater practices. No longer being updated by EPA, but still in use.	✓	✓	—	—

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Minnesota Stormwater Manual	Website	2023 (continually updated)	Minnesota Pollution Control Agency	Written for Minnesota but much of the information is broadly relevant	Details on stormwater control practices, including many NBS. Includes design and construction guidelines, operations and maintenance information, assessing project performance, and case studies.	✓	✓	✓	✓
Planning Stormwater Parks	Guidebook	2022	Puget Sound Regional Council	Written for Puget Sound but much of the information is broadly relevant	Guidance for stormwater park planning and design, including information on engaging with communities, working with consultants, and post-construction operations	✓	✓	✓	✓
Rainwater Harvesting Tool	Online tool	Not provided	Federal Energy Management Program	National	Spatial information on the potential for rainfall harvest (in general and for irrigation) based on annual precipitation patterns	—	✓	—	—
Rain Gardens for RainScapes Technical Design Manual	Guidebook	2015	Department of Environmental Protection RainScapes Program, Montgomery County, MD	Written for Maryland but generally applicable for rain garden design (suitable plant species will vary by region)	Guide to designing and constructing a rain garden, including maintenance and trouble-shooting	✓	✓	—	—

GRAY INFRASTRUCTURE ALTERNATIVES

Urban stormwater and runoff management can be an alternative to gray stormwater infrastructure. The ability of an NBS urban stormwater project to replace or supplement gray infrastructure depends strongly on the project's location and whether it is designed to create the necessary outcomes. Certain environmental conditions may require gray infrastructure rather than NBS stormwater approaches. See the gray infrastructure alternative tables in the cross-cutting material for a comparison of NBS to gray stormwater infrastructure.

LIKELY BENEFITS AND OUTCOMES

Primary objectives for each strategy are highlighted.

Climate Threat Reduction

- **Reduced flooding:** These NBS techniques are designed to address localized urban flooding by promoting water retention and infiltration, thereby reducing peak discharge (Copeland 2016). However, there is high variability in stormwater retention performance between and within techniques; more data is needed to improve the certainty of this outcome (Kõiv-Vainik et al. 2022).
- **Heat mitigation (all except rainwater harvesting and permeable pavement):** All vegetated urban stormwater techniques can help to reduce urban heat island effects through shading and evapotranspiration (Laurenz 2019, Sagrelius et al. 2022).
- **Carbon storage and sequestration (all except rainwater harvesting and permeable pavement):** All vegetated urban stormwater techniques promote carbon storage and sequestration by plants and trees (Copeland 2016).
- **Drought mitigation:** When sized and used properly, rainwater harvesting allows for on-site reuse of water, reducing pressure on the water supply system during droughts (Jones and Hunt 2010). Other urban stormwater NBS techniques promote infiltration that can help to recharge groundwater supplies during droughts (Li et al. 2009; Weerasundara et al. 2016).

Social and Economic

- **Recreational opportunities (stormwater parks only):** Stormwater parks can provide a variety of recreational opportunities, depending on their design, including hiking or walking trails, playgrounds, athletic fields and courts, picnic areas, and community gardens (Puget Sound Regional Council 2022).
- **Reduced erosion:** Slowing runoff flow reduces channel erosion (Li et al. 2009; Vijayaraghavan et al. 2021).
- **Increased property values (all except rainwater harvesting and permeable pavement):** Studies have found increases in residential property values when trees and other vegetation are present, and when properties have views of or access to recreational sites such as stormwater parks (Foster et al. 2011; Lee and Li 2009).

- **Aesthetics (all except rainwater harvesting and permeable pavement):** Rain gardens, bioswales, and stormwater parks are more aesthetically pleasing than gray stormwater infrastructure and can improve the aesthetics of streets, sidewalks, and parking lots (Foster et al. 2011; Weerasundara et al. 2016).
- **Aquifer recharge (all except rainwater harvesting):** Promoting infiltration recharges underlying aquifers (Li et al. 2009; Weerasundara et al. 2016).
- **Reduced energy use (rainwater harvesting only):** Harvesting and reusing water on-site reduces energy used to treat and transport water from local utilities (Copeland 2016).

Ecological

- **Improved water quality (all except rainwater harvesting):** Slowing runoff and promoting infiltration traps sediment and other nutrients, improving the quality of water reaching streams and other water bodies (DeBusk and Wynn 2011; Vijayaraghavan et al. 2021).
- **Reduced runoff:** All of the urban stormwater and runoff management techniques collect, retain, or promote infiltration of precipitation (Li et al. 2009; Weerasundara et al. 2016).
- **Supports wildlife (all except rainwater harvesting and permeable pavement):** Rain gardens, bioswales, and stormwater parks create habitat for native wildlife species (Weerasundara et al. 2016).
- **Supports native plants (all except rainwater harvesting and permeable pavement):** It is recommended to plant rain gardens, bioswales, and stormwater parks with native plants adapted to local conditions (Weerasundara et al. 2016).

BARRIERS AND SOLUTIONS FOR PRACTITIONERS

Several barriers are common across many of the NBS strategies; these are described in more detail in Section 1 of the Roadmap. Additional notes about the barriers specific to urban stormwater and runoff management are included here.

- **Expense**
- **Capacity**
- **Public opinion**
- **Conflict with other land uses**
- **Regulation:** Especially local ordinances, building codes, plumbing and health regulations, street width and parking requirements, and restrictions on using reclaimed water (Copeland 2016).
- **Lack of effectiveness data:** In particular, gaps in data on performance in different climates and function over time (Copeland 2016; Weerasundara et al. 2016; Vijayaraghavan et al. 2021).

Economic

- **Financing:** It can be difficult to acquire financing for these types of projects, which can have longer payback times than similar gray infrastructure approaches (Copeland 2016).

Community

- **Displacement:** NBS urban stormwater projects can contribute to gentrification via increased housing costs, resulting in displacement of lower-income community members and exacerbating inequality (Taguchi et al. 2020; Walker 2021). Planning for community protection alongside stormwater projects—for example, by supporting cooperative housing, rent control, or participatory budgeting—can help avoid these unintended consequences (Walker 2021).

EXAMPLE PROJECTS

Name and Link	Location	Leading Organizations	Techniques Used	Size	Cost, $	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
Robbins Stormwater Park and Midlothian Creek Restoration Project	Chicago, IL	Metropolitan Water Reclamation District of Greater Chicago	Diversion channel to stormwater pond, streambank stabilization, stormwater park with naturalized wetland area, rain garden, bioswales	52 acres	20 million	Planned for two years (in progress)	Stormwater park and other project components are designed to reduce overbank flooding from Midlothian Creek and protect property and infrastructure in Robbins, IL.	Flooding	No (project is in progress)
Arlington Stormwater Wetland Park	Arlington, WA	City of Arlington	Stormwater park, including constructed wetlands	21 acres	1.325 million	Not available	Stormwater park with trails, picnic area, dog park, and wildlife viewing as well as a constructed wetland for stormwater, reclaimed water, and clean effluent from water treatment plant	Flooding	Helpful to have staff from multiple city departments involved (stormwater, natural resources, planning, parks). Early public outreach leads to greater acceptance. Maintenance is a good opportunity for students and community volunteers.

Name and Link	Location	Leading Organizations	Techniques Used	Size	Cost, $	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
Plum and Walnut St. Green Intersection	Lancaster, PA	City of Lancaster	Tree trenches, curb extension planter for rain garden, permeable pavement, rainwater harvesting	Not available	115,000 (estimated)	Not available	Green stormwater component were added as part of a roadway realignment project to improve traffic safety, enhance pedestrian amenities, and reduce stormwater runoff	Flooding	High road salt levels required transition to Mid-Atlantic coastal grasses
Silver Lake Beach Parking Lot	Wilmington, MA	Town of Wilmington	Permeable pavement, rain gardens, bioswales	Approximately 25,000 ft^2 of permeable pavement	448,000 (includes design, construction, and three years of maintenance	Approximately 8 months	Stormwater management at a popular parking area for recreational use of Silver Lake was designed to reduce stormwater runoff to the lake to improve water quality	No	No adverse effect on groundwater underneath permeable pavement. Fewer closures of swimming beach due to bacterial contamination following project.

Bolding indicates DOI affiliates.

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