MISSISSIPPI DEPARTMENT OF ENVIRONMENTAL QUALITY

Managing Stormwater for Healthy Watersheds in Coastal Mississippi: **Best Practices**

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The Mississippi Department of Environmental Quality has developed this document to support watershed planning efforts for coastal environments in Mississippi by providing guidance on recommended stormwater management practices. This guidance was developed in compliance with Section 6217(g) of the Coastal Zone Act Reauthorization Amendments of 1990.

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Acronyms/Abbreviations

BMP	best management practice
CWA	Clean Water Act
CWP	Center for Watershed Protection
CZARA	Coastal Zone Act Reauthorization Amendments
EPA	U.S. Environmental Protection Agency
ESC	erosion and sediment control
ft	foot, feet
GI	green infrastructure
in/hr	inch per hour
IWS	internal water storage
LCGP	Large Construction General Permit
LID	low impact development
LOD	limit of disturbance
MDEQ	Mississippi Department of Environmental Quality
MS4	municipal separate storm sewer system
NRCS	National Resources Conservation Service
NPDES	National Pollutant Discharge Elimination System
NPS	nonpoint source
NRCS	Natural Resources Conservation Service
PVC	polyvinyl chloride
ROW	right-of-way
SCGP	Small Construction General Permit
SWPPP	Stormwater Pollution Prevention Plan
TSS	total suspended solids
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

Glossary

Aquifer: An underground area that contains fresh water in sufficient amounts to yield useful quantities to wells and springs.

Berm: An earthen mound used to direct the flow of runoff around or through a structure.

Best Management Practices (BMPs): Activities or structural improvements that help reduce the quantity and improve the quality of stormwater runoff. BMPs include treatment requirements, operating procedures, and practices to control site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

Bioretention: A water quality practice using landscaping and soils to treat urban stormwater runoff by collecting it in shallow depressions, subsequently filtering it through a engineered soil and ultimately through an underdrain.

Buffer Strip or Zone: Strips of trees, grass or other erosion resistant vegetation located between a waterway and an area of more intensive land use.

Bypass: The intentional diversion of water, either preventing it from entering the BMP or directing it to the BMP.

Discharge: The volume of water that passes a point within a given period of time, typically measured in units such as cubic feet per second (cfs), cubic meters per second (cms), or million gallons per day (mgd).

Ecosystem: A biological community of interacting organisms and its environment.

Erosion: When land is diminished or worn away due to wind, water or glacial ice. Often the eroded debris (silt or sediment) becomes a pollutant via stormwater runoff. Erosion occurs naturally, but can be intensified by land clearing activities such as farming, development, road building, and timber harvesting.

Evaporation: The movement of water from its liquid form on the Earth's surface to its gaseous form in the atmosphere.

Evapotranspiration: The sum of evaporation and transpiration.

Filter Fabric: A textile of relatively small mesh that allows water to pass through, while retaining sediment (permeable) or water and sediment (impermeable).

Flood Control: The specific regulations and practices that serve to manage stormwater runoff such that damage to property, infrastructure, or land is reduced or prevented.

Flood: A temporary rise in flow or stage of any watercourse or stormwater conveyance system that results in stormwater runoff exceeding its normal flow boundaries and inundating adjacent, normally dry areas.

Floodplain: Any land area susceptible to inundation by stormwater from any source.

Forest Buffers: Strips of forest located between a waterway and an area of more intensive land use.

General Permit: A permit issued under the NPDES program to cover a certain class or category of stormwater discharges. These permits reduce the administrative burden of permitting stormwater discharges.

Grading: The cutting and/or filling of the land surface to a desired slope or elevation.

Groundwater: Water beneath the surface of the Earth (subterranean) in aquifers that can be collected with wells, tunnels, or drainage galleries, or that flow naturally to the Earth's surface via seeps or springs.

Hydrologic Modification: The alteration of the natural circulation, flowpaths, or distribution of water by the alteration of soil slopes, placement of structures, or other activities.

Impervious Cover: Surfaces that do not absorb rainfall, immediately turning it into sheet flow runoff. Traditional asphalt surfaces, concrete surfaces, and buildings are examples of impervious cover.

Infiltration: The penetration of water from the ground surface into sub-surface soil or into sewer or other pipes through defective joints, connections, or manhole wells.

Inlet: An entrance into a ditch, storm sewer, BMP, or other waterway.

Large Construction: Clearing, grading, and excavating resulting in a land disturbance altering more than five (5) acres of land or less than five (5) acres of total land area but is part of a larger common plan of development or sale that will ultimately disturb greater than or equal to five (5) acres. Large construction activity is covered by the Large Construction General Permit.

Large Municipal Separate Storm Sewer System (MS4): A storm sewer system located in an area serving a population of 250,000 or more, as determined by the latest U.S. Census. Comprising multiple conveyance systems, including ditches, that transfer stormwater from impervious surfaces to streams.

Medium Municipal Separate Storm Sewer System (MS4): A storm sewer system located in an area serving a population 100,000 or more but less than 250,000, as determined by the latest U.S. Census. Comprising multiple conveyance systems, including ditches, that transfers stormwater from impervious surfaces to streams.

Mitigate: to lessen or make less severe

National Pollutant Discharge Elimination System (NPDES): The surface water quality program authorized by Congress as part of the 1987 Clean Water Act. This is EPA's program to control the discharge of pollutants to waters of the United States.

Non-Point Source (NPS) Pollutants: Pollutants from diffuse sources. Rainfall or snowmelt moving over and through the ground causes NPS pollution. As the runoff moves, it picks up and transports natural and human-made pollutants, ultimately depositing them in lakes, rivers, wetlands, coastal waters, and even groundwater aquifers (sources of drinking water).

On-site Disposal System (OSDS): a sewage treatment and effluent disposal system that does not discharge into waters of the state, that serves only one (1) legal tract and that accepts only human sanitary waste and similar waste streams maintained on the property of the generator.

Permeability: The characteristic of soil that allows water or air to move through it. Usually described in inches per hour or inches per day.

Point Source Pollutant: Pollutants from a single, identifiable source such as discharges from a factory, refinery, or other place of business, and often through a pipe.

Recharge: Re-supplying of water to an aquifer. Recharge water generally comes from snowmelt and stormwater runoff.

Residual: The amount of pollutant that remains in the environment after a natural or technological process has taken place, such as particulates remaining in air after passing through a scrubber.

Resiliency: The ability of a system to respond to, or recover readily from, stresses or disruptive forces.

Riparian: Of, or pertaining to, land areas adjacent to or closely surrounding aquatic systems, such as rivers, streams, lakes, wetlands, and estuaries; for example, streambanks, lakeshores, and shorelines.

Runoff: Drainage or flood discharge that leaves an area as surface or pipeline flow, ultimately reaching a channel, surface waterbody, or pipeline by either surface or sub-surface routes.

Sedimentation: The settling process of soil, clay, sand, or other particles initially moved by the flow of water.

Small Construction: includes clearing, grading, and excavating resulting in a land disturbance altering between one (1) and five (5) acres of land or less than one (1) acre of total land area but is part of a larger common plan of development or sale that will ultimately alter between one (1) and five (5) acres. Small construction activity does not include routine maintenance that is performed to maintain the original line and grade, hydraulic capacity, or original purpose of the facility.

Small Municipal Separate Storm Sewer System (MS4): A storm sewer system located in an area serving a population less than 100,000, as determined by the latest U.S. Census. Comprising multiple conveyance systems, including ditches, that transfers stormwater from impervious surfaces to streams.

Storm Drain: A slotted opening leading to an underground pipe or an open ditch carrying surface runoff. These lead directly to streams and do not go through a treatment or processing plant.

Stormwater: Precipitation from a storm event that flows quickly into streams or accumulates in natural or constructed storage systems. Depending on characteristics of the surface area on which it falls, stormwater often includes pollutants and sediment mobilized and transported from land surfaces.

Stormwater Management: Functions associated with planning, designing, constructing, maintaining, financing, and regulating the facilities (both constructed and natural) that collect, store, control and/or convey stormwater.

Stormwater Management Plan: A plan that is designed to manage stormwater flows and reduce contamination of receiving waters by collecting, storing, controlling, and conveying runoff.

Stormwater Pollution Prevention Plan (SWPPP): a plan that includes site map(s), an identification of construction/contractor activities that could cause pollutants in the stormwater, and a description of measures or practices to control these pollutants.

Stormwater System: The entire assemblage of stormwater facilities located within a watershed.

Surface Water: Water that remains on the surface of the ground, including rivers, lakes, reservoirs, streams, wetlands, impoundments, seas, estuaries, etc., in contrast to groundwater.

Sustainability: The support of long-term ecological integrity; the capacity of humans to survive and reproduce over long periods of time while at the same time assuring maintenance of biological, physical, hydrologic, and chemical integrity of their surroundings.

Total Maximum Daily Load (TMDL): a tool for establishing the allowable loadings of a given pollutant in a surface water resource to meet predetermined water quality standards.

Total Suspended Solids (TSS): A measure of the filterable solids present in a sample.

Transpiration: The movement of water to the atmosphere through plants.

Understory: The vegetation under the forest canopy

Urban Runoff: Stormwater from urban areas, which tends to contain heavy concentrations of pollutants from vehicles and industry.

Water Quality Standard (WQS): A law or regulation that consists of the beneficial use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.

Watercourse: A lake, stream, creek, channel, stormwater conveyance system, or other topographic feature, over which stormwaters flow at least periodically.

Waters of the State: All waters within the jurisdiction of the state of Mississippi, including all streams, lakes, ponds, wetlands, impounding reservoirs, marshes, watercourses, waterways, wells, springs, irrigation systems, drainage systems, and all other bodies or accumulations of water, surface and underground, natural or artificial, situated wholly or partly within or bordering upon the State, and such coastal waters as are within the jurisdiction of the State, except lakes, ponds, or other surface waters which are wholly landlocked and privately owned, and which are not regulated under the Federal Clean Water Act (33 U.S.C.1251 et seq.). [11 Miss. Admin. Code Pt. 6, R. 1]

Waters of the United States (WOTUS): All waters that are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters subject to the ebb and flow of the tide. WOTUS include all interstate waters and intrastate lakes, rivers, streams (including intermittent streams), mudflats, sand flats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds. [See 40 CFR 122.2 for the complete definition.]

Watershed: That geographical area which drains to a specified point on a water course, usually a confluence of streams or rivers (also known as drainage area, catchment or river basin).

Wetlands: Land with a wet, spongy soil, where the water table is at or above the land surface for at least part of the year. Wetlands are characterized by a prevalence of vegetation that is adapted for life in saturated soil conditions. Examples include swamps, bogs, fens; wetlands can be upland, lowland, and tidally-influence marshes.

1. Introduction

Protecting and conserving the quality of Mississippi's water resources is critical to ensuring a healthy environment and a thriving, productive economy. As is common to coastal watersheds nationwide, there are constant challenges to sustaining the quality of surface water and groundwater resources that support a variety of uses, such as drinking water supplies, commercial and recreation fishing, and swimming. Mississippi is fortunate to have an abundance of water resources, but the demands of communities and urban development are evolving and increasing. As landscapes are developed and populations grow, work must be done to mitigate the impact of these changes on the environment.

Stormwater runoff from urban areas can be a significant contributor of pollution in developed and developing watersheds. The purpose of this guidance manual is to provide information to communities in coastal Mississippi on protecting water quality by managing stormwater runoff from new and existing development. This document provides information for public officials, local program staff, developers, and engineers in counties and communities in coastal and near-coastal watersheds, particularly in areas not regulated by the National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit program. Use of this guidance manual does not replace regulatory requirements. Section 404 of the Clean Water Act (CWA) and other federal, state, and local regulatory requirements still apply.

Watershed: A geographical area that drains to a specified point on a water course, usually a confluence of streams or rivers. Also known as drainage area, catchment, or river basin.

This guidance focuses on coastal and near-coastal watersheds located in southern Mississippi (**Figure 1-1**). These watersheds compose the majority of the lands in Hancock, Harrison, Jackson, George, Marion, and Pearl River counties as well as smaller portions of Lamar, Stone, and Walthall counties (**Figure 1-2**). Hancock, Harrison, Jackson, and Lamar counties are subject to NPDES permits under the MS4 program and, therefore, have plans that have been developed specifically to address stormwater planning and mitigation needs. These counties have the largest populations and the most significant impacts from development occurring on the land (MDMR and MDEQ 2020). For counties not currently covered by requirements under the MS4 permit program, the recommendations from this guidance document along with county and/or local requirements and/or ordinances should be used to address the environmental impacts associated with development.

Figure 1-1. Saint Martin Bayou. (Photo: James Starnes, MDEQ)

Communities can use sections of the guidance manual or the entire manual as a guide to managing stormwater for new developments, including residential, commercial, and office developments as well as for redevelopment projects that add impervious cover. Impervious cover is any man-made surface that inhibits the ability of rainwater to be absorbed naturally into the ground, thereby increasing surface runoff. Emphasis is placed on sustainable and resilient development design approaches that reduce the environmental impact while retaining and enhancing the overall purpose of the development. The guidance also includes information related to protecting water quality during construction and identifying stormwater performance objectives, design approaches for new development, and how to incorporate sustainable and resilient designs into areas that are already developed.

1.1. Surface Water Quality

Mississippi has approximately 758 square miles of estuaries with around 84 miles of coastline (**Figure 1-3**). Some of the larger estuaries include St. Louis Bay, Back Bay of Biloxi, Pascagoula Bay, and Mississippi Sound with the state boundary extending three miles south of the Barrier Islands into the Gulf of Mexico (MDEQ 2020). Water quality along Mississippi's coastline and in tidal streams, bays, and estuaries is directly influenced by the quality and volume of fresh water draining from upland areas. Fresh water flowing into the coastal and marine ecosystems is provided by streams, rivers, groundwater, and stormwater runoff. Therefore, to ensure good water quality along Mississippi's beaches and in estuaries, it is critical to protect the integrity and health of water resources in the upper parts of the watershed.

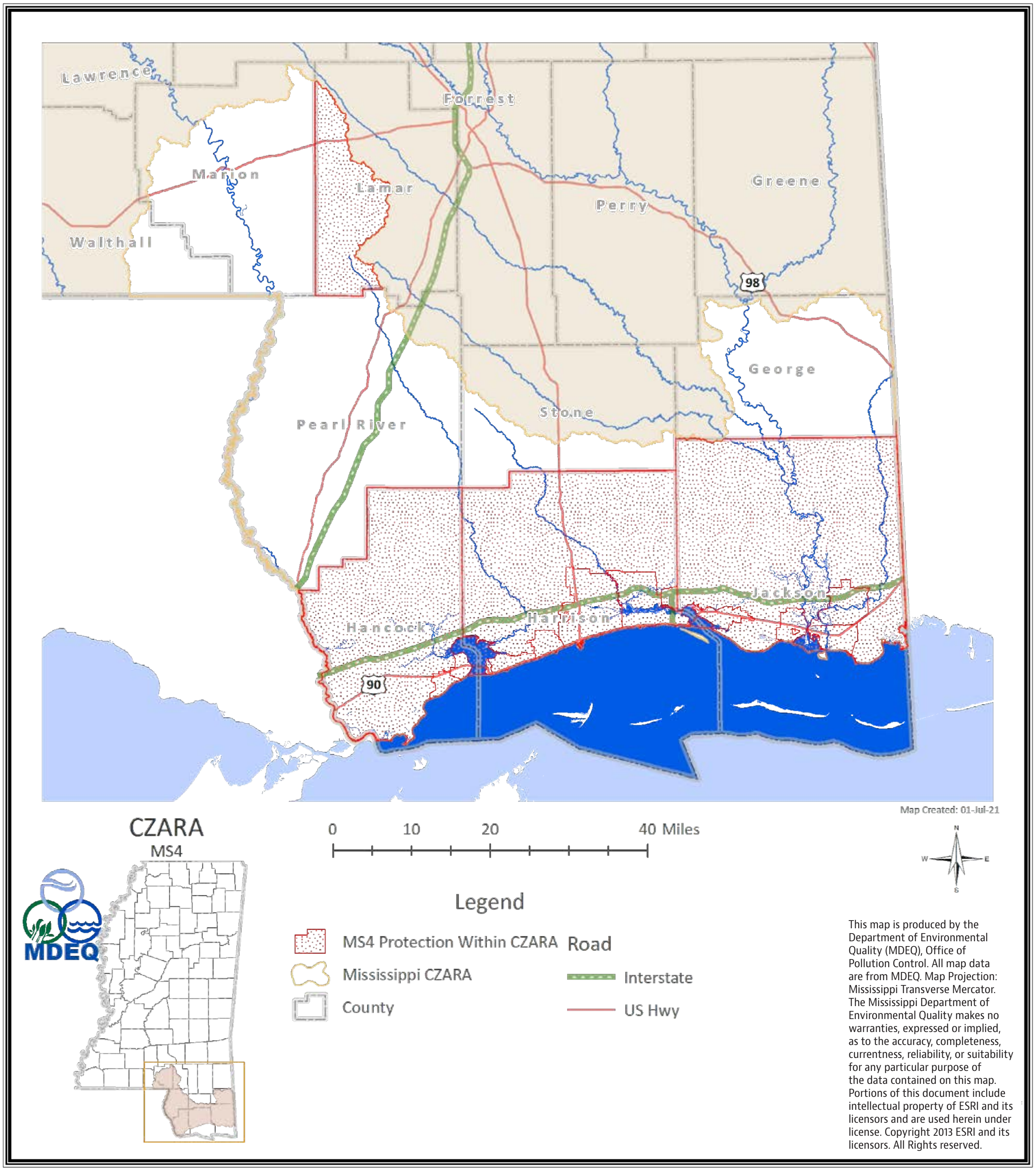


Figure 1-2. **Mississippi's coastal watersheds include portions of nine counties, four of which are covered by the NPDES MS4 program.**

Figure 1-3. Mississippi coastline. (Photo: James Starnes, MDEQ)

Water quality can be influenced by a wide array of pollutants, originating from both "point" and "nonpoint" sources of pollution. Point sources of pollution are from a single point or a discrete pipe such as a municipal wastewater treatment plant. Nonpoint source (NPS) pollution originates from diffuse sources primarily associated with stormwater runoff. Typical pollutants transported in stormwater runoff include metals, bacteria, sediment, organic matter, and nutrients. Protecting water quality in Mississippi's coastal region will require ongoing commitments from businesses, developers, homeowners, landowners, and drainage districts as well as municipal, county, and state governments. Pollution associated with stormwater runoff from development activities on the land is the primary focus of the recommendations and strategies described in this guidance document.

1.2. Rainfall and Runoff: Stormwater Basics

On average, Mississippi gets approximately 60 inches of rainfall each year, with areas closer to the Mississippi Gulf Coast receiving anywhere from 60–65 inches annually (NOAA 2022). When it rains, water is either absorbed into the ground, where it can be used by plants or for groundwater recharge, evaporates back into the air, or hits rooftops, roads, and other impermeable surfaces and runs off into storm drains. In areas with denser populations and more roads, buildings, and sidewalks, the water cannot be absorbed, causing issues with stormwater runoff. As this water moves across the landscape, whether that is over grass, off roofs, along roads, or off pavement, it picks up pollutants along the way that eventually make their way into downstream rivers, creeks, lakes, and estuaries.

In urban areas, stormwater often flows into storm drains where it is piped to a location where it can discharge into streams and rivers. Although this can reduce flooding and standing water in cities, it does not allow the water to absorb naturally into the ground, limiting opportunities for pollutant removal that happens in natural systems. Over time, pollution from stormwater runoff can harm the quality of water in downstream systems. This is why understanding how development is linked to water quality is critically important to supporting healthy watersheds, ecosystems, and communities.

When land is converted from its more natural state (e.g., forests, pastures, and grasslands) into housing, roads, parking lots, and buildings, it drastically changes how rainfall is stored and moved across this altered landscape. There are fewer places where rainfall can be absorbed, and it often moves much more quickly, resulting in increased flooding. Development also often causes increased soil compaction, which limits overall opportunities for infiltration. **Figure 1-4** shows the difference in how rainfall is processed in landscapes with more natural features and how rainfall is processed on landscapes with higher densities of impervious surface. As development occurs and more hard surfaces are created on the landscape, the volume of runoff increases while the overall quality of the stormwater decreases. If stormwater management is considered in the planning process and new development is designed to follow best practices to mitigate impacts from stormwater, however, it is possible to reduce the amount of stormwater leaving the developed area while improving the overall quality of the stormwater runoff. The diagrams in **Figure 1-5** illustrate several processes employed in managing stormwater through the implementation of best management practices (BMPs). Practices that detain, retain, and filter water and increase evapotranspiration can all contribute to healthier ecosystems.

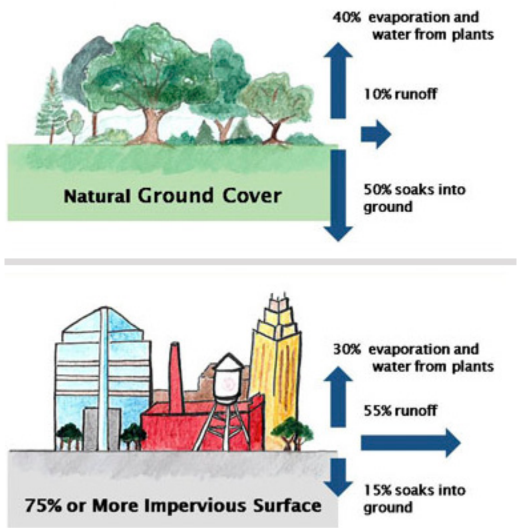


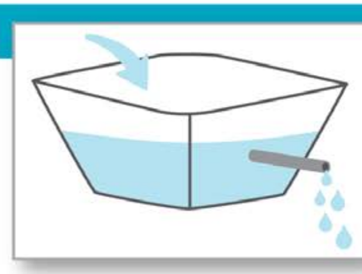
Figure 1-4. Influence of impervious cover on runoff. (Courtesy of City of Durham, NC)

Evapotranspiration is the sum of evaporation and transpiration.

Evaporation is the movement of water from its liquid form on the Earth's surface to its gaseous form in the atmosphere. **Transpiration** is the movement of water to the atmosphere through plants.

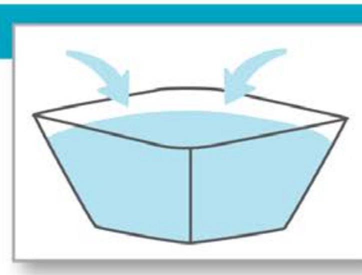
DETENTION

The temporary storage of stormwater runoff (in ponds, underground systems, or depressed areas) to allow for controlled discharge at a later time. The outlet structure restricts outflow to pre-development rates.



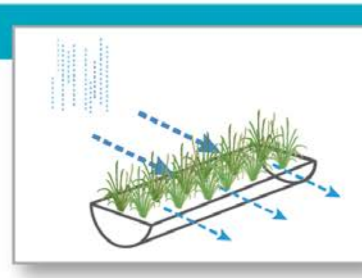
RETENTION

The storage of stormwater runoff on site and not released at a later time.



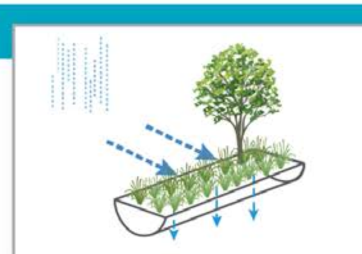
FILTRATION

The removal of sediment and other pollutants from stormwater runoff by the movement of runoff across a vegetated area and through media.



INFILTRATION

The vertical movement of stormwater through plants and soil. In systems without an under drain or liner, infiltration recharges groundwater.



EVAPOTRANSPIRATION

The combined amount of evaporation and plant transpiration from the soil surface or from the plant's vascular system to the atmosphere.

Figure 1-5. Processes employed in stormwater best management practices. (Source: Hegemier et al. 2019)

1.3. Benefits: Planning and Protection

As landscapes are developed, time and effort spent on planning activities that limit stress on ecosystems while implementing practices that will benefit the community over time results in long-term economic and environmental benefits. Often, incorporating proactive stormwater practices can provide opportunities for green spaces or other areas that result in quality-of-life benefits for the public living and working in these spaces. Even in areas that are not highly populated, appropriate management of stormwater from current and future development is important. Sustainable and resilient stormwater design approaches can alleviate some of the challenges posed by development and provide a proactive approach to protecting and maintaining water quality. As part of the overall planning process, implementation strategies are designed to limit the impact from development activities on the landscape and protect the quality of water downstream. Whether development is being considered at a larger watershed scale or in smaller areas, such as individual sites, stormwater management strategies should be designed to reduce the overall impact on the environment, integrate into coastal landscapes, and provide benefits to the communities where the development is planned.

Sustainable refers to approaches that support long-term integrity of ecological systems.

Resilient approaches promote the ability of a system to respond to, or recover readily from, stresses or disruptive forces.

1.3.1. Environmental Benefits

The most obvious and direct environmental benefits from appropriate stormwater management practices are lowering the volume of stormwater from the developed land and reducing the pollution associated with the runoff, thereby limiting the impact the runoff has on overall water quality. Although these are important, other environmental benefits also can be realized, such as limiting disturbance of natural habitats in riparian areas, allowing opportunities for infiltration in support of groundwater recharge, and, with some designs, improving existing habitats. These benefits can have positive effects on nearby aquatic ecosystems as well as those located downstream.

Prevention and Minimization of Pollution

When effective stormwater management systems are implemented, disturbances of natural lands are reduced, thereby preventing or minimizing pollution generated by development activities. Where existing vegetation is retained and soils are not disturbed, the potential is lessened for sediment, nutrients, and other pollutants to be transported to local waterways in the form of runoff. This is especially important in areas susceptible to erosion. The presence of erodible soils, steep slopes, and ongoing exposure to powerful stormflows can all make an area more susceptible to erosion. Beneficial stormwater design contributes to pollutant removal by employing strategies that mimic natural processes, such as settling, filtration, adsorption, and biological uptake. Using these methods to reduce the pollutant load in runoff improves habitat for aquatic organisms and wildlife. It also results in cleaner water to support recreational use of these waters. Stormwater practice types differ in their ability to reduce various pollutants. BMP selection should consider which will result in the greatest water quality benefit, along with other siting considerations. The International Stormwater BMP Database (www.bmpdatabase.org) is a reference for pollutant removal data from BMP implementation across the country (WRF et al. 2022).

Protection of Downstream Waters and Riparian Areas

Implementation of stormwater BMPs minimizes both water quality and quantity impacts to downstream waters, providing protection for the aquatic organisms, wildlife, and people who use those waters. In addition, practices that focus on the protection of riparian areas can serve as natural buffers along waterways to filter pollutants from runoff, capture overland and subsurface flow, provide natural shade to reduce water temperatures, and serve as a source of natural wood and leaf litter in streams which is vital for habitat and food sources to aquatic organisms (**Figure 1-6**). Stormwater management practices can also help to prevent or reduce hydrologic impacts on downstream waters, reduce erosion and sedimentation, improve water quality, increase water supply, and enhance recreational value and natural beauty of the receiving waters.

Figure 1-6. Natural vegetation provides habitat and serves as a protective buffer for adjacent waters. (Photo: Tracy Wyman, GCCDS)

Groundwater Recharge

Stormwater BMPs can be designed and implemented to allow increased opportunity for runoff to be absorbed, thereby promoting groundwater recharge. As water shortages become more prevalent, water resource management strategies designed to collectively integrate practices to address stormwater, drinking water, and wastewater issues can ultimately prove to be cost-effective and beneficial. Urban/suburban development typically results in increases in the amount of impervious surface, leading to a higher volume of runoff while decreasing the availability of water for groundwater recharge. Infiltration practices can replenish groundwater and increase streamflow, especially important during periods of dry weather.

Groundwater recharge is the process by which water moves through soils or from surface waters down to the water table, thus supplying water to an aquifer.

Habitat Improvements

Sustainable development, conservation design, and other innovative stormwater management techniques can improve natural resources and wildlife habitat while reducing or avoiding expensive mitigation costs. Healthy aquatic habitats are supported through stormwater management practices designed so that quality, volume, rate, and temperature of stormwater runoff entering receiving water bodies is similar to the conditions that existed on the landscape prior to development.

Conservation design is a design approach that takes into account the natural landscape and ecology of a development site and facilitates development while maintaining the most valuable natural features and functions of the site. Conservation design includes a collection of site design principles and practices that can be combined to create environmentally sound development. The main principles for conservation design are:

- Flexibility in site design and lot size
- Thoughtful protection and management of natural areas
- Reduction of impervious surface areas
- Sustainable stormwater management

1.3.2. Economic and Quality-of-Life Benefits

Proper stormwater management has many direct and indirect benefits including:

- Improved land value resulting from reduced flooding
- Greater aesthetic value
- Additional lot yield resulting from better use of developed land
- Quality-of-life benefits from the addition of green spaces and water features

Implementing adequate stormwater management and BMPs can enhance the quality of life within a community in many ways, creating improved landscapes with a strong sense of place.

Reduced Potential for Flooding and Property Damage

Implementing stormwater practices that reduce peak flows and decrease total runoff volume helps to lessen or alleviate downstream flooding. Designs that support flood prevention reduce the potential for property damage, thereby saving money on costly repairs. Strategies to manage runoff on-site or as close as possible to the source reduce erosion and sediment transport from development activities as well as reducing flooding, scouring, and in-channel erosion. With effective stormwater controls in place, costs for cleanup and stream bank restoration after flood events can be reduced or even avoided. Applying innovative and proactive stormwater management techniques across larger landscape, neighborhood, and regional scales can protect floodplains, resulting in areas that can be used as green spaces or wildlife habitat (Trust for Public Land 2007).

Peak flow is the maximum rate of flow of water at a particular point resulting from a storm event.

Total runoff volume is the volume of water that leaves a drainage area during a storm event.

Efficient Use of Land: Lot Yield

Design approaches that manage runoff on-site or close to its point of generation can reduce the need to set aside land for use as large detention areas and/or easements needed for stormwater conveyance infrastructure. In cases in which stormwater practices are incorporated into individual house lots and along roadsides as part of the landscaping, land that would otherwise be dedicated to a stormwater pond or other large BMP can be developed into additional housing lots. The BMPs described in Section 5 illustrate various measures that can be used to reduce the stormwater footprint. One example is the use of pervious pavement where runoff can be stored below the surface, thereby removing the need to set aside land for another type of stormwater BMP.

Aesthetic Value

Clean and healthy waterways add value to the surrounding landscape, whether it is in cities, towns, or rural areas (**Figure 1-7**). Properly designed stormwater features can also add aesthetic value to the landscape. This can be seen where stormwater basins are incorporated into the development as water features or when using visually appealing landscaping options as an integral part of the design. Trees, shrubs, and flowering plants that are complementary to other landscaping can be used to enhance the aesthetic quality of the developed landscape. Stormwater ponds, rain gardens, and bioretention areas can be designed to add beauty and value to a property and provide for recreation and enjoyment of outdoor spaces. **Appendix A** provides details on plants native to southern Mississippi and that are appropriate for use in restoration and BMP designs.

Figure 1-7. **Biloxi Beach, Harrison County, MS. (Photo: Barbara Viscup, MDEQ)**

Public Spaces and Quality of Life

Homeowners and neighborhood associations can work to implement small scale stormwater practices on individual lots and promote awareness of how these practices can improve water quality. These practices can include the use of community open spaces which also serve the dual purpose of runoff management. Mississippi State University conducted a study in coastal Mississippi and Alabama that found 57% of people surveyed regularly used local open space and 94% believe that local government has a responsibility to provide usable public space for citizens (Dahal et al. 2022). Similarly, 93% of people who responded to the National Recreation and Park Association's 2019 Engagement with Parks survey believe it is essential that local governments support local parks, trails, and green spaces near bodies of water to protect natural resources (NRPA 2019).

Economic Benefits

Stormwater management practices can provide great value to local communities by reducing erosion and flooding potential. Reducing the volume of runoff and associated pollutants can bring economic benefits to the people and industries that depend on good water quality and healthy ecosystems in downstream waterways and estuaries. Sustainable stormwater management can provide long-term benefits to property owners and businesses, increase tourism and recreational activity, increase fishery yields, and provide cost savings for developers and local governments. The benefits from good stormwater management are realized not only in the surrounding local area, but also in communities farther downstream.

A healthy coastal ecosystem provides numerous assets and services that enhance Mississippi's coastal communities and contribute to their overall welfare. Healthy waters and habitats support recreational activities, fisheries, and the marine industry (**Figure 1-8**). Intact coastal habitats can mitigate impacts from storms, protecting both communities and their economies. Coastal resources also provide aesthetic and social benefits, enhancing the quality of life along the Mississippi Gulf Coast. Kayaking, fishing, and other outdoor recreation enjoyed by local residents and visitors alike depend on clean, healthy waters. These activities all lead to a healthier economic base for Mississippi's coastal communities (GoCoast 2020 Commission 2013).

Mississippi has an extensive integrated array of coastal habitats and natural resources that sustain each other and support numerous ecosystem services. These coastal ecosystems are rich sanctuaries of biodiversity and include a variety of coastal and marine habitats, including barrier islands, beaches, tidal and freshwater wetlands, soft bottom habitats, and oyster reefs. Extensive wetland complexes along the shoreline and within coastal embayments provide foraging and nesting habitats for numerous species of animals along one of the most productive areas of the world (GoCoast 2020 Commission 2013). Immediately inland, habitat areas include extensive pine savannas with diverse flora and

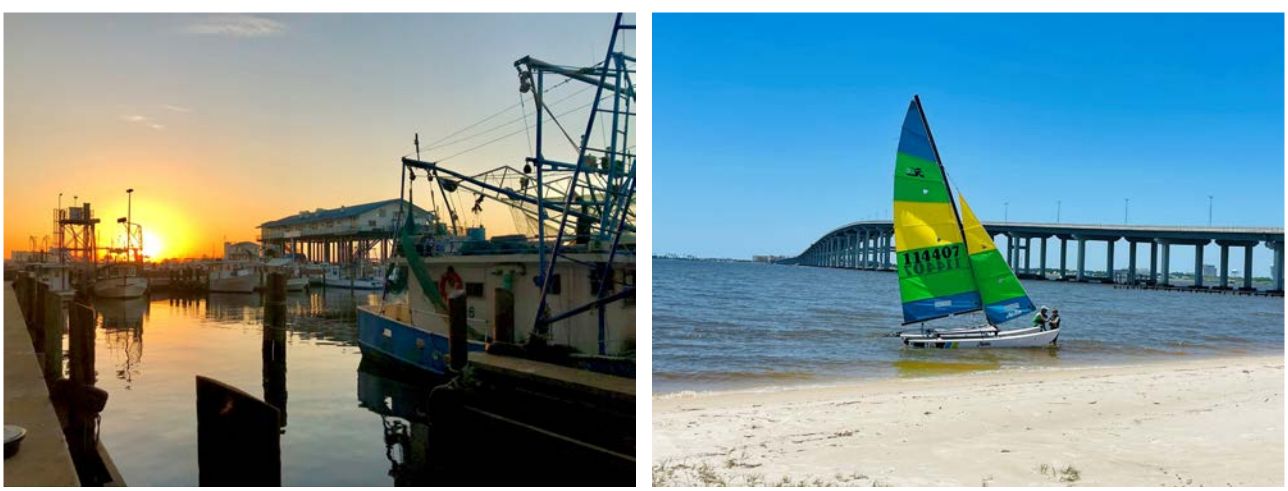


Figure 1-8. The seafood, tourism, and recreation industries are important to Mississippi's economy. (Photos: James Starnes, MDEQ)

fauna that integrate with the coastal wetlands and tidal systems and provide areas for future habitat expansion (GoCoast 2020 Commission 2013).

These ecologically important areas also provide essential nursery habitat for ecologically, commercially, and recreationally important species of fish and invertebrates. Collectively, these habitats are connected to cities and towns, integral not only to the local economy, but also to the entire regional and national economies. These habitats provide a range of natural resource services, including fisheries, food production, nutrient assimilation, energy production, infrastructure protection, and recreational opportunities.

Healthy habitats, especially the barrier islands and marshes, also help to protect coastal communities, providing a line of defense against powerful storms. Mississippi's wetlands provide natural flood attenuation, which might reduce the impacts of flooding associated with storms and long-term sea level rise.

Many economic benefits are derived from preserving and restoring natural features and open space, through conservation and sustainable development actions. Healthy waters and intact coastal habitats can bring economic benefits to coastal communities by sustaining local outdoor recreation, tourism, and seafood businesses.

In addition, environmental conservation and sustainable development practices provide economic benefits by avoiding the costs of construction and maintenance associated with conventional infrastructure. Preserving open space and concentrating development on smaller, clustered lots also provides cost saving to municipalities or developers through lower infrastructure costs for roads, water supply, and sewer systems (Shoup and Ewing 2010).

Examples of activities critical to the Mississippi economy that are tied to the health of its bays and estuaries include the following:

- The Mississippi Development Authority estimated that visitors spent $1.7 billion in tourism dollars on the Mississippi Gulf Coast during fiscal year 2011 (GoCoast 2020 Commission 2013). This substantial contribution of tourism to the region's economy has continued in recent years. In 2019, Mississippi's coast welcomed 14.2 million visitors, with total tourist expenditures of $1.816 billion (Segarra 2021).
- In fiscal year 2019, tourism in Mississippi's three Gulf Coast counties supported 29,100 jobs, or 18.7% of the total for that area (MDA 2020). With nearly one in five people on the Coast employed in the tourism industry, this sector is a critically important component of region's economy.
- Mississippi's seafood industry generated an average of $279 million per year in its total economic contribution during the decade from 2006 to 2016, creating an average of 6,400 jobs (MSU 2021).

Biloxi, MS. (Source: ©Adobe Stock)

2. Sustainable and Resilient Development Design

Sustainable and resilient development design involves protections and practices employed during the site development process that reduce the environmental impact of a project while retaining and enhancing the owner/developer's purpose and vision for the site (**Figure 2-1**). This section expands on the definitions of *sustainability* and *resiliency* in the context of urban development and redevelopment and provides guidance to support these objectives and minimize effects of NPS pollution on the environment.

Sustainability is the support of long-term ecological integrity. Where lands are slated for development, there are conservation and sustainable site design approaches that can be used to help meet important watershed protection objectives, including the following:

- Avoiding and minimizing land cover conversion in areas susceptible to erosion
- Preserving areas that provide important water quality benefits and habitat features
- Developing sites in a manner that protects water bodies and natural drainage systems

Figure 2-1. Sustainable and resilient design practices help maintain a healthy environment. (Photo: James Starnes, MDEQ)

Sustainable site design practices mimic predevelopment hydrologic conditions by preserving natural features and reducing impervious cover to the maximum extent possible (**Figure 2-2**). Many of these practices can reduce the cost of infrastructure while maintaining or even increasing the value of the property compared to conventionally designed developments. Typical elements of sustainable site design (adapted from Hegemier et al. 2019) include the following:

- Preserving natural areas and native vegetation, especially minimizing disturbance of existing, mature stands of vegetation
- Reducing the impact on watershed hydrology
- Incorporating natural drainage pathways as a framework for site design
- Preventing stormwater impacts rather than having to mitigate for their effects
- Managing stormwater quantity and quality as close to the source as possible and minimizing the use of large, regional collection and conveyance structures
- Using simple conservation methods for stormwater management, which are often lower cost and lower maintenance than structural controls
- Reducing the amount of soil compaction during construction to maintain infiltration capacities of the soil

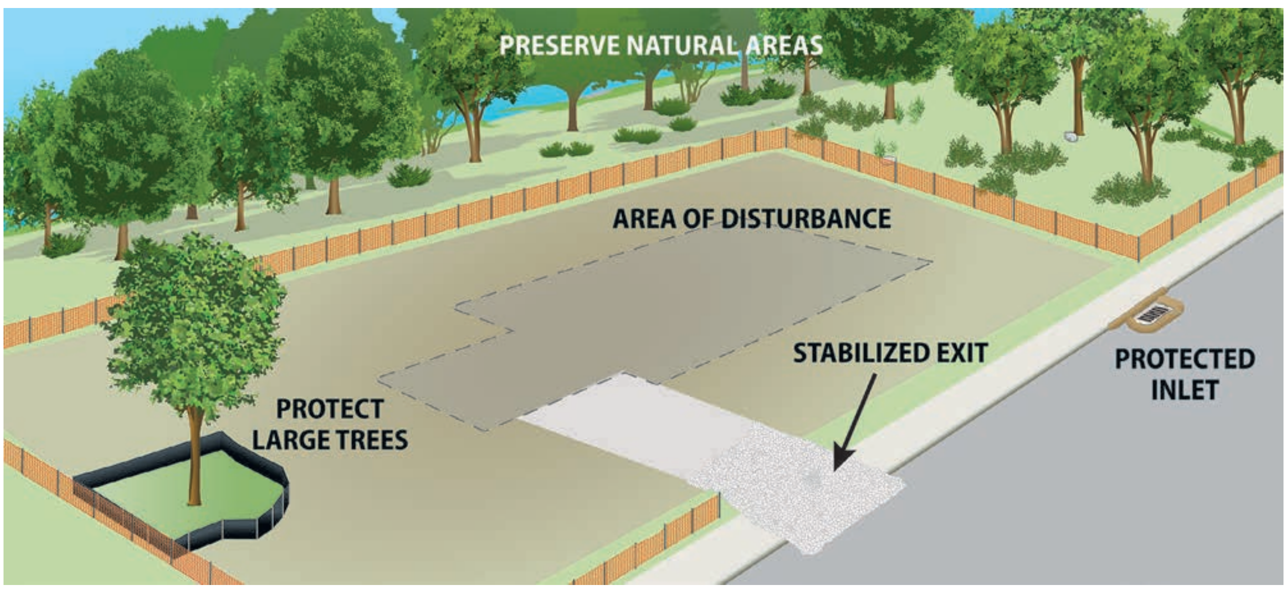


Figure 2-2. Examples of sustainable site design elements.

Many of the elements in sustainable site design also increase resiliency. **Resiliency** is the ability of a system to respond to, or recover readily from, stresses or disruptive forces. New development should be guided away from known hazards, such as areas subject to extreme high tides, hurricane surges, flood waters, and potentially subsiding ground. Consistent with this approach, this guidance manual supports implementing practices in new developments and communities to be resilient, strong, and flexible. When areas are identified for development, one primary goal is to design systems that can continue functioning in the face of these types of threats and hazards (Hegemier et al. 2021). Additionally, natural environmental protective systems should be conserved to maintain their valuable hazard mitigation functions. One example of stressors that developed areas face is higher frequency and intensity of rainfall, which can cause inland or coastal flooding. Resilient design can help a developed area more readily recover from heavy rains through practices such as preserving natural vegetation around streams and coastal areas, encouraging infiltration and rainwater storage by maximizing pervious areas and tree canopy, and incorporating storage and conveyance of excess runoff into site design features.

An area's resiliency is important to consider during the site assessment process for new and existing developments. Consider possible hazards early in the design process. This type of comprehensive approach to new developments can protect communities and businesses from losses associated with flooding and other extreme weather. Hazard mitigation activities include:

- Planning to identify hazards and vulnerability
- Implementing smart growth and hazard mitigation plans before disasters occur
- Avoiding known or previously affected vulnerable areas (e.g., floodplains), and directing new development away from hazardous locations (Hegemier et al. 2021)

Hazard mitigation also seeks to address identified hazards using appropriate structural and nonstructural approaches.

The Center for Watershed Protection's (CWP's) *Better Site Design: A Handbook for Changing Development Rules in Your Community* provides 22 model design principles in three categories as options for more environmentally sustainable designs that reduce impervious cover and retain natural land cover. The three types of recommendations are related to conservation of natural areas, appropriate design of streets and parking lots, and appropriate site and lot development plans (CWP 1998). For example, the handbook describes how to design a development to protect a site's natural features by reducing overall street lengths or narrowing street widths. The principles touch on benefits such as a reduced need for clearing and grading, greater community open space, more forest canopy, and opportunities for conservation incentives (CWP 1998). Mississippi Department of Environmental Quality (MDEQ) recommends practices outlined in CWPs Better Site Design Manual and provides further details in its own handbook, the Stormwater Runoff Management Manual, Volume 2 (MDEQ 2011b).

This guidance document provides conservation and development approaches that will enhance resiliency and function while managing NPS pollution. This guidance encourages low-impact approaches that will serve multiple functions: protecting water quality, managing runoff, minimizing long-term maintenance, and promoting public safety.

Section 2.1 discusses the benefits of identifying and preserving wetlands, streams, floodplains, forests, and other natural features before development occurs. These features are abundant in Mississippi's coastal areas and provide valuable protections for water quality and the environment. State and federal regulations protect some of these features; however, conservation strategies can be incorporated into the development process to provide further protections.

As discussed in Section 2.2, sustainable development practices include site assessment, low impact development (LID) and green infrastructure design, conservation design, and reducing and disconnecting impervious cover. Additionally, these practices should include special considerations for road, highway, and bridge design; channel modification; and erosion protection.

2.1. Protecting Natural Lands

Preserving natural features involves identifying and protecting areas that are beneficial to water quality and provide natural habitat. Preservation efforts can include setting aside a large contiguous area as a preservation zone or several smaller areas designated as important to maintain in undeveloped condition. Protecting existing lands and vegetation from development can help reduce the risk of erosion, protect wildlife habitat and water resources, maintain healthy ecosystems, and reduce revegetation requirements.

Protecting natural features is a key consideration during the planning phase of a development project and can include implementing appropriate BMPs during construction and properly maintaining them after a site is established. The MDEQ *Stormwater Runoff Management Manual* provides detailed approaches and guidance for protecting natural features throughout project planning, implementation, and maintenance (MDEQ 2011b).

Benefits of preserving natural vegetation include the following:

- An immediate finished, aesthetically pleasing landscape that requires no time for vegetation to reestablish
- Enhanced stormwater infiltration by mature vegetation that will soak up more stormwater runoff than newly seeded areas
- Reduced runoff volume and velocity because plants will intercept rainfall, promote infiltration, and lower the water table through transpiration
- A buffer against noise and visual disturbance during and following construction
- Less maintenance than clearing land and planting new vegetation

Development plans should prioritize protection of sensitive habitats and unique natural resources. Key habitats and natural features to target for preservation include wetlands, streams, floodplains, forests, and forested riparian buffers. Areas with erodible soils, natural depression storage, steep slopes, special ecological value, or other undevelopable land also are good candidates for preservation.

2.1.1. Wetlands

> The U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency (EPA) define **wetlands** as those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. In general, wetlands include swamps, marshes, bogs, and similar areas.

Wetlands provide critical ecological and water quality functions, serving as wildlife habitat, attenuating floodwaters, processing nutrients, and serving as a natural filter that improves water quality in adjacent waterways (**Figure 2-3**). Generally, wetlands are areas where regular or intermittent saturation supports specific wetland soils and vegetation.

Nontidal wetlands occur in floodplains along rivers and streams, in isolated depressions surrounded by dry land, along the margins of lakes and ponds, and in other low-lying areas (**Figure 2-4**). Wetland plants and soils filter stormwater before it drains into streams and rivers or soaks through the soil into groundwater. Nontidal wetland types in Mississippi include bogs, swamps, riverbanks, bottomland forests, bayheads, coastal flatwoods, and savannas. Bottomland forests (forested wetlands), swamps (forested or scrub-shrub wetlands), and freshwater marshes (emergent wetlands) account for most of Mississippi's wetland acreage (NAWM 2015). Tidal wetlands are found at the edge of coastal waters and provide habitat for birds and a nursery for shrimp, fish, and other aquatic life. Tidal wetlands include salt and brackish marshes, freshwater marshes and swamps, mud flats, and tidal openwater habitats such as bayous, rivers,

Figure 2-3. Pond with wetlands. (Photo: Adam McWilliams, MDEQ)

oyster beds, and other coastal waters. Common trees in tidal swamps include bald-cypress and tupelo gum. In total, woody and herbaceous wetlands make up about 32% of the land area in Mississippi's coastal watersheds (**Figure 2-5**).

Figure 2-4. Forested wetland. (Photo: James Starnes, MDEQ)

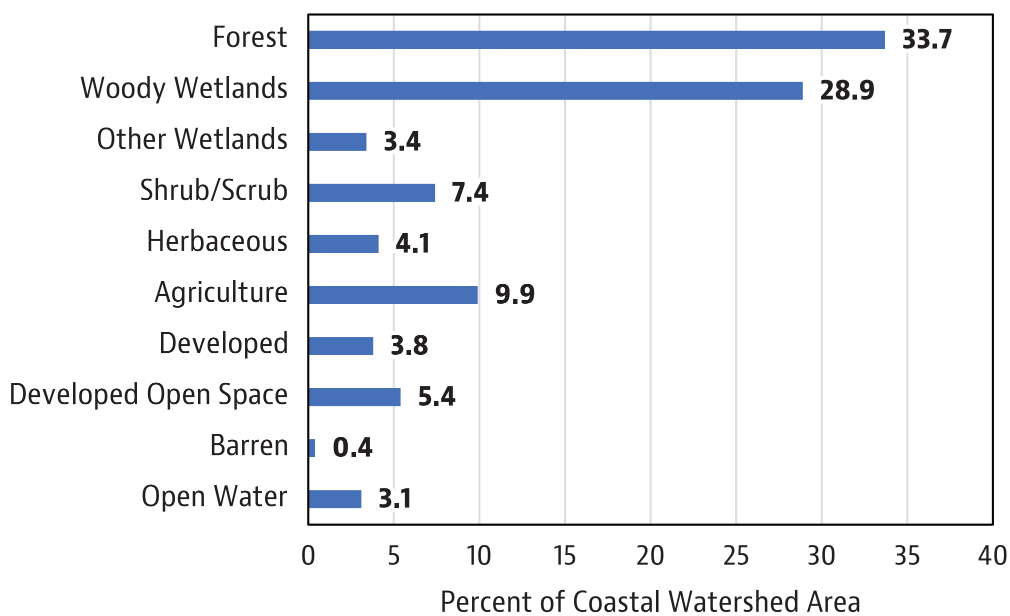


Figure 2-5. Land Use/Land Cover in Mississippi's coastal watersheds (Data Source: MDMR and MDEQ 2020)

There are state and federal programs that regulate impacts on wetlands from development. The MDEQ *Erosion and Sediment Control Practices, Volume 1 of the MDEQ Handbook* (MDEQ 2011a), emphasizes the importance of protecting intact wetlands and stream channels and provides further information on the regulatory programs in place for their protection. Wetlands are considered waters of the United States and are regulated under Section 404 of the federal CWA (discharge of dredge and fill materials into waters of the United States) and Section 10 of the Rivers and Harbors Act of 1899 (all activities affecting navigable waters). The U.S. Army Corps of Engineers (USACE) must issue a federal permit for any actions that impact tidal wetlands, nontidal wetlands, and shallow water habitat. USACE issues two types of Section 404 permits: general permits and individual permits.

Activities requiring USACE authorization include the following (MDEQ 2011a):

- Construction of piers, marinas, ramps, and cable or pipeline crossings
- Dredging and excavation in or adjacent to waters of the United States
- Fill for residential, commercial, or recreational developments
- Construction of revetments, groins, breakwaters, levees, dams, dikes, and weirs
- Placement of riprap (for channel stabilization)

Federal wetlands regulations are covered in Title 40 of the *Code of Federal Regulations* (CFR) Part 230 and 33 CFR Parts 320–332. A good overview of the USACE wetlands regulatory program is provided in a "Regulatory 101" presentation prepared by the USACE Mobile District (USACE 2019).

The Section 404 permit process requires the developer to take steps to avoid or minimize wetland impacts that could be caused by implementing a project and provide compensatory mitigation for any remaining unavoidable impacts. The Mississippi Department of Marine Resources (MDMR) serves as the lead regulatory agency for projects in Hancock, Harrison, and Jackson counties and permit applications should be submitted to the MDMR Bureau of Wetland Permitting for review. For projects in all other counties, permit applications should be submitted directly to USACE. Most of the coastal watershed area in Mississippi falls within the jurisdiction of the USACE Mobile District; a portion is in the Vicksburg District. A map of the area covered by the various Districts is available on the USACE website at https://www.usace.army.mil/Missions/Locations/.

Section 401 of the CWA gives MDEQ the authority to prohibit a proposed activity, including a construction project, if the activity would degrade water quality or have other unacceptable environmental consequences. Projects that require a Section 404 permit also require a Section 401 water quality certification from MDEQ. Water quality certifications are issued under state authority and provide further water quality protection from projects undertaken in sensitive areas by adding state-specific conditions to the federal permit (MDMR and MDEQ 2020).

Early in the site planning process, the permittee should undertake efforts first to avoid, then to minimize, impacts on existing wetlands. Delineation of wetlands is an important early step to understanding the extent and location of these natural features and to tailoring the project site plan to avoid impacts on wetlands and to provide buffers where possible.

2.1.2. Natural Streams

Natural streams (**Figure 2-6**) provide habitat, flood attenuation, water quality protection, and sediment retention. Stream water quality and habitat can be degraded by disturbance to the natural landscape and channelization, which can lead to accelerated erosion and downstream flooding. Removing riparian (streamside) vegetation can degrade habitat and lead to channel erosion. In contrast, site designs that protect vegetated corridors along natural streams will avoid impacts on stream habitat, protect water quality, and reduce the risk of channel and bank erosion. It is important to provide for sufficient stormwater management across the entire developed area. Maintaining a natural hydrologic regime will reduce the potential for stream channels to be subjected to damaging, erosive flows.

Streams that are considered waters of the United States are regulated under Section 404 permits and Section 401 water quality certifications for activities affecting both wetlands and waterways. As much as possible, avoid negative impacts on streams and streamside vegetation.

Figure 2-6. Forested riparian buffer provides protection for the adjacent stream. (Photo: Natalie Segrest, MDEQ)

2.1.3. Floodplains

Floodplains adjacent to waterways provide area for rising waters to occupy during rain events, dissipating the energy of high flows (**Figure 2-7**). Development in floodplain areas can reduce the ability of the floodplain to convey stormwater, potentially causing safety problems or significant flooding damage to the site and any structures on it as well as to upstream and downstream properties. Ideally, the entire 100-year floodplain should be avoided for clearing or building activities and should be preserved in a natural undisturbed state.

Each of the coastal counties participates in the National Flood Insurance Program, which is managed by the Federal Emergency Management Agency (FEMA). As participants in the program, these local governments are each required by FEMA to adopt a local ordinance that restricts the placement of any structure, fill, or obstacle within the floodway of a stream or river. While this program targets flooding and flood-related issues, the ordinance requirements promote setbacks from significant streams, rivers, and waterways. These requirements have additional environmental benefits, as they help to avoid the conversion of riparian areas likely to be susceptible to erosion and sediment loss and preserve riparian areas that provide filtering for NPS pollution. They also include the review of proposed site developments within the floodway to identify alternative designs that would have the least impact on the floodway (FEMA 2020).

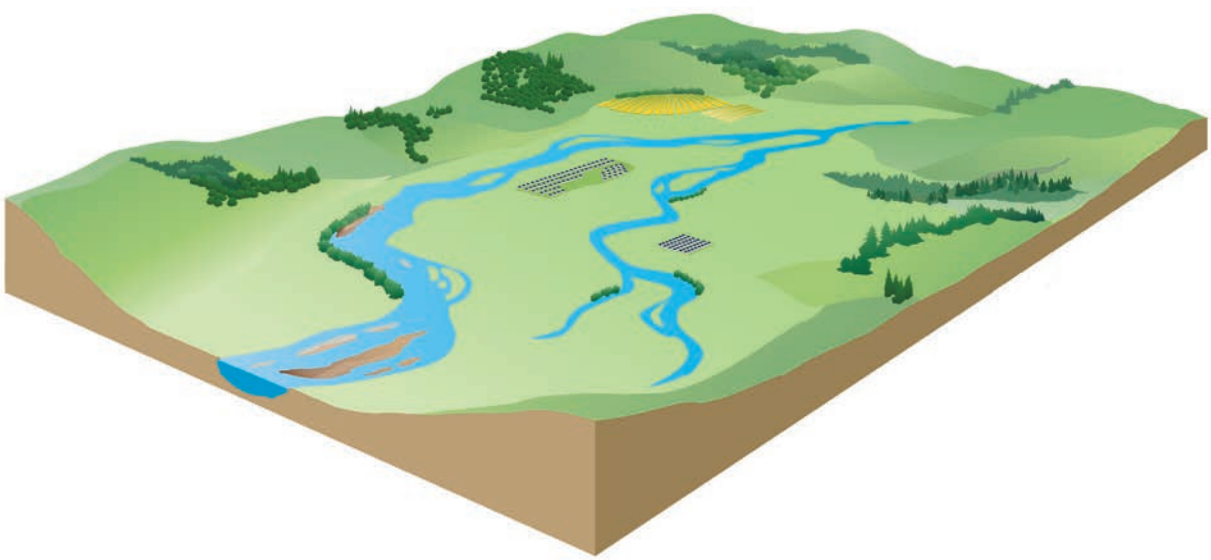


Figure 2-7. Topography and frequency of high flows define the floodplain area along a waterway.

Within Mississippi, development in floodplains is regulated by county and city floodplain and development ordinances (**Table 2-1**). The ordinances typically focus on activities that "control the alteration of natural floodplains, stream channels, and natural protective barriers which are involved in the accommodation of flood waters" and "control filling, grading, dredging and other development which may increase erosion or flood damage" (City of Picayune 2007).

Table 2-1. Floodplain and development ordinances and regulations in non-MS4 Mississippi coastal areas (adapted from MDMR and MDEQ 2020)

County or City	Flood and Development Ordinances and Regulations
George County	Flood Damage Prevention Ordinance (George County 2019)
Marion County	Marion County Road Department web page County road department is responsible for drainage (culverts, ditching, curbs, and guttering) (Marion County 2022)
Pearl River County	Subdivision Regulations (Pearl River County, 2023a) Article V: Section 503. Storm Drainage Flood Damage Prevention Ordinance (Pearl River County, 2023b) Article V: Section F. Standards for Erosion, Sediment, and Stormwater Utility Authority Regulations for Development (Pearl River County Utility Authority 2010)
Stone County	Stone County Developer's Guide (Stone County 2008) Flood Damage Prevention Ordinance Utility Authority Rules and Regulations for Development Subdivision Regulations (Stone County 2019)
Walthall County	N/A; coastal zone portion of the county is mostly rural agricultural land
City of Lucedale	Subdivision Regulations (City of Lucedale 2004) Land Development Code (City of Lucedale 2020)
City of Picayune	Ordinance Number 919, Flood Damage Prevention Ordinance (City of Picayune 2016) Modification and construction of drainage systems are covered as well, with the assistance of the engineering department. Pearl River County regulations also apply.
City of Poplarville	Land Subdivision Regulations (City of Poplarville 2011) Article V: Section 504 *20 Year Comprehensive Development Plan for the City of Poplarville, Mississippi* (City of Poplarville 2010)

2.1.4. Forests and Forest Buffers

Forest are important components of the natural landscape, not only providing habitat for birds and other wildlife, but also protecting water quality in nearby waterways, reducing soil erosion, filtering and cycling nutrients and other materials, and providing shade that moderates air and water temperatures (**Figure 2-8**). Forested land cover, including evergreen, mixed, and deciduous forest plus woody wetlands, makes up about 63% of the coastal Mississippi landscape (**Figure 2-5**).

Figure 2-8. **Longleaf, slash, and loblolly pines in the DeSoto National Forest, Stone County, MS. (Source: Wikimedia Commons)**

The coastal area falls within Mississippi's East Gulf Coast Plains ecoregion. Most of the forest types and subtypes found in this region are identified in Mississippi's Forest Action Plan 2020 as having a conservation status of "imperiled," "critically imperiled," or "vulnerable", pointing to the importance of sustaining the area's remaining forest resources (Mississippi Forestry Commission 2020). Although much of the larger forest area is within the region's parks, wildlife refuges, wildlife management areas, and other protected areas, forest cover on private land is still a good candidate for special consideration during development.

Forests and other naturally vegetated buffers along creeks and rivers (**Figure 2-9**) play an important role in maintaining water quality. Forest and other natural riparian vegetation stabilize stream channels and floodplain areas, reducing the potential for creek erosion. Riparian buffers also provide filtration for overland flow from adjacent developed and agricultural lands, capturing pollutants such as nitrogen, phosphorus, pesticides, fertilizers, and sediments. This filtering is beneficial during construction to retain sediment from up-gradient disturbed areas and after construction to further clean stormwater discharged from BMPs or to slow and infiltrate overland flow not captured by BMPs.

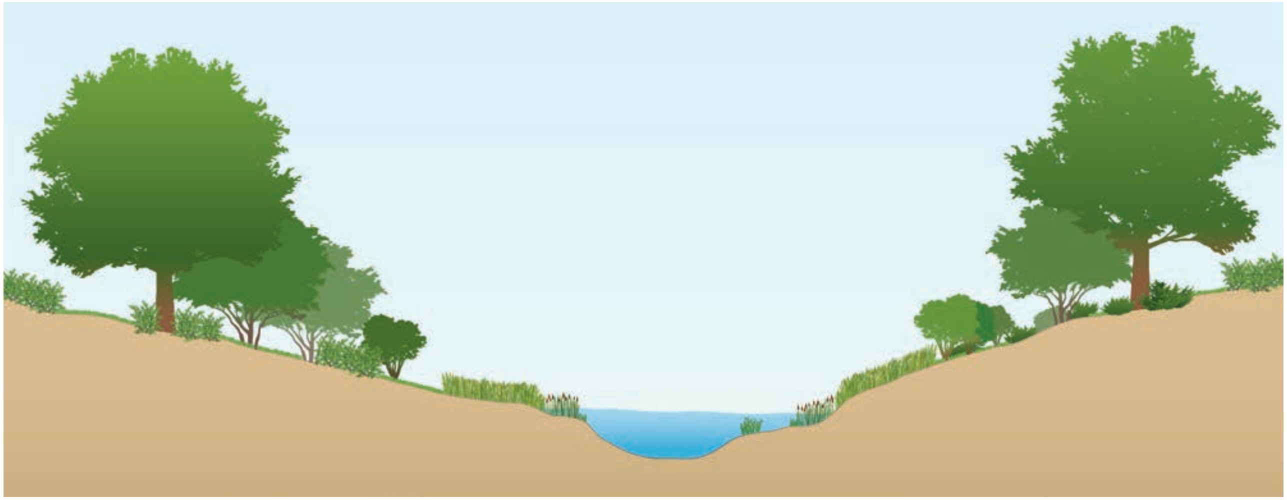


Figure 2-9. Along a stream, a vegetated riparian buffer protects the channel, filtering sediment, nutrients, and other pollutants.

Buffers provide additional benefits, including the following:

- Providing flood control
- Helping protect properties from shifting and widening of stream channels that occur over time
- Increasing property values
- Minimizing activities that degrade, destroy, or reduce the value and function of coastal marshlands
- Enhancing scenic value and recreational opportunities of wetlands
- Protecting coastal habitat for nesting and feeding wildlife
- Protecting important nursery areas for fisheries, which provide food and habitat to numerous species of fish and shellfish, including commercially important species

The purpose of establishing a riparian buffer zone is to adequately protect waterways and aquatic resources from the short- and long-term impacts of development activities by providing a contiguous protection zone along the riparian corridor. In many creeks, streams, and rivers, a defined floodplain already provides a level of protection for the stream/riparian system. In natural topography, however, some streams are constrained to narrow valleys or ravines, and the riparian zones can extend important protection beyond those narrow corridors.

In a forested ecosystem, existing forested riparian buffers should be maintained. Where no wooded buffer exists, reforestation should be undertaken. Proper reforestation should include all layers of the forest plant community, including trees, understory, shrubs, and ground cover.

Along tidal waterways and wetlands, buffer zones can be established to protect these sensitive areas from the short- and long-term impacts of upstream land activities. Buffers of forest or other vegetation reduce the potential for erosion, sediment, and pollution runoff to impact tidal waters and wetlands. Buffer vegetation also provides greater habitat connectivity with nearby tidal marshes and open waters.

In Mississippi, all development projects of more than 1 acre are subject to a 50-ft buffer requirement under the MDEQ construction general permit program for small sites (i.e., the Small Construction General Permit (SCGP) and, for developments of 5 acres or more, a 150-ft buffer is recommended in the Large Construction General Permit (LCGP) (MDEQ 2019, 2022). Section 3 provides further details on buffer requirements under the construction general permits.

2.1.5. Other Features for Protection

Other features on the landscape may be identified as good candidates for protection. These include areas with erodible soils, depression storage, and steep slopes. Areas of special ecological value can include habitats for wildlife or aquatic species. In some cases, lands that are deemed undevelopable for other reasons may also be set aside for protection.

Erodible soils should be conserved as much as possible. Construction should be directed away from areas on a site with highly erodible or unstable soils to prevent erosion and sediment issues as well as potential future structural problems. Erodible soils can be identified from soil mapping information. When possible, areas with highly erodible or unstable soils should be left in an undisturbed and vegetated condition.

Depression storage is found where land retains water in natural depressions, temporarily storing stormwater and allowing it time to infiltrate into the soil. Typically, areas draining to depression generate no runoff until the storage has been filled, making depression storage a natural, effective, and cost-free method of reducing the overall volume of stormwater runoff. Often, design and construction practices remove these natural features to promote drainage; however, small, natural depressions in the landscape should be treated as sensitive resource areas and should be protected from construction activities. Because of the important role depressions play within drainage and water quality and as ecological components of the natural stormwater system, attempts should be made to incorporate depressions within localized stormwater management plans.

Steep slopes are typically unable to be developed and can be good targets for retaining natural vegetation that will prevent soil erosion. Often along riparian areas, vegetated slopes can provide good buffers.

Areas of special ecological value may include habitat for rare, threatened, or endangered species or specialized habitat (e.g., bird nesting areas) (**Figure 2-10**). These areas might make up a portion of a property and should be mapped early in the planning process.

Other undevelopable areas should be avoided during development planning, including areas with clay soils or high groundwater.

2.1.6. Regional Land Conservation

Throughout the Mississippi coastal area, many lands that provide water quality benefits or support key habitat are protected from development. These protected areas include state parks, wildlife refuges and wildlife management areas, coastal preserves, national forest lands, and other federal lands (**Figure 1-3**).

Development is restricted in other places because of the presence of floodplains (i.e., under the legally enforceable floodplain ordinances described in Section 2.1.3), lack of public water and sewer, high groundwater (i.e., less than 24 inches from the surface), clay soils, and steep slopes. Buffer restrictions limit development near waterways, as discussed

Figure 2-10. Areas with special ecological value include habitat for threatened and endangered species. (Photo: James Starnes, MDEQ)

above. Specifically, developments are subject to the buffer requirements of the MDEQ SCGP and LCGP (MDEQ 2019, 2022).

In addition to lands conserved within these designated areas, it also is important to consider protecting other lands and waterways that play key roles in the ecosystem. Protecting natural lands will help reduce pollution sources, maintain good water quality, and provide habitat (**Figure 2-11**). Across the coastal area, land development is managed in the MS4 counties by their stormwater management programs. At present, residential and commercial development is fairly limited in the non-MS4 upland counties, but these areas still provide opportunities for implementing conservation and land development practices that support good water quality and watershed health. Various management tools are available to protect beneficial uses of lands set aside for conservation, including the following:

- Fee simple acquisition
- Conservation easements
- Transfer or purchase of development rights
- Land trusts
- Agricultural and forest districts

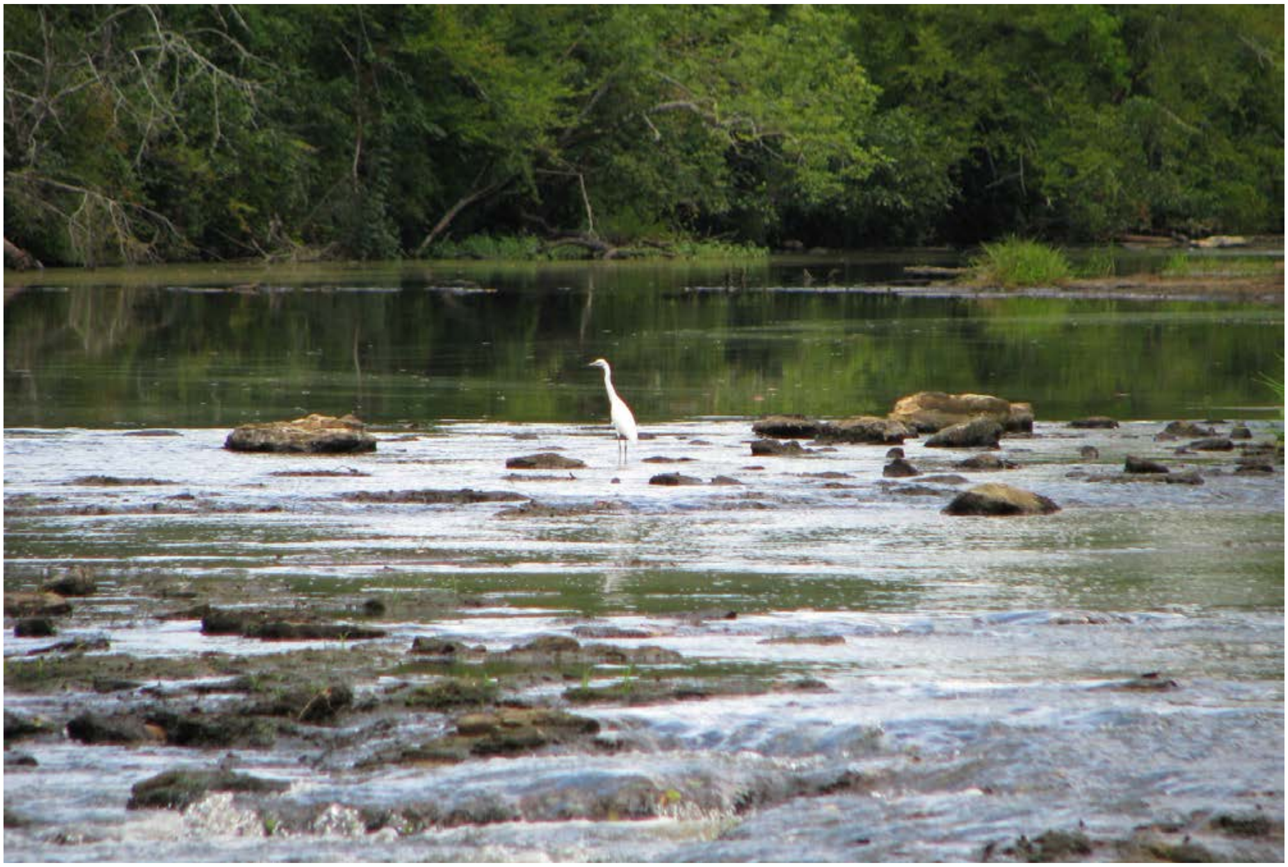


Figure 2-11. Snowy egret wading. (Photo: Matthew Hicks, USGS)

2.2. Sustainable Development Practices

This section describes various sustainable development practices to guide local communities and development practitioners in implementing practices that will help sustain water quality and habitat within the coastal region.

2.2.1. Site Assessment

To support preservation of natural features, the first step is to identify and locate sensitive areas on the site so proposed designs can avoid or minimize negative impacts on these features (**Figure 2-12**). A site assessment is an in-depth evaluation of the ecological conditions and natural features present at the proposed development or redevelopment site and is conducted prior to developing a detailed site design. Natural conservation areas are identified with available mapping information and on-site field reconnaissance to characterize existing features. Proposed areas for protection should be identified and delineated early in the planning stage, long before site design or land clearing begins. Preservation continues through the phases of design, construction, and long-term maintenance and land management (Hegemier et al. 2019).

Conditions and features to investigate during a site assessment include the following:

- Wetlands
- Floodplains
- Riparian areas, streams, and other waterways
- Soil types, infiltration capability, and soil erodibility
- Mature forests and other woodlands
- Types and health of other existing vegetation (trees, shrubs, grasses, and forbs)
- Prominent landforms
- Steep slopes
- Depression storage
- Aquifer recharge areas

Figure 2-12. Site assessment can identify key features, such as large, mature trees. (Photo: James Starnes, MDEQ)

Identifying these aspects of the site upfront will help inform design plans, which can be customized to avoid sensitive resource areas. Buildings, roads, and parking areas should be sited to fit the terrain within areas that will have the least impact. Protection of natural features can help reduce revegetation requirements, reduce long-term erosion, preserve habitat, protect water and land resources, and maintain healthy ecosystems.

Undeveloped sites often have natural features that provide environmental, aesthetic, and recreational benefits if preserved and protected from the impacts of construction and development. Once identified, preservation areas should be incorporated into site development plans and clearly marked on all construction and grading plans. This will ensure that construction activities are kept out of these areas and that native vegetation is not disturbed.

Protecting natural areas and features is not limited only to new development sites. Properties being redeveloped also might have attractive open space, well-drained soils, natural vegetation, or riparian areas that should be identified and considered for preservation early in the planning process.

2.2.2. Green Infrastructure and Low Impact Development

Managing stormwater close to its source and using nonstructural methods for stormwater management are consistent with **green infrastructure** approaches promoted for use in Mississippi. In contrast to traditional "gray infrastructure," which uses built structures such as concrete curb and gutter systems, pipes, and retention basins, green infrastructure uses vegetation and soils to manage stormwater through the processes of infiltration (allowing water to slowly sink into the soil), evaporation/transpiration (returning water to the air through vegetation), and rainwater capture and reuse (e.g., storing runoff to water plants). Green infrastructure (also known as "green stormwater infrastructure") can be an important component of sustainable and resilient design. Sections 4 and 5 provide examples of green infrastructure practices, and additional information is provided in Mississippi's *Green Infrastructure Toolbox* (MDMR and AllenES 2017).

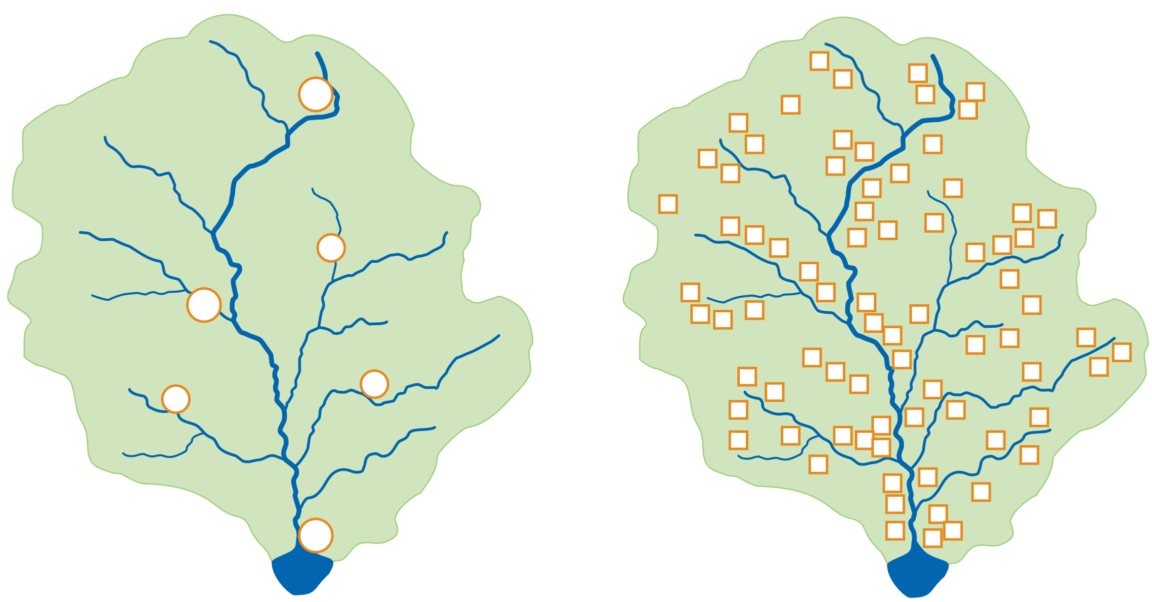
Sustainable design approaches are consistent with **LID** and other smart growth practices outlined in the MDEQ *Stormwater Runoff Management Manual* (MDEQ 2011b). Applying smart growth practices can support common goals of preserving natural areas and open space, reducing impervious cover, directing redevelopment to already developed areas with infrastructure in place, and promoting tree canopy protections. Applying concepts of smart growth to stormwater management and using a variety of available planning tools can help shift the focus toward development in appropriate areas with techniques that reduce impacts on local waterways.

LID focuses on managing rainfall at the source, using distributed, decentralized small-scale controls on the lot level that mimic natural hydrology (**Figure 2-13**) (LID 2007, cited in MDEQ 2011b). A 20-year study found that distributed stormwater management provides advantages over centralized stormwater management in several ways (Hopkins et al. 2022). Hydrologic benefits included mitigating runoff volumes and peak flows and, for small storms, replicated predevelopment conditions.

LID practices encourage infiltration and reduce the volume of stormwater discharged from a site. Key LID elements include the following (MDEQ 2011b):

- Conservation
- Small-scale controls
- Customized site design
- Pollution prevention and education
- Directing runoff to natural areas

The preservation of native trees, understory vegetation, and natural drainage processes is an important aspect of LID. LID designs are tailored to protect hydrologic processes, reduce pollutant loads, and direct stormwater to areas of infiltration to facilitate groundwater recharge. LID promotes hydrologic function at the lot level. Use of LID practices often can result in a 25–30% reduction in costs associated with site development, stormwater fees, and maintenance for residential developments (MDEQ 2011b). These savings are associated with reductions in clearing, grading, pipes, ponds, inlets, curbs, and paving. LID practices are easily applied to open space, rooftops, streetscapes, parking lots, sidewalks, and medians. Preserving open space allows for large conservation areas where stormwater can infiltrate into the ground and promote groundwater recharge. LID makes use of narrow streets and driveways, reducing impervious surfaces to reduce potential for flooding and stormwater pollution. Typically, LID designs feature sheet flow across grassy areas rather than curb-and-gutters. Placing houses closer to the street and employing shared driveways are other approaches that reduce overall impervious surface area.



Centralized Stormwater Management
A few, large practices

Distributed Stormwater Management
Many, smaller practices

Figure 2-13. **LID encourages the use of smaller, distributed stormwater practices.**

In general, LID design components include vegetation, pervious surfaces, and stormwater BMPs, especially those incorporating vegetation. Plants help manage stormwater through evapotranspiration and provide pollutant removal through nutrient cycling. Grassy areas, permeable pavement, and other pervious surfaces allow stormwater to infiltrate into underlying soils, promoting groundwater recharge and pollutant processing while reducing the runoff volume. Bioretention systems detain water long enough for infiltration and pollution removal to occur. BMPs may be designed as buffer strips, bioretention cells, rain gardens, constructed stormwater wetlands, and grass swales. Other LID practices covered in the MDEQ *Stormwater Runoff Management Manual* include rain barrels, cisterns, and filter strips (MDEQ 201b).

Municipal governments can promote sustainable approaches to site design through ordinances and incentives. A number of sustainable design approaches are included in the U.S. Environmental Protection Agency's (EPA's) *Water Quality Scorecard: Incorporating Green Infrastructure Practices at the Municipal, Neighborhood, and Site Scale* (USEPA 2009). EPA developed the scorecard to help local governments identify opportunities to better protect water quality by removing barriers and revising or adopting pertinent codes, ordinances, and incentives. The scorecard guides municipal staff through a review of relevant local codes and ordinances across multiple departments to ensure they work together to support a sustainable site design approach. The guide offers resources and case studies for each of five featured topics: (1) protecting natural resources (including trees) and open space; (2) promoting efficient, compact development patterns and infill; (3) designing complete, smart streets that reduce overall imperviousness; (4) encouraging efficient parking areas; and (5) adopting green infrastructure stormwater management provisions.

2.2.3. Using Conservation Design

"Conservation design," also known as "open space design" or "cluster development," includes laying out the elements of a development project to take advantage of a site's natural features and preserve sensitive areas, while also considering site constraints and opportunities to prevent or reduce environmental impacts (Hegemier et al. 2021). Conservation design begins with outlining the open space and letting its size and layout become the central organizing element for the overall design (Arendt 1996).

Conservation design techniques include the following:

- Preserving undisturbed areas
- Preserving stream buffers
- Reducing clearing and grading
- Locating projects in less sensitive areas
- Reducing front and side yard setbacks
- Aggregating shared open space rather than focusing on individual yards
- Clustering built features to minimize the amount of disturbed area

As described in Section 2.2.1, features of natural conservation areas are typically identified through a site assessment. When a site assessment is completed during the early phase of developing a site design, identifying sensitive features as outlined above and designating conservation areas can inform the layout of a project to accommodate both built and natural features.

Subdivisions in which conservation design has been implemented typically incorporate smaller lot sizes than are offered in subdivisions featuring conventional design to reduce overall impervious cover while providing more undisturbed open space, which results in greater protection of water resources. This approach groups structures and impervious surfaces on a portion of the development site in exchange for providing open space elsewhere on the site (**Figure 2-14**). Somewhat smaller lots and nontraditional lot designs can be used to cluster development and create conservation areas as community amenities on the site (Hegemier et al. 2021).

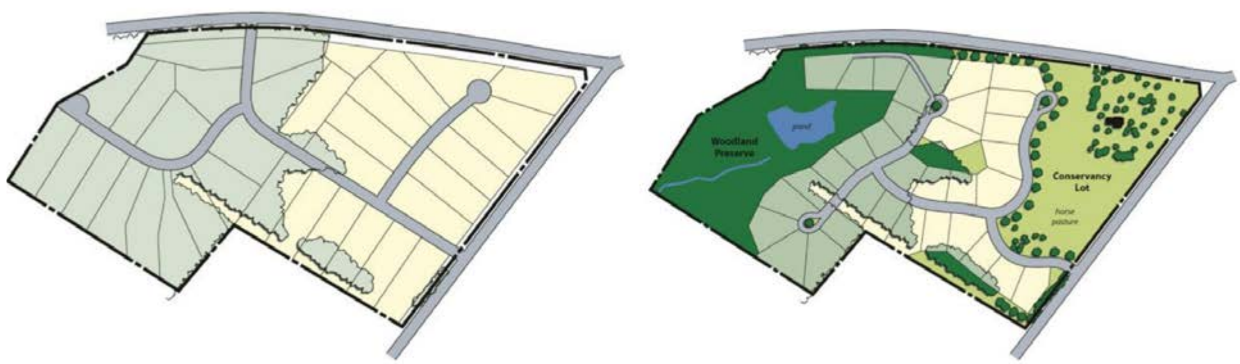


Figure 2-14. **Example of conventional design (left) and conservation design (right). (Source: Arendt 2018)**

Conservation developments offer many more benefits than conventional commercial developments or residential subdivisions, including the following:

- Reducing impervious cover, which reduces runoff volume and rate
- Reducing development and construction costs by reducing the amount of grading, stormwater conveyance infrastructure, and landscaping
- Placing development above flood levels and potential stormwater hazard areas
- Protecting floodplains, tidal waters, and wetlands
- Enhancing the community experience
- Enhancing access to open green space
- Enhancing the sense of place and character
- Providing a safer pedestrian environment

In addition to reducing the amount of impervious surface and its associated benefits, conservation design applied across the landscape can provide a range of other environmental benefits, including the following:

- Preventing encroachment on conservation and buffer areas
- Creating larger areas of protected meadows, fields, and forested lands, providing more well-connected habitat
- Helping provide larger, contiguous areas to protect farmland and natural areas while still accommodating development allowable under current zoning

Because less land is cleared during the construction process, soil erosion and modifications of the natural hydrology are reduced (Hegemier et al. 2021).

Conservation developments also can be significantly less expensive to construct than conventional projects. A large part of the reduced cost is through the reduction in road and stormwater infrastructure. Properties in conservation developments often command higher prices than in more conventional developments because of the aesthetic, natural, and recreational value they provide. Several studies have found that residential properties in open space developments sell at premium prices that are higher than those in conventional subdivisions (Crompton 2007, cited in Hegemier et al. 2021).

One long-term consideration is that once established, open space and natural conservation areas must be managed and maintained in a natural state in perpetuity. Typically, the designated conservation areas are protected by legally enforceable deed restrictions, conservation easements, or maintenance agreements. Often, the responsible party may be a homeowners' or community association.

Preservation of natural areas through the use of conservation design can help preserve predevelopment hydrology of sites and reduce stormwater runoff and pollutant load. Undisturbed vegetation will conserve soils that will better filter and infiltrate stormwater runoff. Protecting existing vegetation can be particularly beneficial to sites in floodplains or wetlands; on streambanks or steep slopes; with critical environmental features; and where erosion controls would be difficult to establish, install, or maintain.

Developments can be planned around significant environmental features, which then can be marketed as amenities. In *Conservation Design for Subdivisions*, author Randall Arendt describes a process for delineating a "development envelope" within which buildings and infrastructure can be placed to avoid impacting natural features (Arendt 1996). The first step in this process is to assemble background information, which includes the following:

- Determining the local context: Is the surrounding area agricultural, forested, and so forth?
- Mapping significant existing features as candidate conservation areas, including floodplains, slopes, soils, wildlife habitat, woodlands, farmland, historical/cultural sites, views, and aquifer recharge areas.

- Ranking conservation areas based on how special, unique, irreplaceable, environmentally valuable, historic, or scenic they are.
- Identifying areas where buildings and infrastructure that would minimally impact conservation areas should be placed.
- Establishing the layout of buildings and infrastructure and employing techniques such as clustering buildings, using smaller lots, shared driveways, and narrower streets (Arendt 1996).

This process of site evaluation and design can allow significant features to be preserved while maintaining the desired overall site density (although density in localized parts of the development will be higher when open space is set aside). Benefits for the community include larger areas of open space, with natural vegetation seen as an amenity, and providing ecosystem services such as those provided by riparian buffers. Lot yield can even be increased, with greater density of housing units within the development envelope, while conserving a greater proportion of land overall (Arendt 1996).

Figure 2-15 illustrates a conservation design for a residential community in Leon County, Florida, in which a substantial portion of land was preserved in its natural state. By carefully locating 200 house lots on the 975-acre property, the developer permanently protected about 650 acres of critically important land, including mature longleaf forests, oak groves, wiregrass savannahs, and gopher tortoise habitat, making up nearly 70% of the total project area. Protecting naturally vegetated land near water bodies was an integral part of the design. In addition, providing neighborhood access along lake frontages instead of dividing the shoreline into individual lots made economic sense while also building a greater sense of community and aesthetic value (Arendt 2022). The CWP provides further details on this project and a suite of other useful conservation design examples in *New Case Studies on Conservation Design and Smart Growth* (CWP 2022).

Local governments can promote the implementation of conservation design by tailoring local plans, zoning, and ordinances that facilitate these design practices. Many specific suggestions and examples are provided in *Conservation Design for Subdivisions and Growing Greener: Putting Conservation into Local Plans and Ordinances* (Arendt 1996, 1999). When practices are implemented across multiple developments, the land conserved in this manner can contribute to a larger, interconnected network of open space.

2.2.4. Reducing Impervious Cover

Once a site assessment has been conducted to identify the natural features of a site proposed for development or redevelopment and the initial planning and design phase has begun, another nonstructural sustainable development approach can be implemented: reducing impervious cover. This approach reduces the total impervious cover, including parking lots, roads, sidewalks, rooftops, and other surfaces that do not permit rainfall to infiltrate into the ground.

There are many methods to reduce the total area (square footage) of impervious surface on a development site. Benefits of applying these methods include reducing the volume of stormwater runoff, increasing groundwater recharge, and reducing pollutant runoff from a site (Hegemier et al. 2021). MDEQ's stormwater manual provides several options for reducing impervious surface cover (MDEQ 2011b), applicable in the following situations:

- Narrower residential streets
- Green parking or shared parking
- Eliminating or minimizing curbs and gutters
- Open space design
- Traditional neighborhood developments
- Mixed-use developments

If low-density development criteria are met with less impervious cover, in some cases, no structural stormwater controls will be required (MDEQ 2011b). In addition, reducing the percentage of impervious cover in a high-density development can reduce the size of BMPs that are needed.

Streets. A first step in achieving a reduction in impervious cover in a development plan is to examine proposed roadway lengths and widths and to consider alternatives. Alternative layouts that reduce the total linear length of roadways can significantly reduce the amount of impervious cover. Site designers should analyze potential options for site and roadway layouts to seek ways to reduce overall street length. In addition, streets should be designed for the minimum required pavement width needed for travel, on-street parking, and emergency access. Several alternatives exist to reduce the total length and width of streets, including the following:

- One-way, single-lane loop roads, which can reduce the width of lower traffic streets
- On-street parking reduced to one lane or eliminated on local access roads with less than 200 average daily trips and on short cul-de-sac streets
- Reducing side yard setbacks and using narrower frontages, which can reduce total street length
- Emphasizing grid patterns for roadways
- Eliminating dead ends and cul-de-sacs
- Designing and building narrower, neighborhood-scale streets

Another way of significantly reducing impervious cover on streets is with alternative turnaround areas, such as modified designs for cul-de-sacs. Many cul-de-sacs have a radius of more than 40 ft, which produces a large amount of impervious cover, contributing to more runoff. Shrinking the size of cul-de-sacs by using alternative turnarounds or eliminating them altogether, however, can reduce the amount of impervious cover created at a site. Alternative design options include the following:

- Reducing the size of cul-de-sacs to a 30-ft radius.

Figure 2-15. Conservation design developed at Centerville, Leon County, Florida. (Source: Arendt 2022)

- Allowing hammer-shaped turnarounds (“hammerheads”) as an alternative form of cul-de-sac.
- Creating rain gardens or bioretention areas in the center of the cul-de-sac to manage stormwater
- Eliminating turnarounds by building loop roads

Sufficient turnaround area is a significant factor to consider in the design of cul-de-sacs, especially for emergency vehicles, service vehicles, or school buses. Some fire trucks, however, are designed for smaller turning radii. In addition, some newer large service vehicles are designed with three axles (requiring a smaller turning radius) and many school buses do not enter individual cul-de-sacs.

Sidewalks. Some local codes require that sidewalks be placed on both sides of residential streets and be constructed of impervious concrete or asphalt. Many subdivision codes also require sidewalks to be 4–6 ft wide and 2–10 ft from the street. These codes are intended to provide for sidewalks that are safe for pedestrians. Despite these types of constraints, there are recommended options for reducing overall impervious area associated with sidewalks. Alternative sidewalk designs include the following (Hegemier et al. 2021):

- Placing sidewalks on only one side of the street.
- Setting sidewalks back, so they drain to vegetated areas between the sidewalk and the street rather than directly to the street (**Figure 2-16**). Depending on slope, this added space also can include practices to capture road runoff.
- Using alternative surfaces for sidewalks and walkways, such as pervious pavements, to reduce total impervious cover.
- Reducing sidewalk sizing requirements, as allowed under the Americans with Disabilities Act, if developments include trails or other alternative pedestrian networks.

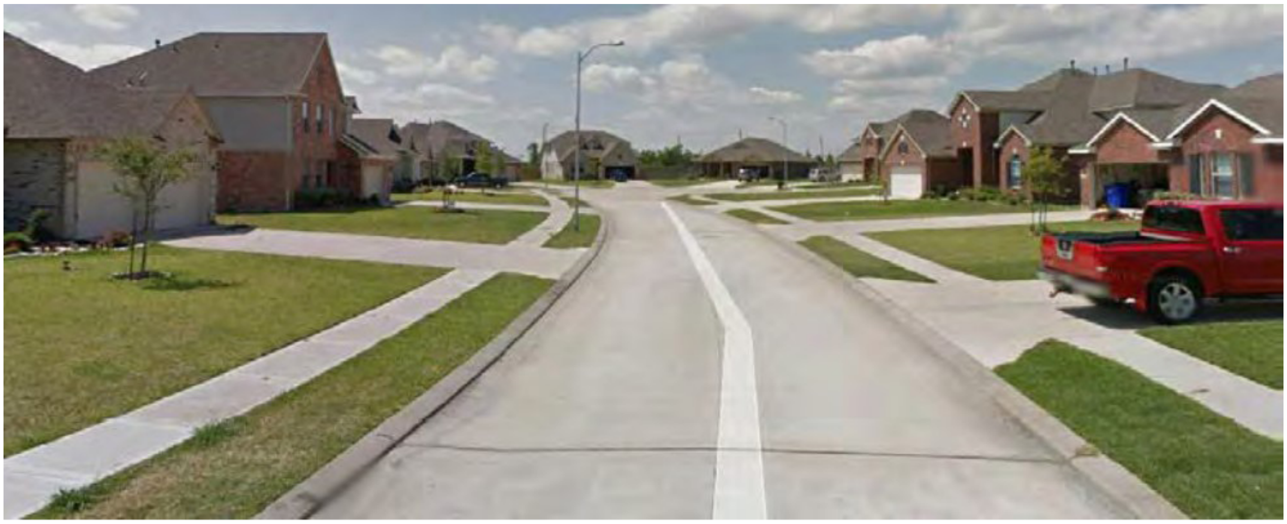


Figure 2-16. A narrow street in a residential neighborhood and setback sidewalks with an example of disconnected impervious cover. (Source: Hegemier et al. 2021; photo: Google Earth)

Driveways and Setbacks. The width of a typical residential driveway ranges from 12 ft wide for one car to 20 ft wide for two cars. Several alternative driveway designs can help reduce impervious cover, including the following (Hegemier et al. 2021):

- Shared driveways, with enforceable maintenance agreements and easements.
- Narrower driveway widths and lengths: if homes are set back from road, the first portion of the driveway can be a single lane, while the second part can be wide enough to accommodate two cars
- Alternative design such as double-tracks, which provide paved surfaces for tires while retaining grassy surfaces in between.
- Alternative surfaces such as reinforced grass or permeable paving materials.

Building and home setbacks can be shortened in some cases to reduce the amount of impervious cover from driveways and entry walkways. A setback of 20 ft is more than sufficient to allow a car to park in a driveway without encroaching into the public right-of-way (ROW) and reduces driveway and walk pavement by more than 30%compared with a setback of 30 ft.

Parking Areas. Often, parking lots are built with more spaces than are actually used. In part, parking standards are sometimes set to accommodate the highest hourly parking use during the peak season or the highest hourly parking demand for the particular use. Since ordinance language often is flexible as to the number of parking spaces allowed beyond the minimum, the result is often an excessive number of spaces. Setting both minimum and maximum parking standards can ensure that a sufficient number of parking spaces is provided to meet the demand without creating excess spaces.

Many options are available for reducing the overall parking lot footprint and site imperviousness (Hegemier et al. 2021). Initial steps include determining average parking demand and lot location, which may be used to set a lower maximum number of parking spaces to handle the demand. Additional design strategies include the following:

- Setting maximums for parking spaces rather than only minimums
- Minimizing parking stall dimensions by reducing both the length and width of the stalls
- Requiring a certain number of spaces to be sized for compact vehicles
- Using structured parking, which can reduce the amount of land converted to impervious cover
- Incorporating efficient parking lanes, such as using one-way drive aisles with angled parking rather than two-way aisles
- Encouraging shared parking, particularly in mixed-use commercial areas
- Using alternative porous surfaces, such as porous pavers or porous concrete

2.2.5. Disconnecting Impervious Cover

Disconnecting impervious cover is a low-cost, effective practice that can reduce total runoff volume, increase the time of concentration, and promote infiltration. The first step is to identify the sources of runoff and understand how it will be managed once disconnection has been implemented. Disconnection can reduce project costs by reducing or eliminating the need for more expensive structural practices.

By disconnecting impervious areas and directing the flow to infiltration basins or designated buffer areas, a portion of additional flow that would contribute to stormwater runoff is instead infiltrated close to the source. In addition to reducing runoff volume, stormwater that would potentially carry pollutants from the site to nearby surface waters gets treated and contributes to groundwater recharge.

Disconnection methods should be incorporated into the project at the planning and design level. These methods, however, must be used in concert with the design of other forms of stormwater conveyance and BMPs. When using disconnection methods, practitioners should still follow standard engineering practices associated with safe conveyance of stormwater runoff and good drainage design.

Downspout Disconnection. Rooftops with exterior drains for rain gutters (common for most residential structures) are one of the easiest disconnection practices to implement. Downspouts should be directed to landscaped portions of the site rather than to impervious driveways or sidewalks (**Figure 2-17**). Another option is to direct roof runoff to cisterns, rain barrels or other storage areas for later use.

Figure 2-17. Rooftop downspouts directed to cistern and stormwater planter at Ecoshed in Jackson, Mississippi.

Disconnecting Urban Areas. Downtowns and commercial strip centers often place buildings close to the sidewalk and the sidewalk close to the street or parking area. However, there are some alternatives for disconnecting these impervious surfaces (**Figure 2-18**).

Linear areas along the street, sidewalk, and building should include vegetation to intercept a portion of stormwater and also can be designed as biofiltration areas, vegetated swales, or vegetated filter strips. Site design should allow for a space of approximately 2–3 ft between the street and the sidewalk and between the sidewalk and the building. Disconnection also can be applied to parking lots. Setting aside a grassy area between the road and the edge of the parking area provides an opportunity for additional sustainable drainage techniques to be incorporated (Hegemier et al. 2021).

These disconnected vegetated areas alone might not be enough to filter all the stormwater from the site. When they are used in combination with other site design practices, however, they can be part of an overall strategy for effective stormwater management.

2.2.6. Design Considerations for Roads, Highways, and Bridges

Site development practices to protect the integrity of water bodies and natural drainage systems include those related to development of roads, highways, and bridges. Their design can benefit from the site assessment process described earlier. Section 2.2.4 outlines several approaches for reducing impervious cover associated with roadways. Section 5 of this guidance describes relevant practices that can be implemented in association with road or highway design, including infiltration practices, porous pavement, grassed swales, vegetated curb extensions, vegetated filter strips, and bioretention cells. Mississippi Department of Transportation (MDOT) specifications and manuals provide the State's detailed requirements for the design of state owned or operated roadways and bridges.

Related regulatory approaches for roadway and bridge design that can be implemented at the local level include tailoring zoning, subdivision regulations, and other ordinances to support green infrastructure and conservation design practices (MDMR and AllenES 2017). For example, details such as narrower minimum street widths in residential communities can be addressed through ordinance modifications. A review or audit of local codes and ordinances allows municipal leaders to identify and remove regulatory barriers to using green infrastructure. Tools such as EPA's Water Quality Scorecard can help identify and overcome barriers (USEPA 2009; MDMR and AllenES 2017). This section discusses more ideas for designing green streets, green highways, and environmentally friendly stream crossings.

Green Streets. Green streets incorporate a wide variety of green infrastructure elements, including street trees, permeable pavements, bioretention, water quality devices, stormwater planters, and swales (MDMR and AllenES 2017). Objectives in implementing green streets include reducing sources of stormwater, limiting stormwater transport and pollutant conveyance to the collection system, and restoring predevelopment hydrology to the maximum extent possible.

Green street technologies (see examples in **Figure 2-19**) can be applied to residential, commercial, and arterial streets as well as to alleys. Designers can select from a range of potential green infrastructure options depending on project needs. Typical features and benefits may include the following:

- Providing efficient site design
- Balancing parking spaces with landscape space
- Using surface conveyance of stormwater
- Adding significant tree canopy
- Improving walkability
- Increasing pedestrian safety
- Improving aesthetics
- Reducing the urban heat island
- Reducing runoff volume and increasing groundwater recharge and evapotranspiration

Figure 2-18. Disconnecting sidewalk runoff by redirecting flow into planter boxes is one strategy to manage stormwater flows in urban areas. (Photos: Natalie Segrest, MDEQ)

Figure 2-19. Green Street in Portland, OR. (Source: MDMR and AllenES 2017)

Green Highways. The Green Highways Partnership (GHP) concept was developed to promote innovative approaches to meeting transportation needs while promoting environmental stewardship, with an emphasis on sustainability (GHP 2008). The partnership originated as a combined initiative involving highway and environmental agencies. Characteristics of green highways related to environmental sustainability (see examples in **Figure 2-20**) include the following:

- Providing a net increase in environmental functions and values to the watershed
- Going beyond the minimum standards set forth by environmental law and regulations
- Identifying and protecting historical and cultural landmarks
- Mapping all resources in a project area to identify, avoid, and protect critical resource areas
- Using innovative natural methods to reduce imperviousness and treat runoff within the project area
- Using recycled materials to eliminate waste and reduce the energy required to build the highway
- Linking regional transportation plans with local land use through partnerships

- Controlling populations of invasive species and promoting the growth of native species
- Incorporating post-project monitoring to ensure environmental results
- Protecting the hydrology of wetlands and stream channels through restoration of natural drainage paths
- Achieving a suite of targeted environmental outcomes based upon local environmental needs
- Reducing disruptions to ecological processes by promoting wildlife corridors and passages in areas identified through wildlife conservation plans
- Encouraging smart growth by integrating and guiding future growth and capacity building within ecological constraints

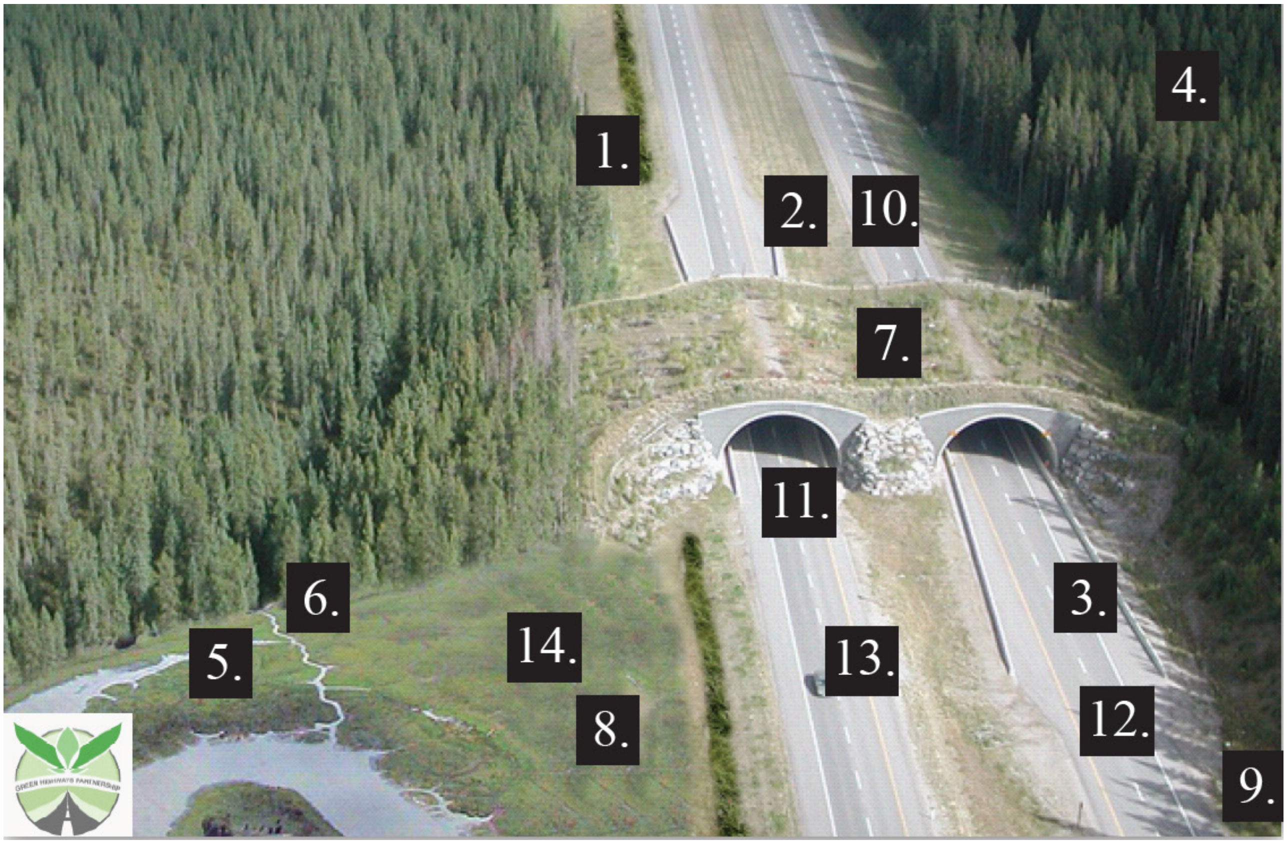


Figure 2-20. Example features that can be incorporated into green highway design: (1) bioretention, (2) porous pavement, (3) environmentally friendly concrete, (4) forest buffers, (5) stormwater wetlands, (6) stream restoration, (7) wildlife crossings, (8) soil amendments, (9) diesel hook-ups, (10) 100-year pavements, (11) use of recycled/reclaimed materials, (12) cool pavements, (13) alternative bio-fuels, (14) vegetated buffer. (Source: Green Highways Partnership 2008)

Stream Crossings. Bridges and culverts can be designed to minimize bank erosion and scour at stream crossings, while also providing passage for fish and other aquatic organisms. Preventing scour can contribute to better water quality. Proper sizing of culverts also is needed to adequately convey flood flows, reduce the frequency of road flooding, and reduce maintenance and replacement costs.

Providing passage for fish and other aquatic organisms might require special attention to design. Design options include various configurations, including bottomless culverts that eliminate impediments to fish passage. In some cases, a channel-spanning bridge can be a better choice than a culvert, as it will allow for natural streamflow, afford space for stream habitat, and accommodate a degree of natural migration of the channel over time. Compared to culverts, channel-spanning bridges tend to have lower risks and higher longevity and provide better passage for aquatic and terrestrial species. Providing space for active floodplains and debris flow also is an important consideration. Resources for stream crossing design for aquatic organism passage include publications by the U.S. Department of Agriculture's Forest Service (USDA 2008), the U.S. Department of Transportation Federal Highway Administration (USDOT 2007, 2010), and the Chesapeake Bay Program (2021).

2.2.7. Hydromodification: Channelization and Channel Modification and Streambank and Shoreline Erosion

Another component of sustainable site design involves minimizing the modification of stream channels and maintaining the integrity of streambanks and natural shorelines.

Channelization and Channel Modification

Hydromodification of channels can be defined as the channelization or modification of existing drainage ways, creeks, and streams that negatively impact water quality and habitat (Hegemier et al. 2021). It includes a variety of stream and shoreline alterations that can adversely affect hydrology, natural flow patterns, and aquatic systems. Examples of hydromodification (Hegemier et al. 2021) include the following:

- Widening, deepening of a channel to increase capacity
- Relocation of a stream
- Enclosing natural streams in pipes and box culverts
- Filling headwater streams and wetlands
- Straightening a stream, steepening its gradient to increase flow velocity
- Decreasing channel length by cutting off natural stream meanders
- Bank or shoreline stabilization using structures and hard engineering
- Bridge and culvert construction that change the flow patterns, vegetation, and slope

Avoiding hydromodification protects natural drainage and aquatic habitat as well as water quality. Retaining stream buffers in accordance with MDEQ requirements will reduce the potential for hydromodification impacts. Both the LCGP and SCGP require buffers of at least 50 feet (ft) in order to protect existing vegetation and support the integrity of existing stream channels (MDEQ 2019, 2022). These general permits are discussed further in Section 3 of this guidance.

For proposed channelization or channel modification projects that may be necessary, such as maintenance of levees, practices should be employed that support water quality, physical condition, aquatic habitat, and adjacent riparian areas (USEPA 1993). Practices include taking steps during the planning process to evaluate potential effects of proposed projects and to ensure that plans and designs reduce undesirable impacts. Appropriate models and methodologies should be used to evaluate the effects of proposed channelization and channel modification projects on instream and riparian habitat and to determine the effects after the projects are implemented. Suggested BMPs include streambank protection, levee protection, check dams for sediment control, vegetative cover, and controlling sediment loads (USEPA 1993).

Streambank and Shoreline Erosion

"Streambank erosion" refers to the loss of land along nontidal streams and rivers, while "shoreline erosion" refers to the loss of beach or land in tidal coastal bays or estuaries. The force of water flowing in a river or stream causes erosion of a streambank, carrying eroded material downstream where it is deposited in the channel bottom or on point bars located along bends in the waterway. In coastal bays and estuaries, waves and currents transport sands and gravels from eroded banks and move them in both directions along the shore, through a process called "littoral drift."

The erosion of shorelines and streambanks is a natural process that can have either beneficial or adverse impacts. Materials eroded from streambanks are deposited in the channel. If erosion is not excessive, this becomes fairly stable instream habitat, maintained over time through a balance of aggradation and degradation of channel substrate. Similarly, under natural conditions, the materials eroded from the shores of coastal bays and estuaries maintain beaches as a natural barrier between the open water and coastal lands. Beaches are dynamic systems that move back and forth onshore, offshore, and along shore with changing wave conditions. The finer grained silts and clays derived from the erosion of shorelines and streambanks are sorted and carried as far as the quiet waters of wetlands or tidal flats, where benefits are derived from addition of the new material (Hegemier et al. 2021).

However, there can be adverse impacts from shoreline and streambank erosion, if erosion rates are too high. Too much sediment can smother submerged aquatic vegetation beds, cover shellfish beds and tidal flats, fill in riffle pools, and contribute to increased turbidity and nutrient loads. Where streambank or shoreline erosion is a NPS pollution problem, streambanks and shorelines may benefit from stabilization. Vegetative methods are strongly preferred, although structural methods may be more effective in some situations.

Nonstructural practices that protect shorelines and streambanks include use of native plantings, soil bioengineering, and wetland creation. These practices are resilient and selfsustaining once they become established. Examples of vegetative techniques include live stakes, live fascines or bundles, and vegetated riprap along banks or shorelines.

In systems that already exhibit excessive streambank erosion, restoration practices can be employed to reduce erosion and restore healthier conditions (**Figure 2-21**). Natural channel design is one technique often used in stream restoration projects. Stream restoration using natural channel design techniques can be part of a multi-objective approach to improve water quality, restore riparian communities, and address flooding concerns. Stormwater BMPs and LID measures can address the quality and quantity of runoff reaching the stream from its upstream watershed. Habitat creation, revegetation of streambanks, preservation of natural communities, and design of streamside trails can be incorporated into the project design to meet multiple objectives.

Figure 2-21. Minebank Run in Baltimore, MD. Before (left) and after (right) stream restoration. (Source: USEPA Archives)

Typical objectives of natural channel design projects include the following (Hegemier et al. 2021):

- Creating geomorphically stable conditions for appropriate stream reaches
- Improving and restoring hydrologic connections between the stream and its floodplain
- Improving aquatic and terrestrial habitat
- Improving water quality by establishing buffers for nutrient removal from runoff and by stabilizing streambanks to reduce bank erosion and sediment loading
- Improving in-stream habitat by providing a more diverse bedform with riffles and pools, creating deeper pools and areas of water re-aeration, providing woody debris for habitat, and reducing bank erosion
- Providing storage within a floodplain to retain and attenuate flood flows

The San Antonio River Authority's Natural Channel Design Protocol (Harman et al. 2013) is one source of detailed guidance for the planning, design, permitting, construction, and maintenance of restored streams. This manual can be used to guide stream restoration and natural channel design in the coastal region and includes information on the following (as described by Hegemier et al. 2021):

- Watershed assessments
- Regional flow curves to define hydrologic conditions and design flows
- Field investigation and base map surveys, including bankfull discharge determination, stability, and bedform diversity; channel evolution; and restoration potential
- Natural channel design methods, including sediment transport analysis
- Natural channel design within flood control channels
- In-stream structures and bioengineering
- Construction plan preparation
- Technical specifications
- Permits
- Construction observation
- Maintenance
- Monitoring and evaluation

In tidal systems, living shorelines offer a sustainable alternative to traditional structural methods for addressing shoreline erosion. A living shoreline uses living plant material, oyster shells, earthen material, or a combination of natural materials and hard structures such as riprap or offshore breakwaters to protect property from erosion (MASGC 2022). Erosion caused by wind, water, and wave action can threaten residential and commercial property, reduce storm buffering capacity, and degrade aquatic and terrestrial habitat, and water quality. To counter these effects, property owners often build bulkheads or seawalls, but these features tend to alter or remove natural habitat. Living shorelines present an alternative that is ecologically sound and feasible for use in low-erosional settings. Living shoreline and structural practices can also be combined in hybrid approaches that provide protection from wave action and still offer ecological benefits (**Figure 2-22**).

Benefits of living shorelines include the following (MASGC 2022):

- Maintain natural coastal processes and shoreline dynamics
- Create or preserve habitats for native species of aquatic flora and fauna
- Preserve access for aquatic and terrestrial organisms
- Maintain land-to-water access for property owners
- Provide economical means of facilitating sediment accumulation, potentially resulting in formation of new land

- Create a natural buffer to reduce effects of erosion
- Trap and retain runoff and pollutants

MDMR's *Alternative Shoreline Management Guidebook* provides excellent guidance for planning and design of living shorelines and hybrid practices (MDMR 2013).

Figure 2-22. **Rock sill with planted marsh, an example of hybrid design employing structural stabilization and living shoreline techniques. (Photo: K. Duhring, MDMR)**

3. Protecting Water Quality during Construction

Excessive sediment and soil erosion from construction sites contributes to NPS pollution and causes other problems in coastal areas. Large sediment loads can cause sediment deposition in stream channels, degrading habitat, water quality, and aquatic life. Pollutants such as pesticides, fertilizers, and petrochemicals also are associated with construction activities. MDEQ's *Erosion and Sediment Control Manual* provides more detailed information on the environmental impacts of construction site erosion and practices that can mitigate those impacts (MDEQ 2011a).

The federal NPDES permitting program establishes requirements for construction projects of one acre or more to control NPS pollutants during construction. MDEQ is the statewide NPDES permitting authority in Mississippi and authorizes discharges from projects that are one acre or more through one of two general permits: Mississippi's SCGP applies to land-disturbing activities of one acre to less than 5 acres, and Mississippi's LCGP applies to land-disturbing activities of 5 acres or more.

Erosion and sediment control (ESC) BMPs are measures used to reduce erosion and retain sediment on-site. ESC BMPs are planned during project design and described

Figure 3-1. **Soil exposed during construction is subject to erosion and may contribute to NPS pollution if sites are not properly managed. (Photo: Natalie Segrest, MDEQ)**

and illustrated in an ESC plan and a Stormwater Pollution Prevention Plan (SWPPP). The MDEQ *Erosion and Sediment Control Manual* discusses the components of an ESC plan and includes examples (MDEQ 2011a), and the MDEQ *Stormwater Runoff Management Manual* describes SWPPP preparation (MDEQ 2011b). ESC BMPs must be appropriately designed, correctly installed, and adequately maintained to prevent erosion and retain soil on-site.

The rest of this section focuses on two specific tactics for protecting water quality during construction: minimizing site disturbance and using vegetated buffers to protect nearby waterways.

3.1. Minimizing Disturbance

Mississippi's general permits governing both large and small construction projects include provisions to reduce disturbance to natural areas and soils. Methods to minimize disturbance should be incorporated into planning construction projects to limit the amount of clearing and grading required on a development site. Two of these methods are minimizing the limit of disturbance (LOD) area for a project and phasing construction activities. These efforts ensure that the minimum amount of bare earth is exposed for the shortest amount of time.

The LOD is shown on construction drawings as the area surrounded by a boundary within which the land will be cleared of vegetation or graded or where infrastructure will be constructed. Minimizing the LOD means allowing disturbance only in the area absolutely necessary to construct the project. The placement of the LOD boundary should reflect reasonable construction techniques and equipment needs as well as the slopes, soils, and other physical characteristics of the development site. The LOD may vary by type of development, size of lot or site, and the specific development feature involved. Natural areas that can be avoided are shown as outside the LOD, thereby protecting established vegetation and the natural hydrology of those areas.

Construction phasing refers to constructing a project on a schedule that limits activity to only one portion of the site at a time. This method of construction phasing minimizes the time that bare earth is exposed to erosive forces and the amount of sediment and soil lost from a construction site due to erosion. Preferred construction phasing is to work in one portion of the site and stabilize it before moving on to another portion of the site. The State's 2022 LCGP includes a requirement that less than 50 acres be disturbed at a time during construction, unless adequate justification and additional controls are provided.

3.2. Protective Buffers

The MDEQ LCGP for sites of 5 acres or more includes enforceable permit requirements related to new development (MDEQ 2022). The LCGP includes provisions for development planning and post-construction stormwater management that affect how new development projects are designed and built, including several related to buffer protection. The LCGP provisions include:

- Where needed, "velocity dissipation devices shall be placed at detention or retention pond outfalls and along the outfall channel to provide for a non-erosive flow."
- The site operator must:
  …(p)rovide and maintain a 50-ft undisturbed natural buffer around waters of the United States; or provide and maintain an undisturbed natural buffer that is less than 50 ft and is supplemented by additional erosion and sediment controls, which in combination achieves the sediment load reduction equivalent to a 50-ft undisturbed natural buffer. **Figure 3-2** illustrates an example of a 50-ft undisturbed natural buffer.
- A minimum 150-ft buffer zone is recommended between land-disturbing activities and perennial water bodies. If a 150-ft buffer zone is not feasible, the permittee may provide and maintain an undisturbed natural buffer that is less than 150 ft supplemented by additional ESCs that, in combination, achieve the sediment load reduction equivalent to a 150-ft undisturbed natural buffer. The SWPPP required under the LCGP must contain written justification as to why specific controls were not deemed feasible.
- Buffer zones are defined in the permit as:
  …a strip of dense undisturbed perennial vegetation, either original or reestablished, that borders perennial streams and rivers, ponds and lakes and wetlands. Buffer zones

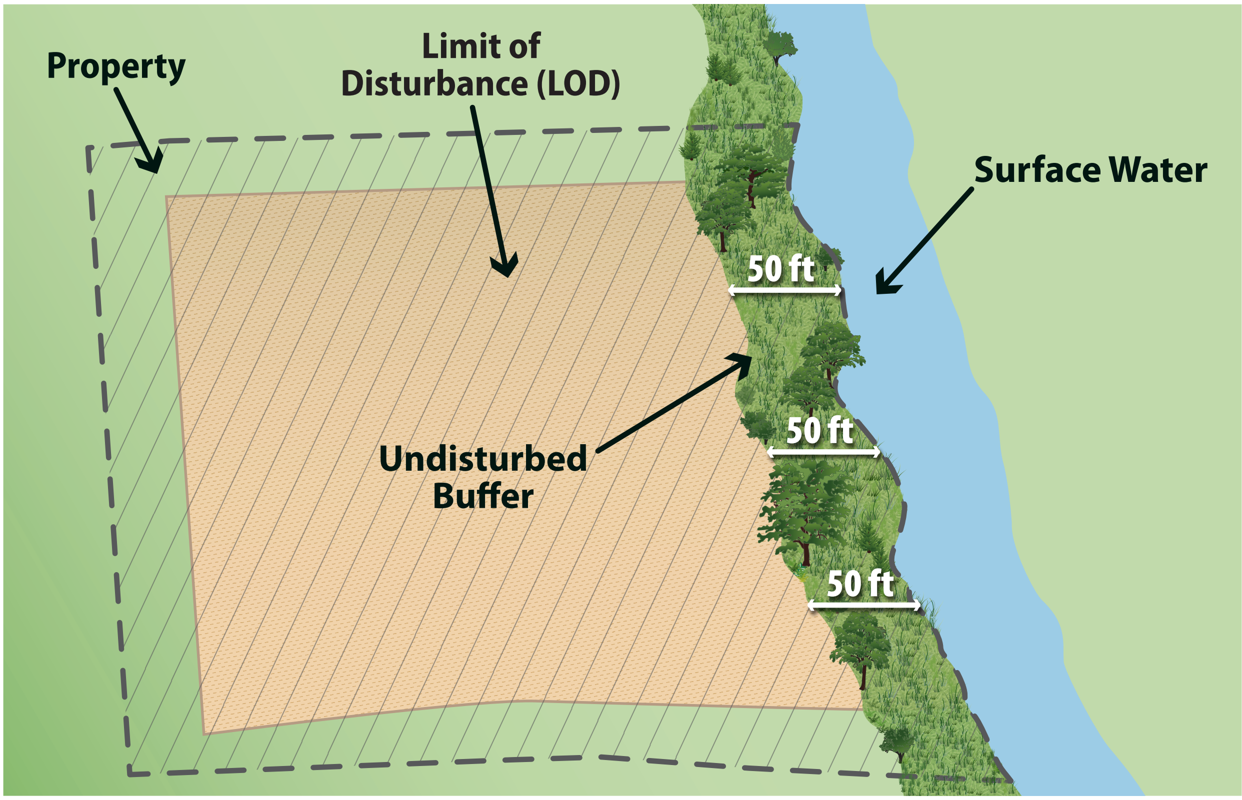


Figure 3-2. 50-ft. undisturbed natural buffer around waters of the United States.

are established for the purposes of slowing water runoff, enhancing water infiltration, and minimizing the risk of any potential nutrients or pollutants from leaving the upland area and reaching surface waters. Buffer zones are most effective when storm water runoff is flowing into and through the buffer zone as shallow sheet flow, rather than in concentrated form such as in channels, gullies, or wet weather conveyances. Therefore, it is critical that the design of any development include management practices, to the maximum extent practical, that will result in storm water runoff flowing into and through the buffer zone as shallow sheet flow.

- The operator must mark off "sensitive areas" by delineating and clearly flagging or otherwise marking off areas such as steep slopes, wetlands, perennial streams, and adjacent water bodies and other sensitive areas.
- Vegetative practices must be implemented to preserve existing vegetation where feasible and initiate vegetative stabilization after land-disturbing activities are completed. The practices may include, but are not limited to, temporary seeding, permanent seeding, mulching, sod stabilization, vegetative buffer strips, tree protection, and topsoil preservation.
- Final vegetative and soil stabilization measures must be initiated when any clearing, grading, excavating, or other land-disturbing activities have temporarily or permanently ceased on any portion of the site. Final stabilization means that all soil-disturbing activities at the site have been completed and either a uniform perennial vegetative cover with a density of at least 70% or equivalent measures (e.g., concrete or asphalt paving, rip rap, or other stable structures) have been established for the area.

4. Stormwater Performance Objectives and Design Approach

MDEQ has established a set of performance objectives for new development and redevelopment projects aimed at preventing NPS pollution in stormwater runoff and protecting the state's coastal water resources.

The performance objectives span the complete development process, from predevelopment planning to maintenance of stormwater practices after construction is complete. These objectives can best be achieved through coordination among public officials, local stormwater program staff, developers, and engineers. Many coastal communities already regulate the development process through development and planning ordinances, some of which also include stormwater management. **Appendix B** provides a model stormwater management ordinance that meets the performance objectives described in this section. Communities can compare their current ordinances with the model ordinance and identify areas in which their ordinances might be strengthened.

4.1. Performance Objectives

MDEQ recommends managing stormwater runoff by incorporating performance objectives into all new development and redevelopment projects that will disturb one acre or more. **Table 4-1** lists MDEQ's performance objectives for stormwater management.

Table 4-1. MDEQ Stormwater Management Performance Objectives

Objective	Purpose	Implementation
Conduct predesign planning	Clarify stormwater requirements, identify areas for protection, encourage low impact development, and expedite permitting	Meet with the jurisdictional stormwater authority staff and/or engineer before beginning the design
Use sustainable drainage design	Improve stormwater runoff quality and manage runoff quantity	Implement low impact development design approach and/or structural practices to reduce TSS by 80%.
Preserve buffer zones	Protect areas around creeks, rivers, wetlands, and tidal waters to manage flood risk and improve water quality	Delineate buffers on development plans and protect buffers from disturbance

Table 4-1. MDEQ Stormwater Management Performance Objectives

Objective	Purpose	Implementation
Protect areas subject to erosion and minimize erosion to nearby waterways	Minimize construction sediment runoff and protect creeks, rivers, wetlands, and tidal waters	Develop a construction ESC plan and SWPPP per the MDEQ SCGP and LCGP
Maintain post-construction BMPs	Promote long-term water quality and peak management performance, and improve appearance and function	Prepare a maintenance plan and conduct regularly scheduled inspections and maintenance when necessary

Note: TSS = total suspended solids.

Additional details on achieving each performance objective are provided below.

4.1.1. Conduct Predesign Planning

Predesign planning is essential for all new development and redevelopment projects. Protecting sensitive habitats and retaining natural landscapes should be incorporated into the process wherever possible. Schedule a predesign meeting, potentially including a site visit, prior to site design and include the jurisdictional stormwater authority staff and/or city engineer. The meeting should include discussion of the proposed land use, slopes, floodplains, buffer zones and other protected resources, and water quality management. Prior to the predesign meeting, it would be beneficial to prepare an exhibit or report with the following elements to facilitate the discussion:

- A site location map identifying the nearest receiving water bodies and any impairments or total maximum daily loads
- Topography
- Existing structures or other site features
- Location of existing water bodies, including wetlands and streams
- Floodplains
- Natural Resources Conservation Service (NRCS) soils group with an estimate of infiltration capacity
- Features required by local stormwater authorities
- Other protected resources, including historical, archaeological, and biological resources

During the predesign meeting, attendees should review the prepared exhibit and discuss features recommended for protective buffers, options for reducing impervious cover, and requirements for ESC and post-construction BMPs.

4.1.2. Use Sustainable Drainage Design

MDEQ's approach to achieving water quality and stormwater management performance objectives for new development and redevelopment is to:

- Design and construct developments with minimal impervious cover;
- Avoid impacts on wetlands and floodplains;
- Avoid concentrated flow to the maximum extent practicable;
- Limit disturbance activities to reduce erosion and sediment loss;
- Limit disturbance of natural drainage features;
- Preserve natural topography and vegetation; and
- Use sustainable drainage infrastructure to manage runoff.

The guidance provided in Section 2 describes how these and other sustainable design practices can be incorporated into new development and redevelopment projects. In addition, MDEQ recommends incorporating sustainable drainage infrastructure designed to mimic the site's natural hydrology by promoting stormwater storage, filtration, infiltration, and evapotranspiration. Benefits of sustainably designed drainage infrastructure include decreasing the erosive potential of increased runoff volumes and velocities associated with development, removing suspended solids and associated pollutants in post-construction runoff, and preserving in-stream habitat. To achieve these benefits, EPA recommends including post-construction stormwater BMPs designed to reduce average annual total suspended solids (TSS) loadings from fully stabilized sites by 80% (USEPA 1993).

To achieve 80% TSS reduction, post-construction stormwater BMPs are located and sized to capture sufficient runoff volume and remove TSS. MDEQ recommends using the runoff volume from the first 1-inch of rainfall as the design runoff volume to size stormwater BMPs in the coastal region. The design runoff volume was determined by evaluating the average annual rainfall in the coastal region, assumed pollutant runoff characteristics, typical stormwater BMP design features, and published stormwater BMP pollutant removal efficiencies.

Section 5 provides technical guidance for the planning, design, and maintenance of post-construction stormwater BMPs.

4.1.3. Preserve Buffer Zones

Buffer zones provide important water quality, habitat, and flood mitigation benefits provided by forested and other naturally vegetated riparian buffers along streams, rivers, wetlands, and tidal waterways. Land development policies and practices can support these benefits by strictly prohibiting certain activities within a defined buffer zone. Restricted uses can be defined for the entire buffer or by using a multiple-zone buffer approach where allowable uses are defined differently for each zone.

Stream Buffer Zones

MDEQ's SCGP and LCGP require a minimum 50-ft undisturbed natural buffer around waters of the United States. To provide greater protection, the LCGP recommends use of a 150-ft buffer, which is consistent with the minimum buffer width recommended by EPA for protection of perennial streams (USEPA 2021a). Perennial streams have water flowing year round during an average year and are generally indicated by a solid blue line on a U.S. Geological Survey (USGS) Quadrangle Map (scale 1:24,000, 7.5-minute series).

Buffer zone widths are measured from the top of a stream bank. The USGS definition of bank is the sloping ground that borders a stream and confines the water in the natural channel when the water level, or flow, is normal (USGS 2021). The top of bank is illustrated in **Figure 4-1**. Buffer boundaries should be clearly shown on construction plans and delineated with physical markers during construction.

A multiple-zone buffer approach is effective for defining buffer uses and protection strategies for areas adjacent to development or agricultural activities. Typically three zones (inner, middle, and outer) are described (USEPA 2021a) and the width, allowable uses, and vegetative cover are defined for each zone. The inner zone is, at a minimum, the area within 50 ft from the top of bank. The inner zone width should be expanded beyond 50 ft to include adjacent wetland and critical habitats. The inner zone should be undisturbed with natural vegetation. If lacking vegetation, these riparian areas would be high priority candidates for restoration of trees or other native vegetation.

The middle zone is typically 50–100 ft depending on stream size, buffer slope, and the limits of the 100-year floodplain. Allowed uses in the middle zone are less restrictive than the inner zone. Forest vegetation is ideal for the middle zone; however, low-impact land cover such as bike paths and some stormwater BMPs may be allowed. Impervious area within the middle zone should be minimized.

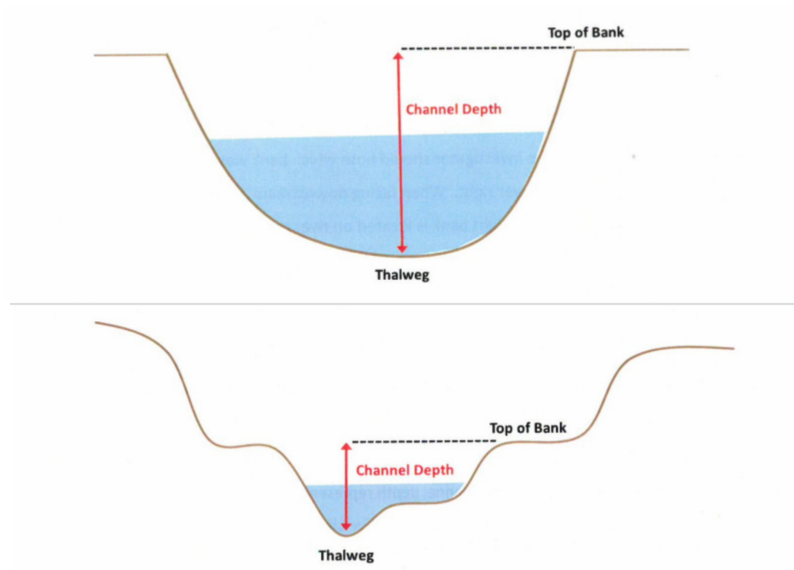


Figure 4-1. Top of bank for a parabolic channel (top) and a channel with terraced floodplains (bottom). (Source: USEPA 2014)

The outer zone is the furthest zone from the stream channel. It functions to slow and filter runoff from the developed area. The width of the outer zone is typically at least 25 ft and can be vegetated with trees, native vegetation, or dense turf grass. Acceptable uses for the outer buffer include lawns, gardens, and most post-construction stormwater BMPs.

Many communities have developed buffer ordinances that define buffer widths and activities prohibited within the buffer. An example of an ordinance for stream and wetland buffers is provided in **Appendix C**. Coastal communities are encouraged to include regular buffer maintenance requirements to ensure that buffers remain an asset to the community.

Wetland and Shoreline Buffer Zones

A buffer of 50 ft should be maintained along all wetlands, tidal waters, and coastal marshlands. The buffer width is measured horizontally from the edge of the wetland boundary or estuarine area. Wetland boundaries should be located by a qualified professional through a wetland delineation. All wetlands deemed to be USACE jurisdictional wetlands under the CWA require buffers.

Other Buffer Zones

In addition to the buffer zone provisions discussed in Section 4.1.3, development projects may be subject to additional buffer zone requirements. Local ordinances may specify different buffer zone sizes or restrictions. In addition, sensitive areas such as state or national parks and state or national forests may require additional protection.

4.1.4. Protect and Minimize Areas Subject to Erosion

New development projects within the coastal region are subject to the same requirements as those outlined in the SCGP and LCGP. Section 3 and the MDEQ *Erosion and Sediment Control Manual* discuss practices for protecting and minimizing easily erodible areas during the construction process (MDEQ 2011a).

4.1.5. Maintain Post-Construction BMPs

Maintenance of structural stormwater practices is critical to effective pollutant removal and runoff reduction and maintenance costs should be considered during the selection of stormwater practices in the site design phase. The responsibility for maintaining stormwater practices in residential subdivisions typically belongs to the homeowners association while the property owner usually is responsible for maintenance on commercial lots. In some instances, the local stormwater authority may accept that responsibility. Responsibility for maintenance for the life of the practice should be clearly identified during the design phase.

The design engineer should develop a structural stormwater maintenance plan that is acceptable to the jurisdictional stormwater authority. The maintenance plan should include the following:

- Specification of routine and non-routine maintenance activities to be performed
- A schedule for maintenance activities
- Provision for access to the practice by jurisdictional stormwater authority or other designated inspectors
- Name, qualifications, and contact information for the party(ies) responsible for maintaining the BMP(s)
- The signature(s) of the party(ies) responsible for maintenance and the date the plan was signed

Typical operations and maintenance activities for each structural stormwater practice are described in Section 5 of this document and in the MDEQ *Stormwater Runoff Management Manual* (MDEQ 2011b).

4.2. Submittal Requirements

Jurisdictional stormwater authorities often require developers to submit information about their proposed project for review and approval. This section discusses information that might be required by jurisdictional stormwater authorities to aid in determining if the new development or redevelopment project has been designed to meet the MDEQ performance objectives.

4.2.1. Introduction

Include the following information in a short written introduction to the existing site:

- Location map and size and existing land use of the site
- Description of existing land use of all adjacent properties
- General description of existing site topography, natural and man-made features, watershed name(s), drainage patterns, flow path, receiving waters, soil types, and ground cover

4.2.2. Project Overview

Consider including the following information in the project overview:

- A general description of proposed uses and improvements, lot subdivision, roadways, and other pertinent improvements
- Phasing and timing of the project

- A general description of proposed drainage, water quality, and ESC facilities expected to be used on-site and the methodology for choosing the facilities
- Total site area and impervious cover planned for the development
- A description of the potential pollutant activities to be conducted at the site, if applicable, including chemical storage and/or use; vehicle, equipment, or boat repair and maintenance; on-site wastewater treatment; product fabrication; and washing/cleaning activities
- Confirmation that all applicable regulations and public health safety requirements will be met by the developer, contractor, and builder
- A simple drawing depicting the proposed layout, impervious cover areas, general hydrologic information, on-site and adjacent drainage conditions and improvements, and other pertinent information required for site stormwater assessment (a conceptual plan)

4.2.3. Site Layout and Drainage Design

The site layout and drainage design should include the following:

- Legend, north arrow, and scale
- Existing property lines, ROWs, structures, impervious surfaces, and improvements
- Existing topography–contours
- Location of FEMA 100-year floodplain, floodway, and velocity zone boundaries that encroach on the site
- Existing drainage patterns, flow paths, stormwater discharge locations, and drainage easements
- Buffer zones
- Limits of existing disturbed area
- Proposed lots and/or building locations, ROWs, roadway locations, cross sections of impervious surface areas, and pavement types
- Proposed grading (contours or elevations), drainage patterns and basins, discharge locations, and proposed easements
- Size, location, and basis of design of all permanent drainage and stormwater quality improvements, including culverts, pipes, detention basins, and swales
- Details of stormwater controls showing outlet structure dimensions, erosion protection, and flow control devices

4.2.4. Design Steps

Include the following steps when designing new developments or redevelopments:

1. Compute the impervious cover for the development.

2. Delineate drainage areas within the site to define the impervious cover percentage at each discharge point or BMP. When a site contains multiple drainage areas, calculate the impervious cover for each area.
3. Disconnect impervious areas and reduce concentrated flow by employing LID techniques wherever possible.
4. Select the appropriate post-construction stormwater BMPs to meet the site constraints and manage stormwater runoff.
5. Compute the stormwater volume based on the runoff from the 1-inch rainfall event as discussed in Section 5.
6. Design the post-construction BMPs according to guidance in Section 5, including discharge to the buffer zone in a sheet flow manner, if applicable.

4.3. Incorporating BMPs into a Typical Development Project

Typical development projects within the coastal region consist of single-family residential, multifamily residential, and commercial, retail, and office. Stormwater BMPs can be employed, alone or in combination, in all types of development. Many existing developments in the region provide stormwater detention for flood control. Designers can enhance flood control detention basins for TSS removal by modifying a typical stormwater detention basin design to promote infiltration, filtration, and settling. Section 6 describes how to retrofit detention facilities to improve the performance of the drainage system while providing aesthetic benefits, recreational opportunities, and wildlife habitat.

4.3.1. Single-Family Residential Development

Stormwater BMPs are typically incorporated into single-family residential subdivisions during the design process. Stormwater BMPs such as bioretention, grassed swales, vegetated filter strips, and vegetated curb extensions work well to capture and treat street runoff and can be designed to be aesthetically pleasing. Stormwater ponds are frequently constructed in residential subdivisions because they can be designed for flood control and water quality benefits and usually there is space available for them. Residential stormwater ponds are often viewed as a neighborhood amenity that provides wildlife habitat and even recreational opportunities.

Homeowners associations are typically responsible for the maintenance of stormwater BMPs in residential subdivisions. Considering BMP maintenance frequency and costs during the design phase will help in BMP selection and increase the likelihood that the BMP is properly maintained and functioning.

While single residential lots developed or redeveloped outside of a subdivision may not meet the 1-acre threshold, MDEQ recommends that lot developers incorporate BMPs that will treat runoff at the source, reducing the potential for cumulative, downstream impacts. BMPs suitable for individual residential lots include rain gardens and cisterns. **Figure 4-2** shows a residential rain garden at the Cottages at Oak Park in Ocean Springs, MS. Mississippi's *Green Infrastructure Toolbox* provides guidance on benefits, limitations, costs, maintenance, design features, and function of many residential lot BMPs (MDMR and AllenES 2017).

Figure 4-2. Residential rain garden at the Cottages at Oak Park in Ocean Springs, MS. (Photo: Kristen Sorrell, MDEQ)

4.3.2. Multifamily Residential Development

Multifamily residential development, such as apartment and condominium complexes, have a significant amount of impervious cover. Bioretention areas, infiltration practices, tree trenches, vegetated curb extensions and stormwater ponds are common BMPs employed at these sites. Multifamily residential developments typically have large parking lots, which generate a large volume of runoff. Distributing multiple smaller practices, such as bioretention areas and curb extensions, throughout the parking lot works well to capture and treat runoff from the first inch of rainfall. Overflows that convey larger flows to a downstream drainage system may be warranted.

4.3.3. Commercial, Retail, and Office Development

Similar to multifamily residential developments, commercial and retail developments frequently have a significant amount of impervious cover, including rooftops and parking lots. Feasible stormwater BMPs include bioretention, infiltration, tree trenches, and curb extensions. If flood control is required, then stormwater ponds may be designed for both flood control and water quality treatment. Downspouts can be directed to landscaped areas or BMPs for treatment of roof runoff. Incorporating BMPs into a retail redevelopment project could be complicated if the area is already fully developed and space is limited.

5. Best Management Practices for Sustainable Drainage Design

Stormwater BMPs are used to manage NPS pollution (stormwater runoff quality) and peak flow rates from new development, after construction has been completed and the site has been permanently stabilized. This section provides technical guidance for BMP planning, design, and maintenance. Following the site design approach described in Section 2 and the general design guidelines in this section will reduce TSS by at least 80% and maintain post-development peak runoff rates similar to predevelopment levels for the first 1.0 inch of rainfall. Sustainable drainage practices are recommended for all new development and redevelopment projects that disturb one acre or more of land and projects less than one acre that are part of a larger common plan of development or sale that will result in disturbance of one acre or more.

5.1. General Design Guidelines

Mississippi has two stormwater BMP design references: *Green Infrastructure Toolbox and Stormwater Runoff Management Manual (*(MDMR and AllenES 2017; MDEQ 2011b*).* This document contains design guidance compiled from these references and other design manuals. When necessary, guidance has been revised or enhanced to support the coastal area stormwater performance objectives.

MDEQ's *Appendices: Developing Plans & Design Best Management Practices*, Volume 3 of the Mississippi Handbook (MDEQ 2011c), provides the equations (Equation 1 and Equation 2) for calculating the volume of runoff from a specified rainfall depth. Set R_D in Equation 1 to 1 inch to calculate the runoff volume for BMP design. This section describes how the runoff volume calculated in Equation 1 is used to size select stormwater BMPs that work well in coastal Mississippi. There are other BMPs not included in this section that also might be used for water quality treatment.

$$V = 3630 \, x \, R_D \, x \, R_V \, x \, A$$ Equation 1

Where:

$V = volume\ of\ runoff\ for\ the\ 1\ inch\ rainfall\ depth\ (ft^3)$

$R_D = \ rainfall\ depth\ (in) = 1\ inch$

$R_V = runoff\ coefficient, unitless$

$A = watershed\ area\ (acres)$

$$R_V = 0.05 + 0.9 \, x \, I_A$$ Equation 2

Where:

$I_A = impervious\ fraction, unitless$

This section discusses the following BMPs:

- **Infiltration Practices (basins, trenches, and dry wells)**—Infiltration practices are stormwater BMPs that enhance water percolation through a media matrix, which slows and partially holds stormwater runoff and facilitates pollutant removal.
- **Permeable Pavements**—Permeable pavers, pervious asphalt, and pervious concrete are three types of permeable pavements that allow water to infiltrate through a surface layer to a stone bed, where it is held until it infiltrates into the surrounding soil. Permeable pavements can be used in most applications where traditional pavements are used, including driveways, parking lots, sidewalks, and trails.
- **Bioretention Cells**—A bioretention cell consists of a depression in the ground filled with a soil media mixture that supports various types of water-tolerant vegetation. The surface of the BMP is depressed in bioretention cells to allow for ponding of runoff that filters through the BMP media. Water exits the bioretention area via exfiltration into the surrounding soil, flows out an underdrain, and is processed through evapotranspiration. The surface of the cell is protected from weeds, mechanical erosion, and rapidly drying out by a layer of mulch.
- **Stormwater Planter Boxes and Tree Trenches**—A stormwater planter or tree trench is a container or enclosed feature located either aboveground or belowground planted with vegetation that collects and treats stormwater using bioretention.
- **Grassed Swales**—Grassed swales are landscape elements designed to concentrate or remove silt and pollution from surface runoff water. They consist of a shallow stormwater channel densely planted with a variety of grasses, shrubs, and/or trees designed to slow, filter, and infiltrate stormwater runoff. While swales themselves are intended to effectively treat runoff from highly impervious surfaces, pretreatment measures enhance swale performance.
- **Rain Gardens**—Rain gardens are shallow depressions planted with native vegetation and designed to capture runoff. Water is held in the shallow depression as it slowly infiltrates into the ground.

- **Vegetated Filter Strips**—A vegetated filter strip is a wide belt of vegetation designed to provide infiltration, intercept sediment and other pollutants, and reduce stormwater flow and velocity. Filter strips are similar to grassed swales but are designed to intercept overland sheet flow (not channel flow). They cannot treat high-velocity flows. Surface runoff must be evenly distributed across the filter strip. Vegetation can consist of existing cover that is preserved and protected or new cover to be planted to establish the strip. Filter strips must be used with another stormwater control practice (such as a grassed swale) to achieve the 80% TSS reduction.
- **Constructed Stormwater Wetland**—Wetlands temporarily store stormwater runoff in shallow pools that support emergent and riparian vegetation. The storage, complex microtopography, and vegetative community in stormwater wetlands combine to form an ideal matrix for the removal of pollutants. Stormwater wetlands also can effectively reduce peak runoff rates and stabilize flow to adjacent natural wetlands and streams.
- **Stormwater Ponds**—Stormwater ponds are constructed basins that have a permanent pool of water throughout the year. Sediment entering the pond falls to the bottom and is removed from the runoff. Designers commonly incorporate flood control and aesthetic features into stormwater pond designs.

This section is organized by stormwater BMP. A one-page fact sheet is provided at the start of each stormwater practice summarizing implementation considerations, including land requirements, capital cost, and maintenance burden. Pollutant removal efficiencies, design criteria, advantages and benefits, and disadvantages and limitations are listed to aid the designer or engineer in selecting practices for new development sites. Detailed planning and design guidance follow the fact sheet introduction. Considerations for successful construction and installation of the BMP are discussed followed by expected maintenance activities.

Practices with TSS removal of less than 80% must be used in series with other stormwater practices to achieve a TSS removal of 80% or more. For example, vegetated filter strips remove approximately 60% TSS. Vegetated filter strips should be used upstream of other stormwater practices to achieve an 80% TSS removal. One example of this is as pretreatment to an infiltration trench.

STORMWATER BEST MANAGEMENT PRACTICES FOR PROTECTING COASTAL WATERS

MISSISSIPPI DEPARTMENT OF ENVIRONMENTAL QUALITY

Implementation Considerations

- (L) Land Requirement
- (H) Capital Cost
- (H) Maintenance Burden

Residential Subdivision Use: YES

Other Considerations:
Highly applicable for roadway projects

Pollutant Removal

Total Suspended Solids	100%
Nutrients:	
Total Phosphorus	100%
Total Nitrogen removal	100%
Metals:	
Cadmium, Copper, Lead, and Zinc removal	100%
Pathogens:	
Fecal Coliform	100%

For more information reference MDEQ's *Managing Stormwater for Healthy Watersheds in Coastal Mississippi: Best Practices*

(L) Low (M) Medium (H) High

Infiltration Practices

An infiltration practice is designed to infiltrate stormwater into the soil. Types of infiltration practices include infiltration basins, trenches, or dry wells.

Design Criteria

- Pretreatment, such as filter strips, grassed swales with check dams, concrete sumps, or forebays, must be provided upstream of all infiltration practices
- Infiltration practices should be designed to completely drain within 72 hours of the end of a rainfall event
- Underlying native soils must have an infiltration rate of 0.52 in/hr or greater
- The distance from the bottom of an infiltration practice to the top of the water table should be 2 feet or more
- Observation wells are used to monitor percolation and performance of the practice
- Infiltration practices must not be placed under pavement or concrete

Advantages/Benefits

- Helps restore pre-development hydrology on development sites and reduces post-construction stormwater runoff rates and volumes
- Provides a very high level of removal for all pollutants
- Provides for groundwater recharge
- Good for small sites with well draining soils
- Can be integrated into development plans as attractive landscaping features

Disadvantages/Limitations

- Can only be used to manage runoff from relatively small drainage areas of 5 acres or less
- Potential for groundwater contamination
- High clogging potential; should not be used on sites with fine-particle soils (clays or silts) in drainage areas
- Should not be located where they may undermine foundations or negatively affect underground utilities or other infrastructure
- Geotechnical testing required, two borings per practice

Montgomery County Planning Commission
https://www.flickr.com/photos/75012107@N05/14660267252/

5.2. Infiltration Practices

An "infiltration practice" is designed to infiltrate stormwater into the soil. Types of infiltration practices include rain gardens, infiltration basins, trenches, and dry wells.

- Rain gardens, discussed in more detail in Section 5.7, are shallow surface depressions planted with native vegetation.
- Infiltration basins are shallow impoundments with an engineered soil mix designed to hold water while it infiltrates into the surrounding soil. They can be planted with native vegetation to increase aesthetics and enhance pollutant removal.
- Infiltration trenches are deeper than infiltration basins and filled with stone.
- Dry wells are shallow stone-filled reservoirs located below the surface. They are well suited to receiving rooftop runoff and runoff from very small drainage areas.

Infiltration practices can be challenging to apply on many sites because of their soils requirements. This practice is believed to have a high pollutant-removal efficiency and can help recharge the groundwater, thus increasing baseflow to streams. In addition, some studies have shown relatively high failure rates compared with other management practices. Pretreatment devices for removing sediment and solids must be used to protect infiltration practices from clogging and include filter strips, grassed swales, concrete sumps, and forebays.

5.2.1. Planning Considerations

The use of infiltration practices is often sharply restricted by concerns over groundwater contamination, soils, and clogging at the site. They work best in relatively small drainage areas (less than 5 acres) and in completely impervious or stable drainage areas to minimize the amount of sediment going to the infiltration practice. Infiltration basins are frequently used to infiltrate runoff from adjacent impervious surfaces, such as parking lots. In these cases, a filter strip should be installed between the pavement and the infiltration practice to trap sediment and litter before it is washed into the practice.

Another approach is to construct infiltration practices at the downgradient edge of permeable pavement. In this case, the permeable pavement is the inlet to the device. Because water also will infiltrate through the base of the pavement, the size of the downstream infiltration device may be reduced significantly. Infiltration practices may appear in a variety of geometries. Runoff frequently is piped to these devices from stormwater inlets on patios, parking areas, roofs, and other impervious areas. These devices may also receive runoff via sheet flow. Infiltration practices may provide partial peak flow reduction for larger rainfall events; however, other BMPs are required to provide full flood protection. Design of the infiltration practice should include a safe bypass for larger flows.

Soils and topography are limiting factors when siting infiltration practices. Soils must be significantly permeable to ensure that the practice can infiltrate quickly enough to reduce the potential for clogging. Soils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for groundwater contamination. A *site-specific* hydrogeologic investigation should be conducted to establish the suitability of site soils for the infiltration practice. To be suitable for infiltration, underlying soils must have an infiltration rate of 0.52 inch or more per hour, as initially determined from the NRCS soil textural classification (typically hydrologic soil groups A and B) and subsequently confirmed by field geotechnical tests.

Infiltration practices should be designed with bottom slopes as flat as possible. Designers always need to provide significant separation distance (2–5 ft) from the bottom of the infiltration basin and the seasonally high groundwater table to reduce the risk of contamination. Infiltration practices also should be separated from drinking water wells.

5.2.2. Design Criteria

The sizing of an infiltration practice is determined by the dewatering requirements. Infiltration devices must be able to completely dewater within 3 days. The time to dewater can be estimated roughly as the runoff capture volume for the device divided by the product of the hydraulic conductivity and the effective infiltrating area. This can be rearranged to produce Equation 3 for determining the effective infiltrating area needed:

$$A = \frac{V}{2\ x\ (K\ x\ T)} \qquad \text{Equation 3}$$

$Where:$

$A = effective\ infiltrating\ area\ (ft^2)$

$V = volume\ of\ water\ requiring\ infiltration\ (ft^3) = volume\ of\ runoff\ for\ the\ 1 - inch\ rainfall\ depth$

$K = hydraulic\ conductivity\ of\ soil\ (\frac{in}{hr})$

$T = dewatering\ time\ (days)$

The volume of water requiring infiltration (V) is the runoff volume from the 1.0-inch storm. The hydraulic conductivity of the soil (K) is the resultant value from the field testing performed on the site. The dewatering time (T) for infiltration devices must be 3 days or less.

Once the effective infiltrating area (A) is obtained from the formula, translating it into actual infiltration device dimensions can still be somewhat difficult. The value for A used in the formula is the larger of either the bottom surface area or one-half of the total (wetted) wall area. The determination of the length, width, and depth dimensions is, therefore, often an iterative process using the effective infiltrating area (A) and typical length, width, and depth recommendations.

A minimum of one observation well should be included in the design of an infiltration system to periodically verify that the drainage media are fully draining. The monitoring well should consist of a 4- to 6-inch-diameter, perforated polyvinyl chloride (PVC) pipe with a locking cap. The well should be placed near the center of the facility or in the general location of the lowest point within the facility, with the invert at the excavated bottom of the facility.

Landscaping can enhance the aesthetic value of infiltration basins and improve their function. Vegetation encourages infiltration and thick vegetation prevents the formation of rills. **Appendix A** includes a list of plants suitable for infiltration basins. Vegetation selected for infiltration basins should be able to tolerate drought and occasional flooding. Infiltration trenches and dry wells do not have vegetation.

5.2.3. Construction Considerations

Care should be used during installation to minimize compaction of soil on the bottom and walls of infiltration devices, since this will reduce the permeability at the soil interface. To avoid compacting the drainage media, lighter weight equipment and construction techniques that minimize compaction should be used.

Runoff should not be directed into an infiltration device until the drainage area is stabilized. A construction sequence must be followed that reflects the need to stabilize the infiltration device. The longevity of infiltration devices is strongly influenced by the care taken during construction.

5.2.4. Maintenance

Regular maintenance is critical to the successful operation of infiltration basins. Immediately after the infiltration basin is established, the vegetation will be watered twice weekly if needed until the plants become established (typically 6 weeks). No portion of the infiltration basin will be fertilized after the initial fertilization required to establish the vegetation. If areas of bare soil and/or erosive gullies form, regrade the soil to remove the gully, plant a ground cover, and water it until it has established.

The vegetation in and around the basin should be maintained at a height of approximately 6 inches. Should sediment accumulation reach 75% of the original design depth, the source of sediment should be identified and remedied. The sediment should be removed, and the basin restored to original design specifics.

STORMWATER BEST MANAGEMENT PRACTICES FOR PROTECTING COASTAL WATERS

MISSISSIPPI DEPARTMENT OF ENVIRONMENTAL QUALITY

Implementation Considerations

L — Land Requirement

M H — Capital Cost

M H — Maintenance Burden

Residential Subdivision Use: YES

Other Considerations:

May be used in conjunction with other BMP solutions

Applicable for treating street runoff

May be applicable in retrofit situations

Pollutant Removal

Pavers

Total Suspended Solids	70–80%
Nutrients	35–70%
Metals	13–90%

Porous Asphalt

Total Suspended Solids	95–100%
Nutrients	45%
Metals	75–100%

Porous Concrete

Total Suspended Solids	90%
Nutrients	N/A
Metals	75–90%

For more information reference MDEQ's *Managing Stormwater for Healthy Watersheds in Coastal Mississippi: Best Practices*

L Low — M Medium — H High

Permeable Pavements

Permeable pavements are BMPs that infiltrate water through the surface layer to a crushed stone bed. The water is stored in the crushed stone bed where it infiltrates into the soil below. For areas where the native soils have low permeability, a perforated underdrain can be provided to collect water and convey it to the downstream conveyance system. Permeable pavements are considered green infrastructure practices that reduce stormwater volume and remove pollutants. Depending upon the design, permeable pavements may also provide peak flow control. There are three primary types of permeable pavement: permeable pavers, pervious asphalt pavement, and pervious concrete pavement.

Design Criteria

- Design subsurface reservoirs to hold the runoff volume from the 1-inch storm event
- Use of underdrain is recommended in low permeable soils
- If infiltration is not desired, use an underdrain and liner
- For slopes greater than 2%, terrace the subgrade base or use underdrains to intercept flow

Advantages/Benefits

- Stormwater runoff reduction
- Improved water quality
- Improved air quality
- May help to reduce the heat island effect

Disadvantages/Limitations

- Should not be used in hot spots
- Should not be used on high-volume or high-speed roadways
- Do not use in areas that may receive high sediment loads
- Should not be used where hazardous materials may be loaded, unloaded, or stored

Photo: Kristen Sorrell, MDEQ

5.3. Permeable Pavements

"Permeable pavements" are BMPs that infiltrate water through the surface layer to a crushed stone bed. The water is stored in the crushed stone bed where it infiltrates into the surrounding soil. For areas where the native soils have low permeability, a perforated underdrain should be provided to collect water and convey it to the downstream conveyance system. Permeable pavements are green infrastructure practices that reduce stormwater volume, remove pollutants, and provide some detention. When properly constructed, permeable pavements are a durable and cost-competitive alternative to conventional pavements (USEPA 2021b). There are three main types of permeable pavements: permeable pavers, pervious asphalt pavement, and pervious concrete pavement.

- Permeable pavers are manufactured units with openings filled with small-sized aggregates or soil creating a permeable surface (**Figure 5-1**). Permeable pavers are highly attractive, durable, and easily repaired; require low maintenance; and can withstand heavy vehicle loads.
- Pervious asphalt is standard hot-mix asphalt with reduced sand or fines that allow water to drain through it.
- Pervious concrete, also known as pervious, gap-graded, or enhanced porosity concrete, is concrete with reduced sand or fines that allow water to drain through it.

Figure 5-1. Close-up views of two types of permeable pavers. Openings filled with aggregate (left); openings filled with soil and planted with grass (right) (Photos: Kristen Sorrell, MDEQ).

For each of these pavement options, a crushed stone aggregate bedding layer and stone base is provided under the pavement layer for structural support and water storage. Permeable pavements provide benefits other than water quality. They reduce pavement ponding and light-colored permeable pavements help reduce urban temperatures and improve air quality.

5.3.1. Planning Considerations

Permeable pavements can be used in most applications where traditional pavements are used, such as roadways, sidewalks, driveways, parking lots, and bike paths. Avoid using permeable pavements in the following areas:

- On high-volume and/or high-speed roadways
- In areas that might receive high-sediment loads
- In areas where land use or activities generate highly contaminated runoff, with higher concentrations than is typically found in stormwater runoff
- In areas where chemical pollutants may be stored or transferred

Heavy loads on permeable concrete results in increased surface abrasion and the pavement deteriorates more quickly than traditional concrete (USEPA 2021b). The strength of permeable asphalt is usually lower than traditional asphalt mixtures; however, strength and performance can be improved depending upon the type of asphalt used (Chen, Sun, & Liao, 2012).

Permeable pavements may be designed to receive concentrated flow from roofs or other impervious surfaces (North Carolina Department of Environmental Quality, 2020). Prevent runoff containing sediment from adjacent pervious surfaces from flowing over the permeable pavement to avoid frequent clogging. Permeable pavement can be used upstream of other BMPs, such as rain gardens and stormwater planters.

These practices should not be installed in areas that may receive heavy sediment loads such as runoff from bare earth areas. Permeable pavements provide some peak flow reduction but are not typically designed to reduce peak flows from large rainfall events. If flood control is required for a new development, another BMP such as a constructed stormwater wetland or wet extended detention pond will likely be required and can be used in conjunction with permeable pavements.

The following items are often considered when selecting the type of permeable pavement used for a specific design (USEPA 2021b):

- Appearance
- Cost
- Types of applied loads on pavement
- Material availability
- Constructability
- Maintenance

Permeable asphalt parking lots have been shown to have a life expectancy of over 30 years, while the life expectancy of permeable concrete is 20–40 years (USEPA 2021b).

5.3.2. Design Criteria

Two critical components of permeable pavement design are meeting the structural design requirements and providing the infiltration rate and volume to treat the runoff from the 1-inch rainfall event. The American Association of State Highway and Transportation Officials, National Asphalt Pavement Association, and National Asphalt Pavement Association are often used as references for permeable pavement structural design. Recommended design criteria for achieving 80% TSS removal and maximizing infiltration of the water quality volume are provided below.

If permeable pavements are used in areas in which the underlying *in situ* infiltration rate is less than 0.5 inches per hour, then an underdrain system should be provided. A minimum of two borings (one per 5,000 square feet) is recommended to test the permeability of the underlying soil. The depth of the surface layer (asphalt, pavers and gravel joints, or concrete) is usually between 4 and 8 inches, depending upon the depth required to achieve bearing strength, manufacturers specifications, or other pavement design requirements (Atlanta Regional Commission, 2016). The crushed stone bed acts as a reservoir layer and is typically 2–4 ft.

Equation 4 can be used to calculate the minimum surface area for permeable pavements (Atlanta Regional Commission, 2016). Calculate the design runoff volume for a 1-inch rainfall depth using Equation 1.

$$A_p = \frac{V(d_s+d_{rl})}{[(k_s \times d_s \times t_{s)+}(k_{rl} \times d_{rl} \times t_{rl})]} \qquad \text{Equation 4}$$

Where:

$A_p = surface\ area\ of\ permeable\ pavement\ (ft^2)$

$V = volume\ of\ runoff\ for\ the\ 1 - inch\ rainfall\ depth\ (ft^3)$

$d_s = surface\ layer\ (asphalt, concrete, or\ paver\ small\ aggregate\ layer)\ depth\ (ft)$

$d_{rl} = stone\ bed\ reservoir\ layer\ depth\ (ft)$

$k_s = coefficient\ of\ permeability\ for\ surface\ layer \left(\frac{ft}{day}\right)$

$k_{rl} = coefficient\ of\ permeability\ for\ reservoir\ layer \left(\frac{ft}{day}\right)$

$t_s = surface\ layer\ design\ drain\ time\ (days)$

$t_{rl} = reservoir\ layer\ design\ drain\ time\ (days)$

Use design drain times of 1–3 days. Designers should check that the storage volume provided in the ponded area and reservoir layer is equal to or greater than the design runoff volume (V). The storage volume provided is calculated using Equation 5.

$$VP = PV + (V_{rl} \times N) \qquad \text{Equation 5}$$

Where:

$VP = storage\ volume\ provided$

$PV = ponding\ volume$

$V_{rl} = volume\ of\ reservoir\ layer$

$N = porosity\ of\ reservoir\ layer$

The reservoir layer is comprised of a washed aggregate base, such as washed 57-size stone with a porosity of 0.4 (40%). Particles finer than standard "crusher run"—mechanically crushed stone with stone dust—will clog the pores at the bottom of the pavement and should not be used. Design the bottom of the aggregate storage layer to be at least 24 inches above the seasonally high-water table.

For native soils with low permeability, a perforated pipe underdrain can be used to collect filtered runoff and transport it to the downstream conveyance system. Include an observation well using a vertical perforated pipe to check the water level in the aggregate layers. Periodically checking the water depth might help to identify clogging.

Design the top of the *in situ* subgrade as close to flat as practicable (slope less than or equal to 0.5%). If this is not possible, baffles, partitions, berms, or terraces can be installed to promote infiltration across the entire area and reduce the potential for lateral flow. Surface slopes should be less than or equal to 6.0%.

Provide a method to safely bypass larger storm events. This may involve using inlets set slightly above the pavement surface to collect and convey flow to the downstream conveyance system.

5.3.3. Construction Consideration

A preconstruction meeting with the builder, contractor, and subcontractor is recommended to review all site constraints and to communicate that pavement subgrades should not be compacted in permeable pavement areas. The contractor should avoid soil compaction during preparation of the subgrade. The subgrade surface should be scarified, ripped, or trenched prior to the aggregate base being installed to prevent a reduction in the infiltration rate being caused by construction. Sequence construction activities such that adjacent areas are fully stabilized prior to installing the permeable pavement. Grade the soil subgrade when it is dry and lay the aggregate base and permeable surface course as quickly as possible to reduce the risk of soil subgrade compaction (North Carolina Department of Environmental Quality, 2020). Infiltration tests, such as ASTM C1701, *Standard Test Method for Infiltration Rate of In-Place Pervious Concrete*, can be used to verify that the in-place infiltration is greater than or equal to the design values (North Carolina Department of Environmental Quality, 2020). Follow all manufacturers requirements for installation.

5.3.4. Maintenance

Permeable pavements becoming clogged is the most common maintenance concern. Paver openings and joints may become clogged over time or with large sediment loads. Replacing aggregate between pavers may be required in case of extreme clogging. Vacuum sweeping of porous asphalt and porous concrete pavements will increase reduced permeability caused by clogging. For areas with isolated clogging, drilling 0.5-inch holes will increase permeability (USEPA 2021b).

Designing a stone apron around the pavement that is connected to the aggregate base may be an effective backup if pavement surfaces become clogged. Permeable pavements are less likely to develop cracks and potholes than traditional pavement. If cracks and potholes do develop, repair them with conventional patching mix.

STORMWATER BEST MANAGEMENT PRACTICES FOR PROTECTING COASTAL WATERS

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Bioretention Cell

A bioretention cell consists of a depression in the ground filled with a soil media mixture and planted with vegetation that can tolerate inundation and dry periods. Bioretention cells contain an underdrain system allowing filtered stormwater to exit the system.

Design Criteria

- Applicable for drainage areas of 5 acres or less
- Media depth should be between 2 and 4 feet
- The permeability of the filter media should be between 1 and 6 inches per hour, and 1-2 inches per hour is preferred
- Ponding depth should be 12 inches or less (9 inches is preferred)
- Provide an overflow or diversion structure to bypass larger flows around the bioretention cell
- Design with an upturned underdrain to provide internal water storage volume and enhanced water quality and infiltration

Advantages/Benefits

- Removes many different types of pollutants
- Appropriate for small areas with high impervious cover
- Good retrofit capability
- Aesthetic feature

Disadvantages/Limitations

- Not recommended for areas with steep slopes
- Soils may clog over time and require cleaning or replacing
- Landscaping plan is required

Photo: James Stribling, Tetra Tech

Implementation Considerations

- L — Land Requirement
- M H — Capital Cost
- M — Maintenance Burden

Residential Subdivision Use: YES

Other Considerations:
Works well in areas of high impervious cover such as parking lots.

Pollutant Removal

Total Suspended Solids	85%
Nutrients:	
Total Phosphorus	80%
Total Nitrogen removal	60%
Metals: Cadmium, Copper, Lead, and Zinc removal	95%
Pathogens:	
Fecal Coliform	90%

For more information reference MDEQ's *Managing Stormwater for Healthy Watersheds in Coastal Mississippi: Best Practices*

L Low · M Medium · H High

5.4. Bioretention Cells

A "bioretention" cell consists of a depression in the ground filled with a soil media mixture that supports various types of water-tolerant vegetation. The surface of the BMP is depressed to allow for ponding of runoff so that water can filter through the soil media. Water exits the bioretention cell via exfiltration into the surrounding soil, outflow through an underdrain, and is processed through evapotranspiration. The surface of the cell has a layer of mulch to protect it from weeds, erosion, and drying out. Bioretention is an efficient method for removing a wide variety of pollutants, such as suspended solids, heavy metals, nutrients, and pathogens (Hunt and Lord 2006). Bioretention cells provide some nutrient uptake in addition to physical filtration. If designed with soil conditions that promote infiltration, bioretention also can effectively reduce the volume of runoff and improve groundwater recharge.

5.4.1. Planning Considerations

Many development projects present a challenge to the designer because of physical site constraints. Bioretention cells are intended to address the spatial constraints found in densely developed urban areas where the drainage areas are highly impervious. They can be used on small urban sites that would not normally support the hydrology of a wet detention pond and where the soils would not allow for an infiltration device. Median strips, ramp loops, traffic circles, and parking lot islands are good examples of typical locations for bioretention cells.

Bioretention cells are generally most effective if they receive runoff as close as possible to the source. This helps to reduce the possibility of erosion at inlets due to concentrated flows and the need for inlets, pipes, and downstream controls. It is common for designers to achieve this by distributing several smaller bioretention cells across the site. Bioretention cells also may address landscaping and green space requirements of some local governments (Wossink and Hunt 2003). Bioretention cells should not be used to provide flood control, and designs should include a bypass for large flows.

5.4.2. Design Criteria

Bioretention cells are sized by first calculating the design volume and using it to determine the bioretention surface area. To reduce average annual TSS loadings by 80%, the design volume is the volume of runoff for the 1-inch rainfall depth. The *Georgia Stormwater Management Manual* uses Darcy's law to estimate the filter surface area (Atlanta Regional Commission 2016). The minimum surface area of the bioretention is calculated using Equation 15:

$$A_f = \frac{V(d_f)}{[(k)(h_f + d_f(t_f)]}$$ Equation 15

Where:

$A_f = surface\ area\ of\ ponding\ area\ (ft^2)$

$V = volume\ of\ runoff\ for\ the\ 1\ inch\ rainfall\ depth\ (ft^3)$

$d_f = media\ depth\ (ft)$

$k = coefficient\ of\ permeability\ of\ planting\ media\ \left(\frac{ft}{day}\right)\ use\ 1\frac{ft}{day}\ for\ silt - loam\ if\ engineered\ soilds\ are\ being\ used.$

$h_f = average\ height\ of\ water\ above\ planter\ bed\ (ft)$

$t_f = design\ planting\ media\ drain\ time\ (days)(1\ day\ is\ recommended\ maximum)$

An internal water storage (IWS) zone can be created by adding an elbow in the underdrain piping at a 90-degree angle vertically perpendicular to the horizontal underdrain, either in retrofit conditions or in new installations. This upturned elbow on underdrains can force water to remain longer in the bottom of the cell, creating a saturated IWS zone. If this zone remains saturated long enough, anaerobic conditions are created, promoting denitrification and increased nitrogen removal (Passeport et al. 2009).

There are several benefits to using the upturned elbow and IWS zone. The IWS zone works for both pollutant and peak flow reduction as anaerobic conditions can be created to increase nitrogen removal. It also allows more water to infiltrate into the surrounding soils. The use of upturned elbows and IWS zones can be especially beneficial in areas where surrounding soils are sandy with high infiltration. For an IWS zone to work correctly, the underlying soils must have some permeability. In general, if the underlying soils are Group A or B soils with a low clay content, the IWS will be effective. If soils are too compacted, water will not infiltrate and may stagnate in the lower portion, causing problems for the BMP. Media depth above the bottom gravel and underdrain layer must be at least 3 ft. The top of IWS should be separated from the outlet and bowl surface by at least 12 inches (ideally 18 inches).

There is often a cost benefit for using upturned elbows, both for new installations and retrofits. In new installations, a cost-saving is associated with installation since the invert of the outlet is not as deep. Often with IWS, there can be less trenching and fewer materials associated with using it. In retrofits, upturned elbows can be cheaply added to existing bioretention cells where increased nitrogen and phosphorus removal rates are needed. Bioretention cells with IWS can be added as retrofits even in areas with restricted outlet depth.

Inflow must enter the bioretention cell via sheet flow or energy-dissipating devices must be used. Pretreatment devices such as a forebay will help to settle out large solids and reduce the potential that the engineered soil media gets clogged. The design should consider an overflow or bypass structure for rainfall events greater than 1-inch to safely bypass runoff without causing damage to the planter or surrounding area. The overflow invert should be set slightly above the maximum ponding depth and designed to discharge away from buildings. **Figure 5-2** shows a typical cross section view of a bioretention cell.

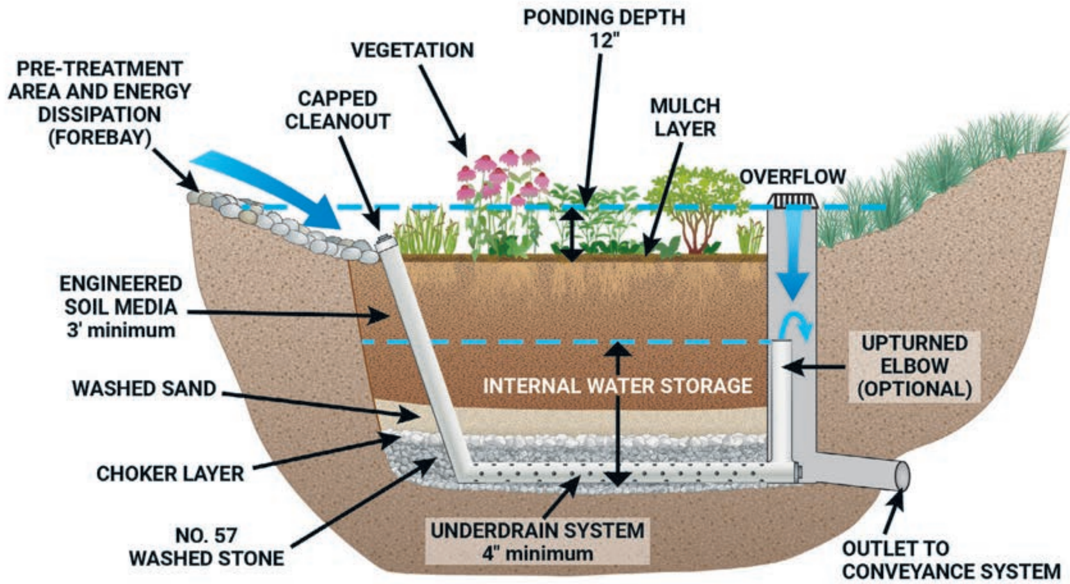

Figure 5-2. Typical cross section view of a bioretention cell.

The preferred ponding depth above the media and mulch should be 12 inches or less (ideally 9 inches or less). The depth of the soil media should be between 2 ft and 4 ft and deep enough to accommodate the vegetation (shrubs or trees). If the minimum depth of 2 ft is used, only shallow-rooted plants can be planted. Grassed bioretention cells with no IWS can be as shallow as 2 ft. If nitrogen is the target pollutant, however, the cell should have at least 30 inches of media because nitrogen is removed 30 inches below the surface. Bioretention facilities where shrubs or trees are planted can be as shallow as 3 ft. If large trees are to be planted in deep fill media, care should be taken to ensure they are stable and will not fall over. As stated above, if IWS is used, cells must have a minimum depth of 3 ft.

The underdrain system will connect to another BMP or to the conveyance system. Because of the risk of underdrain clogging, designers are encouraged to install more than one underdrain of smaller diameter to facilitate drainage. The minimum diameter of pipe for underdrain systems is 4 inches. As previously discussed, an upturned elbow may be used to provide IWS. Capped clean-out pipes must be provided (at a minimum of one per every 1,000 square feet of surface area).

The engineered soil media is underlain by 4 inches of washed sand followed by 2 inches of either No. 8 or No. 89 washed stone and No. 57 stone around the underdrain. The No. 8 or No. 89 stone acts as a choker layer to keep fine particles from the upper layers from clogging the underdrain. Crusher run should not be used around the underdrain, as it can form an impermeable layer (Amerson et al. 1991).

The mulch layer plays an important function in the performance of the bioretention system by reducing weed establishment, regulating soil temperatures and moisture, reducing soil compaction from rainfall, preventing erosion, and promoting an environment suitable for soil microorganisms at the mulch/soil interface (important for filtering nutrients and other pollutants). Mulches prevent soil and possibly fungi from splashing on the foliage, reducing the likelihood of soil-borne diseases (Evans 2000).

Mulch serves as a pretreatment layer by trapping the finer sediments that remain suspended after the primary pretreatment. Additionally, most attenuation of heavy metals in bioretention facilities occurs in the first 1–-2 inches of the mulch layer (Hinman 2005).

The following are other considerations related to mulch:

- Mulch should be free of weed seeds, soil, roots, and other material that is not trunk or branch wood or bark.
- Use commercially available double- or triple-shredded hardwood mulch. Hardwood mulch has been found to be less likely to wash away than other forms of mulch (e.g., pine).
- Mulch depth depends on the type of material used and the drainage and moisture-holding capacity of the soil. A 2–4-inch layer (after settling) is adequate for most applications. Excessive application of mulch can result in the plants growing in the mulch and not the soil. Overmulched plants are easily damaged during periods of drought stress. Mulching in an area that is poorly drained can aggravate the condition (Evans 2000).
- Mulch can be applied any time of year; however, the best time to mulch is late spring after the soil has warmed. It should be placed uniformly about 3 inches deep.
- Mulch should be at least 6 months old (12 months is ideal).
- Mulch should be renewed as needed to maintain a 2–4-inch depth; on previously mulched areas, apply a 1-inch layer of new material. It should be added 1–2 times per year and completely removed or replaced once every 2 years.

Proper vegetation can enhance the aesthetics of bioretention cells and improve their function by encouraging evapotranspiration and pollutant removal. **Appendix A** includes a list of plants suitable for bioretention cells.

5.4.3. Construction Considerations

Grading for a bioretention cell should begin late in the construction sequence to minimize the possibility of it clogging. Ideally, the entire upstream area should be stabilized before construction of the bioretention cell begins. If this is not feasible, using sod around the cell perimeter will help prevent sediment from entering (Hunt et al. 2012). If roadway construction occurs within the drainage area, the subbase course (crusher run) and the base course layer of asphalt need to be in place prior to cell construction. If fine particles get washed into the excavated bioretention cell, they must be removed before building the cell, to restore the permeability of the *in situ* soils. It is recommended that the cell media be covered with impermeable plastic during construction.

To enhance exfiltration, the final 12 inches should be raked with the teeth of the bucket during construction prior to installing the No. 57 stone (Hunt et al. 2012). Raking causes less compaction resulting in better percolation into the underlying soil.

The soil mix should be uniform and free of stones, stumps, roots, or other similar material larger than 2 inches. It should be a homogenous soil mix of 85–88%by volume sand (USDA Soil Textural Classification), 8–12%fines (silt and clay), and 3–5%organic matter (such as peat moss). The higher (12%) fines content reduces the infiltration rate and should be reserved for areas where total nitrogen is the target pollutant. In areas where phosphorus is the target pollutant, a 2-inch per hour (in/hr) infiltration rate is recommended so a lower (8%) fine content should be used. Additionally, the phosphorus (P) content of the soil mix should be low. The P-Index for bioretention soil media should always range between 10 and 30, regardless of the target pollutant (Hunt and Lord 2006). The P-Index is an extremely important design element. Cells that are constructed of high P-Index soils can export phosphorus.

5.4.4. Maintenance

Common maintenance activities include remulching, treating diseased trees and shrubs, and weeding and removing unwanted vegetation. Newly planted vegetation should be watered regularly until properly established. Erosion issues should be addressed immediately. Clean inlet and outlet pipes when needed. Replace soil media as needed.

STORMWATER BEST MANAGEMENT PRACTICES FOR PROTECTING COASTAL WATERS

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Implementation Considerations

- L — Land Requirement
- H — Capital Cost
- M — Maintenance Burden

Residential Subdivision Use: YES

Other Considerations:
Soils: the soils used within stormwater planter planting beds should be an engineered soil mix

May be designed as pretreatment for other BMP solutions

Pollutant Removal

Total Suspended Solids	80%
Nutrients:	
Total Phosphorus	60%
Total Nitrogen removal	60%
Metals: Cadmium, Copper, Lead, and Zinc removal	N/A
Pathogens: Fecal Coliform	80%

For more information reference MDEQ's *Managing Stormwater for Healthy Watersheds in Coastal Mississippi: Best Practices*

L Low — M Medium — H High

Stormwater Planters

A stormwater planter is a container or enclosed feature located either above ground or below ground, planted with vegetation that collects and treats stormwater using bioretention. Bioretention systems collect and filter stormwater through layers of mulch, soil, and plant root systems where pollutants such as bacteria nitrogen, phosphorus, heavy metals, oil, and grease are retained degraded, and absorbed.

Design Criteria

- Should be planted with native vegetation
- Captured runoff should drain out in 24 hours
- The structural elements of the planters should be stone, concrete, or brick
- Requires use of an underdrain
- A maximum ponding depth of 6 inches is recommended within stormwater planters

Advantages/Benefits

- Reduces stormwater runoff volumes, flow rate, and temperature
- Treats stormwater runoff
- Provides wildlife habitat and aesthetic benefits
- Requires limited space
- Flexible for use in areas of various shapes and sizes

Disadvantages/Limitations

- Small size of feature limits stormwater quantity/quality benefits
- Relatively high cost to install
- Can only receive runoff from small drainage areas (less than 2,500 square feet)

Photo: Corry Gallo, Mississippi State University

5.5. Stormwater Planters and Tree Trenches

Stormwater planters and tree trenches are like bioretention cells except they are constructed within a container or enclosed feature whereas bioretention cells are constructed at ground level interfacing with the surrounding soil on the sides and bottom. Planters and tree trenches include a waterproof liner with an engineered soil mix and can be used in both poorly draining and well-draining native soils. Perforated underdrains are provided to collect runoff after it has filtered through the engineered soil mix to convey it to the stormwater system or another BMP. The difference between stormwater planters and tree trenches is the type of vegetation they contain. The paragraphs below refer mostly to stormwater planters; however, the guidance also applies to tree trenches.

5.5.1. Planning Considerations

Stormwater planters can be used in urbanized areas with high pollutant loads. Because they can be constructed immediately adjacent to buildings, they are ideal for urban areas and small spaces, especially where drainage areas are 2,500 square feet or less (Atlanta Regional Commission, 2016). Stormwater planters may be used as a pretreatment BMP for other practices, such as stormwater ponds or infiltration practices. Areas that would benefit from using stormwater planters include:

- Parking garages;
- Office buildings;
- Residential buildings;
- Other building uses (e.g., commercial, light, industrial, and institutional);
- Transportation facilities; and
- Urban streetscapes.

Stormwater planters should not be used to provide flood control, and designs should include a bypass for large flows. The depth to the water table should be 2 ft or more. Do not use stormwater planters in areas where they may interfere with subsurface structures such as sanitary sewer systems or if they might cause basement flooding.

5.5.2. Design Criteria

Stormwater planters should be designed to contain the runoff volume generated from a 1-inch rainfall event and completely drain within 24 hours (Atlanta Regional Commission, 2016). If this cannot be accomplished, overflow or discharge should be directed to another BMP, such as a stormwater pond or constructed stormwater wetland, for additional treatment. Provide an engineered soil mix depth of at least 2 ft unless the depth interferes with a shallow water table, a minimum width of 18 inches, and a maximum depth of ponding of 12 inches (Atlanta Regional Commission, 2016). Stormwater planters should be designed with slopes as flat as possible with a maximum slope of 0.5%.

The engineered soil mix should have an infiltration rate of at least 0.25 in/hr, although an infiltration rate of between 1 in/hr and 2 in/hr is preferred. The infiltration rate of the engineered soil mix should be determined by a qualified licensed professional.

The design should consider an overflow structure for rainfall events greater than 1 inch to safely bypass runoff without causing damage to the planter or surrounding area. The overflow invert should be set slightly above the maximum ponding depth and designed to discharge away from buildings.

The *Georgia Stormwater Management Manual* uses Equation 6 to estimate the filter surface area (Atlanta Regional Commission, 2016). The equation for the minimum surface area of the stormwater planter is:

$$A_f = \frac{V(d_f)}{[(k)(h_f + d_f(t_f)]} \qquad \text{Equation 6}$$

Where:

$A_f = surface\ area\ of\ ponding\ area\ (ft^2)$

$V = volume\ of\ runoff\ for\ the\ 1\ inch\ rainfall\ depth\ (ft^3)$

$d_f = media\ depth\ (ft)$

$k = coefficient\ of\ permeability\ of\ planting\ media\ \left(\frac{ft}{day}\right) use\ 1\frac{ft}{day} for\ silt - loam\ if\ engineered\ soils\ are\ being\ used.$

$h_f = average\ height\ of\ water\ above\ bioretention\ area\ bed\ (ft)$

$t_f = design\ planting\ media\ drain\ time\ (days)(1\ day\ is\ recommended\ maximum)$

Stormwater planters should be equipped with an underdrain consisting of a 4-inch perforated (AASHTO M 252) PVC pipe bedded in a 6-inch layer of clean, washed stone. The pipe should have 3/8-inch perforations, spaced 6 inches on center, and a minimum slope of 0.5%. The clean, washed stone should be ASTM D448 size No. 57 stone (i.e., 1-1/2–1/2 inch in diameter) and should be separated from the planting bed by a layer of permeable filter fabric or a thin, 2–4-inch layer of choker stone (i.e., ASTM D 448 size No. 8, 3/8–1/8 inch or ASTM D 448 size No. 89, 3/8–1/16 inch) (Atlanta Regional Commission, 2016).

Proper vegetation can enhance the aesthetics of stormwater planters and improve their function by encouraging evapotranspiration and pollutant removal. **Appendix A** includes a list of plants suitable for stormwater planters.

5.5.3. Construction Considerations

Do not construct stormwater planters from chemically treated wood. They should be constructed from stone, concrete, brick, or other durable material. Install stormwater planters only after the contributing area has been stabilized to avoid sediment from clogging the practice. Waterproof liners should be 30 millimeters (0.030 inch) PVC or equivalent pipe. Stormwater planter engineered soils should meet the following criteria (Atlanta Regional Commission, 2016):

- Texture: Sandy loam or loamy sand.
- Sand content: Soils should contain 85–88% clean, washed sand.
- Topsoil content: Soils should contain 8–12% topsoil.
- Organic matter content: Soils should contain 3–5% organic matter.
- Infiltration rate: Soils should have an infiltration rate of at least 0.25 in/hr, although an infiltration rate of between 1 in/hr and 2 in/hr is preferred.
- Phosphorus Index (P-Index): Soils should have a P-Index of less than 30.
- Exchange capacity (CEC): Soils should have a CEC that exceeds 10 milliequivalents per 100 grams of dry weight.
- pH: Soils should have a pH of 6–8.

Till the native soil 3–4 inches before laying the filter fabric or choker stone and engineered soil mix. Landscape and plant the stormwater planter immediately after construction to avoid soil loss. Watering may be required to establish vegetation quickly.

5.5.4. Maintenance

Common maintenance activities for stormwater planters includes replacing mulch, removing sediment buildup, unclogging downspouts for planters that receive roof water, establishing vegetation, and unclogging the underdrain (Atlanta Regional Commission, 2016). Remove invasive plant species and maintain plant health by pruning, weeding, and watering.

STORMWATER BEST MANAGEMENT PRACTICES FOR PROTECTING COASTAL WATERS

MISSISSIPPI DEPARTMENT OF ENVIRONMENTAL QUALITY

Grassed Swales

Grassed swales refers to vegetated, open-channel management practices designed specifically to treat and attenuate stormwater runoff for a specified water quality volume. To enhance pollutant removal, grassed swales are designed with a filter bed that may overlay an underdrain system.

Design Criteria

- Treats runoff from small drainage areas of less than 5 acres
- Should be used on slopes of less than 4 percent; 1 to 2 percent slope is recommended
- Typically include relatively flat side slopes (flatter than 3:1)
- Designed to provide a storage volume equal to the runoff volume from the first 1-inch rainfall
- A small forebay or pea gravel diaphragm is needed for pretreatment where water enters the swale
- Minimum 2 ft clearance between the swale bottom and groundwater

Advantages/Benefits

- Ideal for linear environments
- Lower cost
- Aesthetic benefits

Disadvantages/Limitations

- Design depended on existing site conditions and topography
- Potential for bottom erosion and sediment resuspension

Photo: Kristen Sorrell, MDEQ

Implementation Considerations

- M — Land Requirement
- M — Capital Cost
- L — Maintenance Burden

Residential Subdivision Use: YES

Other Considerations: Highly applicable for roadway projects

May be designed as pretreatment for other BMP solutions

Pollutant Removal

Total Suspended Solids	80%
Nutrients: Total Phosphorus Total Nitrogen removal	 50% 50%
Metals: Cadmium, Copper, Lead, and Zinc removal	 40%
Pathogens: Fecal Coliform	 N/A

For more information reference MDEQ's *Managing Stormwater for Healthy Watersheds in Coastal Mississippi: Best Practices*

L Low — M Medium — H High

5.6. Grassed Swales

"Grassed swales" (also called enhanced grassed channel and dry swale) refer to vegetated, open channels designed specifically to treat and attenuate stormwater runoff for the water quality peak flow rate. Swales remove pollutants from stormwater by biofiltration, settling, and infiltration. To achieve 80% TSS removal, grassed swales should be designed with berms and/or check dams, a filter bed, and possibly an underdrain system. Grassed swales that do not have these components should be used in conjunction with another BMP to enhance pollutant removal. Grassed swales filter pollutants as stormwater runoff moves through the filter bed, leaves, and roots of the vegetation. By reducing flow velocities and increasing a site's time of concentration, grassed swales contribute to reducing runoff peaks.

5.6.1. Planning Considerations

Grassed swales can be applied in most situations with some restrictions. Use of grassed swales should be limited to drainage areas of 5 acres or less. Swales are well suited for treating highway or residential road runoff because they are linear practices. Swales also are useful as one of a series of stormwater BMPs, such as conveying water to a constructed wetland or stormwater pond and receiving water from stormwater planters, vegetated curb extensions, and vegetated filter strips.

The use of grassed swales in new developments can be a cost-effective alternative to curb and gutter installation. The swale practices are considered more aesthetically pleasing, although there is the potential for standing water and possible mosquito infestations. The effectiveness of a swale in reducing flow rates, reducing volume of runoff, and removing pollutants is a function of the size and composition of the drainage area, the slope and cross section of the channel, the permeability of the soil, the density and type of vegetation in the swales, and the swale dimensions. Broad swales on flat slopes with dense vegetation are the most effective. Grassed swales do not reduce peak flows from large storm events. If large flows are to be managed, additional BMPs working in conjunction with the grassed swale, such as constructed stormwater ponds and wetlands, will be necessary.

5.6.2. Design Criteria

To achieve 80% TSS removal, grassed swales are sized to allow the entire runoff volume from the first 1-inch rainfall to infiltrate through the channel bottom. To determine the actual volume provided in the swale, use Equation 7 (Atlanta Regional Commission, 2016). The volume of the grassed swale (VP) should be greater than or equal to the runoff volume from the first 1-inch rainfall.

$$V_P = P_V + V_{ES}(N) \qquad \text{Equation 7}$$

Where:

$V_P = volume\ of\ the\ grassed\ swale\ (ft^3)$

$P_V = ponding\ volume\ (ft^3)$

$V_{ES} = volume\ of\ engineered\ soils\ (ft^3)$

$N = porosity$

Next determine the swale dimensions needed to achieve the calculated grass swale volume. Limit ponding depth at the downstream end to 18 inches. Recommended swale slopes are 1–2% and should not exceed 4%. Swale bottom widths typically range between 2 ft and 8 ft with side slopes flatter than 2:1. Check dams or similar structures might be required to achieve the desired swale volume. A check dam is constructed of earth, stone, or timber 3–6 inches high to retain runoff from routine events. A weep hole may be added to enable the area behind an earthen or timber dam to drain slowly. However, the weep hole may be subject to clogging. Shorter check dams can act as level spreaders to help distribute the flow along the swale's cross section. Drawdown time of the ponded water in the swale must be 48 hours or less.

The engineered soil media should have an infiltration rate of at least 1 ft per day and contain 3–5%organic matter. Place permeable filter fabric between the media and gravel underdrain layer.

An underdrain is provided below the planting media. The underdrain is a perforated PVC pipe with a minimum diameter of 4 inches and encased in a gravel layer. Design of grassed swales should include a bypass for large flow. If site development requirements include detention for flood control, another BMP must be provided to reduce peak flows. Swales can be designed with drop structures and downstream velocity dissipation.

For pretreatment, a small forebay should be used at the front of the swale to trap incoming sediments. A pea gravel diaphragm, a small trench filled with river-run gravel, should be constructed along the length of the swale and used as pretreatment for runoff entering the sides of the swale.

During construction, it is important to stabilize the channel while the vegetation is becoming established, either with a temporary grass cover or with natural or synthetic erosion-control products. In addition to treating runoff for water quality, grassed swales must convey runoff from larger storms safely. Typical designs allow the runoff from the 2-year storm to flow through the swale without causing erosion. Swales also should be designed with the capacity to pass larger storms (typically a 10-year storm) safely.

Proper vegetation suitable for the site soils and hydric conditions improves grassed swale function. **Appendix A** includes a list of plants suitable for grassed swales.

5.6.3. Construction Considerations

Restrict heavy construction equipment from the swale area to prevent compaction. The upslope drainage area to the swale should be fully stabilized prior to swale construction to avoid clogging of the planting media and underdrain system, if applicable.

5.6.4. Maintenance

Typical routine maintenance of grassed swales includes the removal of trash and debris and pruning, mowing, and weeding vegetation. Maintenance is typically more frequent in the first year after construction to allow vegetation to become established. If bare soil or signs of erosion are evident, regrade the soil to remove gully erosion and then resod and water until the grass is established. If persistent erosion occurs, implement velocity dissipation measures at inflow locations and /or install ditch checks to slow down the flow. Sediment should be removed once it accumulates to 25% of the swale design volume. If standing water is observed within 48 hours of a storm event, the planting soil may need to be rototilled or cultivated to increase infiltration rates.

STORMWATER BEST MANAGEMENT PRACTICES FOR PROTECTING COASTAL WATERS

MISSISSIPPI DEPARTMENT OF ENVIRONMENTAL QUALITY

Rain Gardens

Rain gardens are a type of infiltration practice featuring shallow depressions planted with native vegetation to capture and treat runoff. Rain gardens can be used in a variety of applications such as in residential lawns or within curb extensions alongside the parking zone of a street. They can be planted with groundcover, grass, shrubs, or trees depending on the site conditions, costs, and design context.

Design Criteria

- Sizing should be based on drainage area
- Infiltration testing is required, and compacted soils should be avoided
- Should be planted with native vegetation
- Does not require an underdrain

Advantages/Benefits

- Reduces stormwater runoff volumes and improves water quality
- Increases groundwater infiltration and recharge
- Treats stormwater runoff
- Provides aesthetic benefits
- Requires limited space
- Wide applicability, including urban areas and retrofits

Disadvantages/Limitations

- Small size of feature limits stormwater quantity/quality benefits
- May reduce on-street parking spaces or conflict with bike lanes if used in curb extension

Photo: Kristen Sorrell, MDEQ

Implementation Considerations

- **L** Land Requirement
- **H** Capital Cost
- **L** Maintenance Burden

Residential Subdivision Use: YES

Other Considerations:

- Use to treat runoff from pervious areas
- May be designed a pretreatment for other BMP solutions
- Applicable for treating street runoff

Pollutant Removal

Total Suspended Solids	80%
Nutrients:	
Total Phosphorus	60%
Total Nitrogen removal	40–50%
Metals:	
Cadmium, Copper, Lead, and Zinc removal	40–90%
Pathogens:	
Fecal Coliform	N/A

For more information reference MDEQ's *Managing Stormwater for Healthy Watersheds in Coastal Mississippi: Best Practices*

L Low — M Medium — H High

5.7. Rain Gardens

"Rain gardens" are a type of infiltration practice featuring shallow depressions planted with native vegetation to capture and treat runoff. They can be used in a variety of applications, such as in school lawns (**Figure 5-3**) or within curb extensions alongside the parking zone of a street (**Figure 5-4**). When used to capture runoff from the street, they are commonly referred to as "vegetated curb extensions." Rain gardens are distinguished from the bioretention cells described in this document because they do not have an underdrain system. The landscaped area can include engineered soil media with a rock or gravel layer underneath to enhance infiltration and pollutant removal. Rain gardens can be planted with groundcover, grass, shrubs, or trees depending on the site conditions, costs, and design context.

Figure 5-3. Rain garden at Bay Waveland Middle School in Bay St. Louis. (Photo: Tracy Wyman, GCCDS)

Figure 5-4. Example of a rain garden configured as a curb extension to capture street runoff.

5.7.1. Planning Considerations

Rain gardens are commonly used on single-family residential properties because they are small and easy to construct and maintain. They also are appropriate for multifamily, commercial, and office locations in situations in which they can be readily maintained. Rain gardens should be located 10 ft or more from a structure with a basement and should not be constructed over utilities or a septic field (City of Atlanta 2022). They can be located within curb extensions to treat street runoff, calm traffic, and increase pedestrian safety. They are easily incorporated into urban areas and retrofit situations where the shrubs, grasses, or trees provide enhanced aesthetic benefit. Care should be taken when using rain gardens in extended curbs to avoid conflicts with bike lanes or reducing too many street parking spaces. When designing rain gardens in retrofit situations, avoid existing utilities and consider incorporating existing inlets into the design.

Bioretention cells may be a better option than a rain garden for larger drainage areas and less permeable soils because they are constructed with a perforated underdrain. Rain gardens provide some peak flow reduction, but they should not be used to manage large flood flows. If large flows are to be managed, additional BMPs working in conjunction with the rain garden, such as constructed stormwater ponds and wetlands, will be necessary.

5.7.2. Design Criteria

The design criteria described in Section 5.2, *Infiltration Practices,* are applicable to rain gardens, too. Rain gardens are sized to capture the first 1 inch of runoff from the contributing drainage area and to completely dewater within 24 hours. The required infiltrating area is calculated using Equation 3 in Section 5.2.2. Limit maximum ponding depths to 6–18 inches (MDNR and AllenES 2017). A bypass to safely transport runoff from rainfall greater than 1 inch should be provided. If the rain garden is offline, then a diversion structure should be incorporated into the design to divert the peak flow rate from 1 inch of rainfall. Typically, roadway runoff enters the rain garden through an opening cut in the roadway curb or a walkway.

The storage area of the rain garden should have a flat bottom and energy should be dissipated with rock or a small level spreader at the location where flow enters. For locations with steep slopes (> 10%), terracing of the storage area may be required. Rain gardens can be designed and constructed using the native soil or with an engineered soil similar to that used in bioretention cells. Native soils may be amended with compost to encourage plant growth. Provide a hardwood mulch layer on the surface of the storage area. If side slopes are planted with turf grass, keep slopes 3:1 (horizontal:vertical) or flatter to facilitate mowing.

Infiltration testing of the native soils should be performed to calculate the dewatering time. To be suitable for infiltration, underlying soils must have an infiltration rate of 0.52 in/hr or more, as initially determined from NRCS soil textural classification (typically hydrologic soil groups A and B) and subsequently confirmed by field geotechnical tests.

Selecting vegetation suitable for the growing conditions within the rain garden is important for optimum pollutant removal and aesthetic benefits. Consider light, moisture, and soil characteristics when selecting plants. Planting a variety of species that vary in height, color, and blooming season may enhance aesthetics and attract bees and butterflies. Plant species appropriate for rain gardens are provided in **Appendix A**.

5.7.3. Construction Considerations

Construct rain gardens only after the contributing area has been fully stabilized. Limit compaction of the soil within the storage area to promote infiltration by using lighter weight equipment and construction techniques that avoid compaction. Grading should be done when the soil is dry. Landscape and plant the rain garden immediately after construction to avoid soil loss. Watering may be required to establish vegetation quickly.

5.7.4. Maintenance

Rain gardens may require watering to establish vegetation immediately following construction and during dry periods. Replace mulch, treat diseased vegetation and trees, and remove litter as needed. Maintenance of rain gardens includes periodic tending to remove weeds and promote the growth of desired native plants. Biannual inspection of cleanouts, inlets, and outlets is needed to check for clogging or damage and to remove accumulated debris.

STORMWATER BEST MANAGEMENT PRACTICES FOR PROTECTING COASTAL WATERS

MISSISSIPPI DEPARTMENT OF ENVIRONMENTAL QUALITY

Vegetated Filter Strips

Vegetated filter strips are grassed surfaces that are designed to treat sheet flow from adjacent surfaces. Filter strips are often used to pretreat runoff before it enters other stormwater practices such as infiltration basins.

Design Criteria

- Should be at least 25 feet long
- Includes a pea gravel diaphragm at the top of the slope
- Slope should be between 2 and 6 percent
- Use in areas where groundwater is deeper than 2 feet
- Use a grass that can withstand relatively high-velocity flows and both wet and dry periods

Advantages/Benefits

- Provide good pretreatment for other stormwater practices
- Best suited for treating runoff from roadways, roof downspouts, very small parking lots if sheet flow can be maintained
- Low cost alternative
- Can provide groundwater recharge

Disadvantages/Limitations

- Concentrated flow within the filter strip will receive little to no pollutant removal. Sheet flow must be maintained
- Typically poor retrofit options due to space requirements
- Requires periodic repair, regrading, and sediment removal to prevent channelization

Photo: Tracy Wyman, GCCDS

Implementation Considerations

- H — Land Requirement
- H — Capital Cost
- L — Maintenance Burden

Residential Subdivision Use: YES

Other Considerations:
Highly applicable for roadway projects

May be designed as pretreatment for other BMP solutions

Pollutant Removal

Total Suspended Solids	60%
Nutrients:	
Total Phosphorus	20%
Total Nitrogen removal	20%
Metals: Cadmium, Copper, Lead, and Zinc removal	40%
Pathogens: Fecal Coliform	N/A

For more information reference MDEQ's *Managing Stormwater for Healthy Watersheds in Coastal Mississippi: Best Practices*

L Low · M Medium · H High

5.8. Vegetated Filter Strips

"Vegetated filter strips" (also called grassed filter strips, filter strips, and grassed filters) are vegetated surfaces designed to treat sheet flow from adjacent impervious surfaces (**Figure 5-5**). As LID practices, filter strips function by slowing runoff velocities and filtering out sediment and other pollutants. When constructed in permeable soils, filter strips provide some infiltration into the underlying soils, thereby reducing stormwater runoff volume. Components of filter strip designs include a level spreader to maintain sheet flow, a vegetated strip, and an optional permeable berm at the downslope end of the filter strip. Designs that include the optional berm have greater pollutant removal and infiltration over facilities designed without a berm.

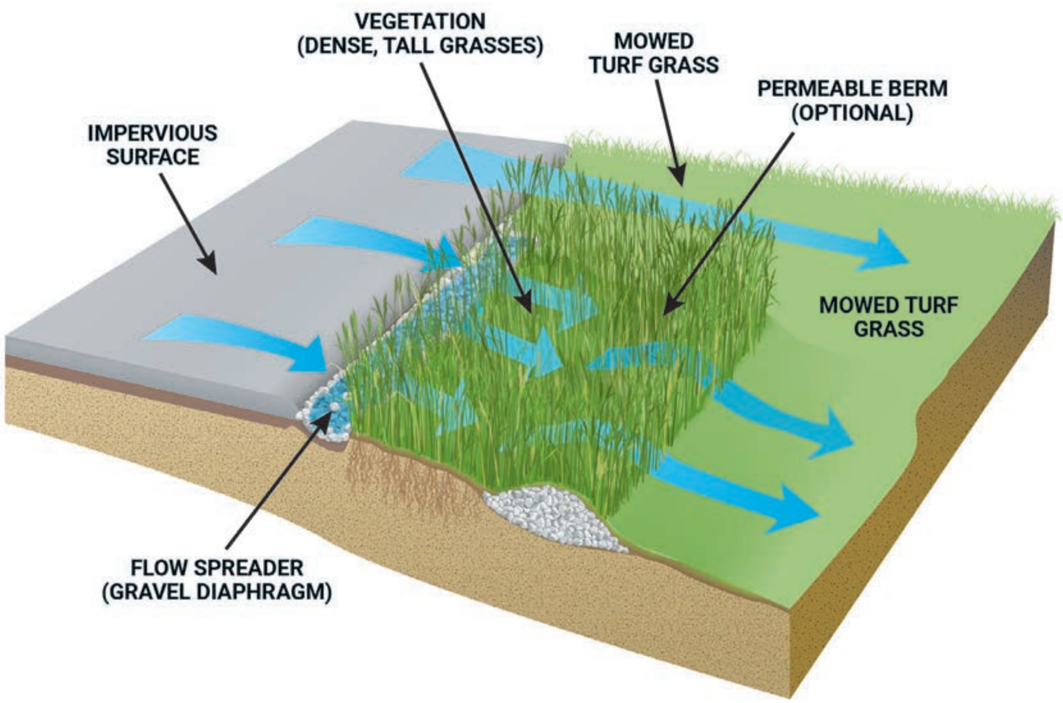

Figure 5-5. Example of a vegetated filter strip designed to treat flow from adjacent impervious surface.

5.8.1. Planning Considerations

Filter strips are best suited to capturing runoff from roads and highways, roof downspouts, and very small parking lots. When used alone, filter strips have been shown to remove approximately 60% TSS and, therefore, must be combined with other BMPs to achieve 80% TSS removal. Filter strips provide good pretreatment for infiltration practices, grassed swales, constructed wetlands, bioretention cells, stormwater ponds, and other BMPs that provide additional sediment removal.

Filter strips typically are used to treat runoff from drainage areas of less than 5 acres (2 acres or less is preferred) where sheet flow is maintained (Atlanta Regional Commission, 2016). Very poor soils that cannot sustain a grass cover crop may limit using filter strips on some sites. Filter strips should be separated from the groundwater by between 2 ft and 4 ft to prevent contamination and to ensure that the filter strip does not remain wet between storms.

Filter strips do not reduce peak flows from large storm events. If large flows are to be managed, additional BMPs working in conjunction with the filter strip, such as constructed stormwater ponds and wetlands, will be necessary.

5.8.2. Design Criteria

The length of flow into the filter strip is limited to avoid concentrated flow, which can lead to scouring. As a rule, flow concentrates within a maximum of 75 ft for impervious surfaces and 150 ft for pervious surfaces (CWP 1996). Using this rule, a filter strip can treat 1 acre of impervious surface per a 580-ft length.

The use of a level spreader may help to maintain sheet flow across the filter strip. A pea gravel diaphragm (a small trench filled with pea gravel) at the top of the filter strip slope acts as a pretreatment device, settling out sediment particles and maintaining sheet flow as runoff flows over the filter strip. Concrete sills, curb stops, and gutters with sawteeth are other examples of level spreaders that can be used with filter strips (Atlanta Regional Commission, 2016). If sheet flow is not maintained, flow is likely to concentrate and receive little or no treatment.

Filter strip slopes should be limited to between 2% and 6% to avoid ponding and developing concentrated flow after it has entered the vegetated area. A flatter filter strip slope is associated with lower nitrate concentrations leaving the filter strip (Geosyntec and Wright Water 2013). Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion.

The length of the filter strip parallel to the direction of flow can be calculated using Equation 8 (Atlanta Regional Commission, 2016), using the formula:

$$L_f = \frac{{T_t}^{1.25} x {P_{2-24}}^{0.625} x S^{0.5}}{0.338n} \qquad \text{Equation 8}$$

Where:

$L_f = length\ of\ filter\ strip\ parallel\ to\ flow\ path\ (ft)$

$T_t = travel\ time\ through\ filter\ strip\ (minutes)$; use a minimum of 5 minutes

$P_{2-24} = 2 - year, 24 - hour\ rainfall\ depth\ (inches)$

$S = slope\ of\ filter\ strip\ (percent)$

$n = Manning's\ \ n\ roughness\ coefficient$

(n=0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass)

The discharge per foot width of the strip width can be calculated using Manning's equation with a flow depth of 2 inches or less:

$$q = \frac{0.00236}{n} Y^{\frac{5}{3}} S^{\frac{1}{2}}$$ Equation 9

Where:

$q = discharge\ per\ foot\ of\ width\ of\ filter\ strip\ (cfs/ft)$

$Y = allowable\ depth\ of\ flow\ (inches, maximum\ flow\ depth\ of\ 2\ inches)$

$S = slope\ of\ filter\ strip\ (percent)$

$n = Manning's\ n\ roughness\ coefficient$

(n=0.15 for medium grass, 0.25 for dense grass, and 0.35 for very dense Bermuda-type grass)

The minimum width of the filter strip (perpendicular to flow) is

$$W_{fMIN} = \frac{Q_{WQ}}{q}$$ Equation 10

Where:

$Q_{WQ} = water\ quality\ volume\ peak\ flow\ (ft^3/s)$

$q = discharge\ per\ foot\ of\ width\ of\ filter\ strip\ (cfs/ft)$

The water quality volume peak flow (Q_{WQ}) is calculated by first estimating a runoff curve number (CN) for the water quality volume using Equation 11:

$$CN = 1000/[10 + 5P + 10Q_{WV} - 10\left(Q_{WV}{}^2 + 1.25Q_{WV}P\right)^{\frac{1}{2}}]$$ Equation 11

Where:

$Q_{WV} = water\ quality\ volume, inches = P\ x\ Rv$

$P = rainfall\ depth\ (in) = 1\ inch$

$R_V = runoff\ coefficient, unitless$

$$R_V = 0.05 + 0.9\ x\ I_A$$ Equation 12

Where:

$I_A = impervious\ fraction, unitless$

Once the CN is computed, determine the initial abstraction (I_a) based on the computed CN. Compute the water quality volume peak flow rate (QWQ) using Equation 10. Read the unit peak discharge (q_u) assuming a NRCS type III rainfall distribution from **Figure 5-6** using the time of concentration for the flow path to the filter strip (tc). The procedure for estimating time of concentration is described in NRCS Technical Release 55, *Urban Hydrology for Small Watersheds* (NRCS 1986).

Use q_u in Equation 13 to calculate Q_{WQ}. Plug Q_{WQ} into Equation 9 to calculate the minimum width of the filter strip:

$$Q_{WQ} = q_u x A x Q_{WV} \quad \text{Equation 13}$$

Where:

$Q_{WV} = water\ quality\ volume, inches$

$A = drainage\ area\ (mi^2)$

$q_u = unit\ peak\ discharge\ for\ Type\ III\ Rainfall\ (cfs/mi^2/inch)$

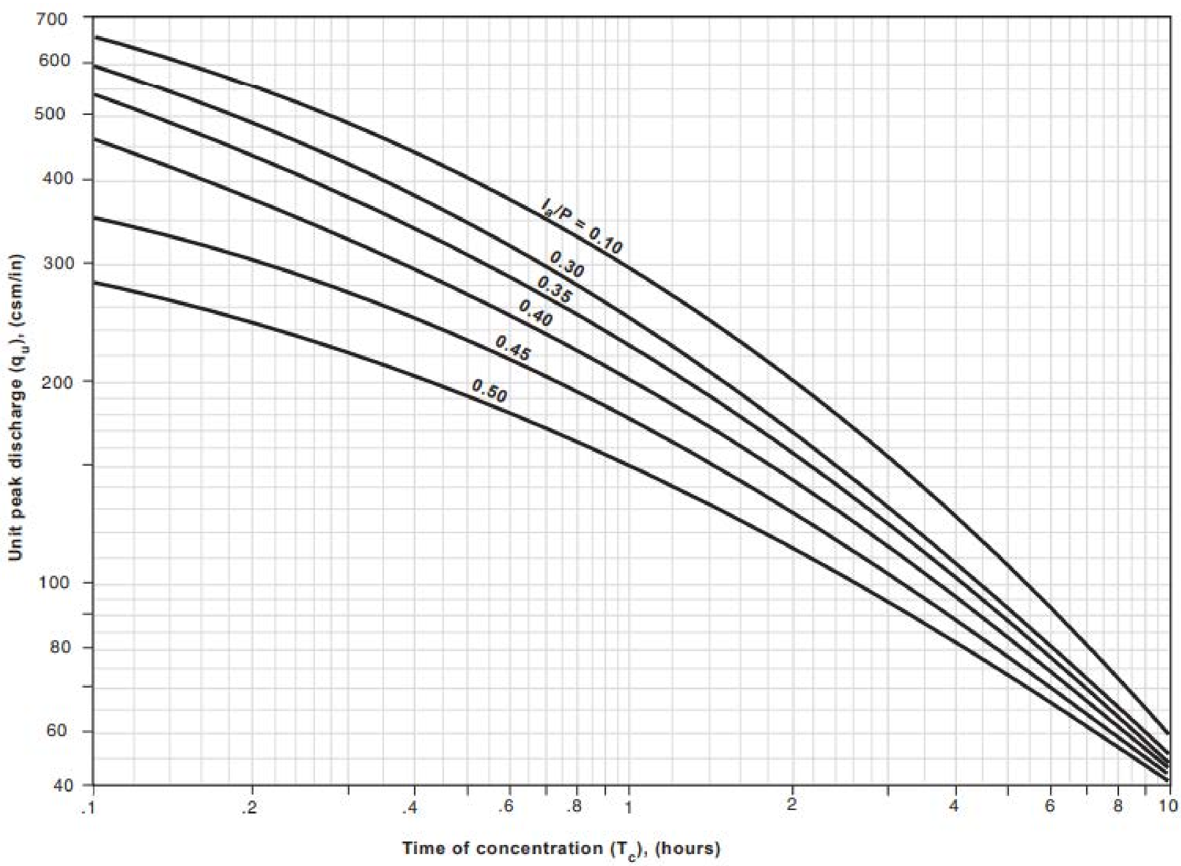

Figure 5-6. Unit peak discharge (qu) for NRCS type III rainfall distribution. (Source: NRCS 1986)

Some filter strip designs include a pervious berm of sand and gravel at the toe of the slope. This feature provides an area for shallow ponding at the bottom of the filter strip increasing stormwater contact time and infiltration. Runoff collects behind the berm and gradually flows through the berm. The volume of runoff ponded behind the berm should be equal to the runoff from the 1-inch storm.

Designers should choose a grass that can withstand relatively high-velocity flows and both wet and dry periods. See **Appendix A** for grasses that are well suited for filter strips in the predominant Mississippi climate.

5.8.3. Construction Considerations

As much as possible, avoid or minimize compaction in the area of the filter strip to encourage infiltration. Construct the filter strip only after the contributing area has been fully stabilized. Take care to uniformly grade the filter strip during construction to prevent concentrated flow and erosion.

5.8.4. Maintenance

Immediately after the filter strip is established, grass may need to be watered until plants become established (typically 6 weeks). Once a year, the filter strip may need to be reseeded to maintain a dense growth of vegetation. Stable groundcover should be maintained in the drainage area to reduce the sediment load to the vegetation. Filter strip maintenance requires mowing the vegetation during the growing season. Vegetation should be cut to a height necessary to maintain a dense cover. If plants are struggling to survive, aerate the soil and test the soil pH. The filter strip may need to be regraded and the accumulated sediment removed if channelization occurs frequently.

STORMWATER BEST MANAGEMENT PRACTICES FOR PROTECTING COASTAL WATERS

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Implementation Considerations

M H Land Requirement

M Capital Cost

M Maintenance Burden

Residential Subdivision Use: YES

Other Considerations:
Soils: Hydrologic group 'A' and 'B' soils may require a liner

Pollutant Removal

Total Suspended Solids	80–85%
Nutrients:	
Total Phosphorus	40–75%
Total Nitrogen removal	30–55%
Metals:	
Cadmium, Copper, Lead, and Zinc removal	50–60%
Pathogens:	
Fecal Coliform	70–85%

For more information reference MDEQ's *Managing Stormwater for Healthy Watersheds in Coastal Mississippi: Best Practices*

L Low M Medium H High

Constructed Stormwater Wetland

Wetlands temporarily store stormwater runoff in shallow pools that support emergent and riparian vegetation. The storage, complex microtopography, and vegetative community in stormwater wetlands combine to form an ideal matrix for the removal of many pollutants. Stormwater wetlands can also effectively reduce peak runoff rates and stabilize flow to adjacent natural wetlands and streams.

Design Criteria

- Requires sufficiently large drainage area or adequate groundwater/surface water supplies to provide year-round hydration, typically about 25 acres
- The upstream slope should not exceed about 15% and local slopes should be relatively shallow
- The elevation drop from the inlet to the outlet should be at least 3 to 5 feet
- Should consist of six components: Inlet, deep pool, shallow water (low marsh), shallow land (high marsh), upland, and outlet

Advantages/Benefits

- High removal rate for a wide variety of pollutants
- Provides wildlife habitat and aesthetic benefits
- Ideal for use in areas with flat terrain and high groundwater

Disadvantages/Limitations

- Requires large land area
- Requires continuous baseflow for viable wetland
- Difficulties in establishing vegetation and maintaining permanent pool may arise
- Potential for escalated mosquito population

Photo: Kristen Sorrell, MDEQ

5.9. Constructed Stormwater Wetland

Stormwater wetlands remove a wide variety of pollutants (e.g., suspended solids, nutrients such as nitrogen and phosphorus, metals, toxic organic pollutants, and petroleum compounds) in a managed environment. Compared with stormwater ponds, sand filters, bioretention cells, and other post-construction stormwater BMPs, wetlands have the best median removal rate for TSS, nitrogen, ammonia-nitrogen, and some metals. Stormwater wetlands also can be used to reduce high levels of fecal coliform and other pathogen contamination. Wetlands temporarily store stormwater runoff in shallow pools that support emergent and riparian vegetation. Stormwater wetlands also can effectively reduce peak runoff rates and stabilize flow to adjacent natural wetlands and streams.

Figure 5-7 shows the common four wetland zones, which are defined by water depth and include deep pool, shallow water, shallow land, and upland.

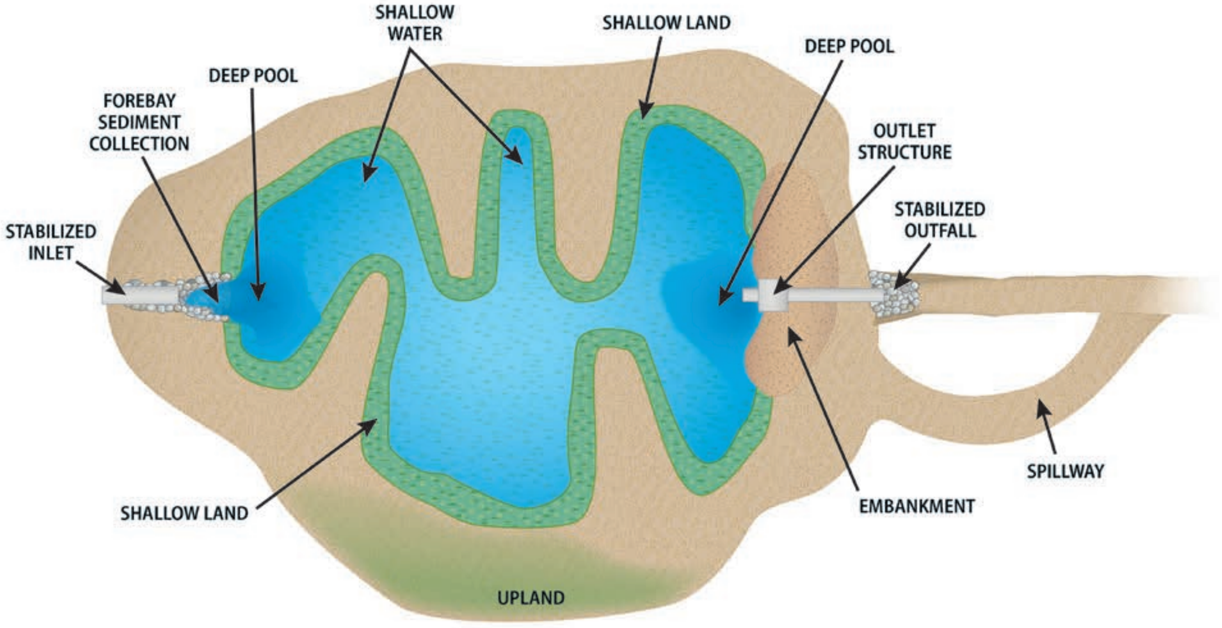

Figure 5 7. Constructed wetland zones.

As water flows through the constructed wetland system, physical, chemical, and biological processes occur, making wetlands effective at removing pollutants from stormwater. Pollutants are taken up and transformed by plants and microbes, immobilized in sediment, and released in reduced concentrations in the wetland's outflow. Wetland plants improve water quality by slowing water flow and settling solids, transforming or immobilizing pollutants, and supplying reduced carbon and attachment area for microbes (bacteria and fungi).

5.9.1. Planning Considerations

Stormwater wetlands occupy somewhat more surface area than a wet detention pond but have the potential to be better integrated into the aesthetic aspects of site design because of the abundance of aquatic vegetation. Typically, constructed stormwater wetlands are 3–5% of the tributary drainage area. Stormwater wetlands require a year-round water source to maintain saturated conditions. Water sources can include direct precipitation, runoff from large drainage areas, interflow, and surface waters. In areas with high groundwater, a separation of 2 ft from the wetland bottom to the seasonal high groundwater elevation is recommended. Constructed stormwater wetlands also can be designed to meet flood control requirements.

Designers should consider site slopes, soils, and tidal influences for successful application of constructed stormwater wetlands. Wetlands can be used on sites with upstream slopes of up to about 15%. Slopes across wetland sites should be no more than 8% and smaller wetlands should be generally flat. In sloping terrain, wetland cells can be arranged in series on terraces. Wetlands can be used in almost all soils and geology. Permeable soils (hydrologic soil groups A and B) require a liner to maintain saturated conditions where hydrologic groups C and D soils adequately maintain saturated conditions without a liner. In tidally influenced areas, high tides may prevent runoff from being conveyed through a stormwater wetland. Consider aerating and stocking wetlands with proper fish species to maintain nutrient cycling and healthy oxygen levels in these areas, including to potentially help control mosquito breeding.

Stormwater wetlands should not be located within existing jurisdictional wetlands or constructed as in-stream impoundments. Runoff containing accumulated pollutants from industrial or commercial land uses may eventually increase environmental risk (e.g., algal blooms) to wildlife using the stormwater wetland. Typical pollutant loads found in residential and commercial settings are unlikely to cause this problem.

5.9.2. Design Criteria

Wetlands need sufficient inflow to maintain a permanent pool and achieve 80% TSS removal. The volume of water maintained above the wetland permanent pool is equal to the runoff from the first 1-inch rainfall (V). V is calculated using Equation 1 in Section 5.1. The surface area of the wetland is calculated using Equation 14:

$$A_W = V/D_{Plants} \qquad \text{Equation 14}$$

Where:

$A_W = wetland\ area\ (ft^2)$

$V = volume\ of\ runoff\ for\ the\ 1\ inch\ rainfall\ depth\ (ft^3)$

$D_{Plants} = Depth\ of\ water\ that\ plants\ can\ sustain\ for\ several\ days\ in\ the\ shallow\ land\ area\ (ft^2) = 12\ inches$

Storage above the permanent pool also can be used to provide flood control and reduce peak flows. Where peak flow reduction is not desired, constructed wetlands must be designed to safely pass extreme storm flows.

Stormwater wetlands are designed so the distance the water flows from the entrance to the exit is maximized, allowing for sufficient contact time for pollutant removal. Wetland components include inlet, deep pool, shallow water, shallow land, upland, and outlet. The inlet is where water enters the wetland. It can be a swale, a pipe, a diverter box, sheet flow, or another method of transporting water to the wetland. Wetland zones are defined by water depth and include deep pool, shallow water, shallow land, and upland. Recommended depth and percent of total wetland area for each zone is shown in **Table 5-1**. The wetland outlet structure consists of a drawdown orifice placed at the top of the shallow water elevation so that stormwater accumulating in the shallow land area will be able to slowly draw down from the wetland. The outlet structure also may be designed to pass larger storm events, which will have higher flow outlet at the proper elevation. Consider maintenance when designing wetlands. Manual values or flashboard risers can be designed as part of the outlet to draw water down for maintenance.

Table 5-1. Wetland Zone Surface Area and Recommended Water Depth

Wetland Zone	Percent of Wetland Surface Area (%)	Recommended Depth
Deep Pool–Non-Forebay	5–10%	18–36 in.
Deep Pool–Forebay	10%	18–36 in. plus additional depth for sediment accumulation
Shallow Water (low marsh)	40%	3–6 in.
Shallow Land (high marsh)	30-40%	Up to 12 in.
Upland	Optional	Up to 4 ft above the shallow land zone

Forebays are required for pretreatment at each inlet, providing 10% or more of the total inflow, and are considered deep-pool wetland zones (Atlanta Regional Commission, 2016). The forebay should be sized to be 4–6 ft deep and with a volume equal to 0.1 inch for each impervious acre of contributing drainage (Atlanta Regional Commission, 2016). Exit velocities from the forebay to the other wetland zones must be non-erosive. If a clay or synthetic liner is used, at least 4 inches of quality topsoil should be added to the top of the liner to support plant growth. Imported or *in situ* soils may be amended with organic material to enhance suitability as a planting medium.

High pollutant-removal efficiencies in a stormwater wetland depend on a dense cover of emergent plant vegetation. Although various plant types differ in their abilities to remove pollutants from the water column, in general, the specific plant species do not appear to be as important for stormwater wetland functioning as plant growth densities (Kadlex and Knight, 1996). In particular, species should be used that have high colonization and growth rates, can establish large areas that continue through the winter dormant season, have a high potential for pollutant removal, and are very robust in continuously or periodically flooded environments. Non-invasive species should be used, with native species being preferred. **Appendix A** includes a list of plants suitable for constructed stormwater wetlands.

Shrubs and wetland plants should be designed to minimize solar exposure of open water areas. A landscape plan prepared by a qualified design professional should outline methods to be used for maintaining wetland plant coverage. It is recommended that five or more species of emergent wetland plants be selected to optimize treatment processes as well as to attract a variety of predator insects for natural mosquito control. Increasing environmental awareness leads many to look for means of biological control of mosquitos. The mosquitofish (*Gambusia*) is proving to be effective, and populations can be stocked in constructed stormwater wetlands (RNJAES 2022). Use of trees and shrubs should be limited if mosquitos are a concern, and they are best planted around the perimeter of the wetland. Cattails should not be planted, as they quickly take over and choke out other plants in the wetland, which limits biodiversity and ultimately leads to mosquito infestation.

5.9.3. Construction Considerations

Plan construction sequencing so that plantings will be installed during preferred planting season to support establishment. Plantings require time to establish themselves before the constructed wetland is brought online. Inflow to the constructed wetland should be diverted during establishment period.

The preferred planting season for most emergent wetland vegetation is early April to mid-June. This allows the wetland plants to have a full growing season to build root reserves to support winter survival. Some emergent wetland vegetation is more successful if planted in early fall. Contact a local plant nursery to confirm the preferred planting season for the species associated with a specific project.

Using plant stock from a nursery is a common and reliable technique for establishing an emergent wetland community in a constructed wetland. Bare root, plugs, and container plantings should be obtained from a local grower, such as a local aquatic plant nursery. Contact the local nursery well in advance of construction to secure the desired species and quantities.

Final grading of the constructed wetland should include staking of the planting zones and confirmation of water depths for each planting zone. If water depths for each planting zone are not as designed, either the planting zone locations or the final grading must be adjusted to support plant survival. The boundaries of the adjusted final planting zones should be surveyed as part of the “as-built” or record design plan.

The constructed wetland disturbed area must be stabilized within 14 days following completion of construction activities. Stabilization should be a combination of temporary and permanent vegetation. In locations where scour may occur prior to vegetation becoming established, protect vulnerable areas using standard erosion control measures, such as those outlined in MDEQ *Erosion and Sediment Control Practices* (MDEQ 2011a).

Vulnerable areas typically include inlet and outlet channels, which experience concentrated flow.

The soil should be moist and workable prior to applying a seed mix or installing plantings. To preserve soil moisture and workability, the wetland outlet structure should not be fully opened for more than 3 days prior to the planting date.

Application of a wet hydroseed mix is a recommended method for installing temporary vegetation. Prior to applying the mix, till the soil to a half-inch to allow for adequate seed contact.

Seed mixes including wet hydroseed mix should not be flooded during the establishment period. Bare root, plugs, and container plantings should not be flooded during establishment, but brief inundation of no more than 2–3 inches may be permitted during this time.

Handling and care of plants prior to installation is critical to plant survival. Plants should be protected from wind damage during transport to the project site from the nursery. Plants should not be dropped during unloading from transport vehicle and should be carefully placed in an on-site staging area. All plants should be clearly identified by scientific name and should be certified as free of invasive species. Root systems of delivered plants should be spot checked for j-rooted plantings or root-bound container plants, which should be rejected and not installed. While awaiting planting, store plants in a covered location on non-paved ground. Do not let the plants dry out. Check the soil moisture of the plants a minimum of twice a day and water a minimum of once a day. Plantings should not be stored longer than 3 days at the project site.

All plantings and seed mixes should be watered thoroughly immediately after installation. During the establishment period, plantings should be inspected frequently with supplemental watering applied as needed.

Inlet and outlet channels should be protected from scour that may occur during periods of high flow. Standard erosion control measures should be used, such as those in *Erosion and Sediment Control Practices* (MDEQ 2011a).

5.9.4. Maintenance

Maintain stable groundcover in the drainage area to reduce sediment load. Keep drainage paths clean so that water can enter and exit the wetland and remove any clogs from inlet or outlet pipes. Remove sediment from forebays after 50% of the total storage capacity has been filled with sediment or after about 5 years.

STORMWATER BEST MANAGEMENT PRACTICES FOR PROTECTING COASTAL WATERS

MISSISSIPPI DEPARTMENT OF ENVIRONMENTAL QUALITY

Implementation Considerations

- H — Land Requirement
- L — Capital Cost
- L — Maintenance Burden

Residential Subdivision Use: YES

Other Considerations:
Soils: Hydrologic group 'A' soils generally require a pond liner

Pollutant Removal

Total Suspended Solids	80%
Nutrients:	
Total Phosphorus	50%
Total Nitrogen removal	30%
Metals:	
Cadmium, Copper, Lead, and Zinc removal	50%
Pathogens:	
Fecal Coliform	70%

For more information reference MDEQ's *Managing Stormwater for Healthy Watersheds in Coastal Mississippi: Best Practices*

L Low — M Medium — H High

Stormwater Ponds

Stormwater ponds are constructed basins that have a permanent pool of water throughout the year. The permanent pool of standing water mixes with and dilutes the initial runoff from storm events. There are two primary configurations of stormwater ponds that achieve 80% TSS removal: wet pond and wet extended detention pond. A wet pond is designed with a permanent pool volume equal to the runoff from the first inch of rainfall. A wet extended detention pond has a smaller permanent pool than a wet pond and a temporary storage volume above the permanent pool designed to hold and release runoff over two days.

Design Criteria

- Requires sufficient inflow to maintain the permanent pool
- The upstream slope should not exceed about 15% and local slopes should be relatively shallow
- Should consist of four design features: pretreatment, permanent pool, outlet structure, and safety features
- Depth of the permanent pool should not exceed 8 feet
- Side slopes to the pond should not exceed 3:1 (h:v) without safety precautions

Advantages/Benefits

- Moderate to high removal rate for urban pollutants
- High community acceptance
- Opportunities for wildlife habitat and aesthetic benefits

Disadvantages/Limitations

- Requires large land area
- May pose safety hazards
- Potential for thermal impacts/downstream warming
- Potential for increased mosquito population

Photo: Kristen Sorrell, MDEQ

5.10. Stormwater Ponds

"Stormwater ponds" are constructed basins that have a permanent pool of water throughout the year (or at least throughout the growing season). In stormwater ponds, a permanent pool of standing water is maintained using an elevated outlet of the pond that mixes with and dilutes the initial runoff from storm events. Two mechanisms that remove pollutants in stormwater ponds are settling suspended particulates and biological uptake or consumption of pollutants by plants, algae, and bacteria in the water.

There are two primary configurations of stormwater ponds that achieve 80% TSS removal: wet ponds and wet extended detention ponds. A wet pond is designed with a permanent pool volume equal to the runoff from the first inch of rainfall. Storage above the permanent pool can be provided for larger flows. A wet extended detention pond has a smaller permanent pool than a wet pond and temporary storage volume above the permanent pool designed to hold and release runoff over 2 days. For wet extended detention designs, the volume of runoff from the first 1-inch of rainfall is divided equally between the permanent pool volume and the temporary pool volume.

5.10.1. Planning Considerations

Stormwater ponds are applicable in residential, industrial, and commercial developments where enough space is available and a permanent pool is included that promotes sediment setting. Stormwater ponds are most suitable as BMPs receiving runoff from larger drainage areas, serving to maintain the permanent pool and provide enough runoff volume to achieve the desired drawdown time for wet extended detention ponds. Precipitation, groundwater inflow, and runoff to the stormwater pond must be sufficient to maintain the permanent pool. In areas with permeable soils, liners may be required to limit infiltration.

Stormwater ponds can be used on sites with an upstream slope up to about 15%. The local slope should be relatively shallow. Runoff from stormwater hot spots can be treated by stormwater ponds as long as infiltration into the surrounding water table is prevented by an impermeable liner or there is a separation distance of 2–4 ft from the water table. Stormwater ponds constructed over an underlying water supply aquifer also should have a separation distance of 2–4 ft from the pond bottom to the water table.

Sediment basins used during construction are often converted to stormwater ponds to provide post-construction runoff control. If this approach is taken, then all sediment deposited during construction should be removed, erosion features repaired, and the vegetated shelf restored before operation of the stormwater pond begins.

5.10.2. Design Criteria

Permanent pool volume and temporary storage volume design criteria to achieve 80% TSS removal differ for wet ponds and wet extended detention ponds. Permanent pool volume for wet ponds is equal to the runoff volume from the 1-inch rainfall depth (V) and temporary storage volume (storage volume above the permanent pool) is optional.

The permanent pool volume within a stormwater pond is the total volume beneath the permanent pool water level and above the sediment storage volume, including the volume in forebays.

For wet extended detention ponds, the permanent pool and temporary storage volumes are each equivalent to 50% of the runoff volume from the 1-inch rainfall. Wet extended detention ponds are designed to hold the temporary storage volume above the permanent pool and release it over a period of 1–2 days.

Much of the suspended sediment and pollutants attached to the sediment are trapped in the stormwater pond and water is slowly released, lessening downstream erosion from smaller storms. A larger permanent pool increases removal of pollutants such as phosphorus. All stormwater pond designs should include the following design features: pretreatment, permanent pool, outlet structure, and safety features. Wet extended detention pond design also includes a temporary storage volume.

Pretreatment

Forebays are highly recommended to provide pretreatment at all inlets to the stormwater pond. A properly engineered forebay can concentrate large sediment particles (e.g., coarse sand to medium gravel) for easier removal and can dissipate the incoming flow energy prior to the stormwater entering the main part of the pond. Energy dissipation reduces resuspension of settled material in the main pool and reduces the likelihood of erosion within the stormwater pond. One method of energy dissipation is to design inlet pipes submerged below the forebay pool level, provided that the flow from the inlet will not resuspend previously captured sediment.

Forebay design volume is recommended to be about 20% of the total stormwater pond permanent pool design volume (0.2V). If the pond has more than one inlet and, therefore, more than one forebay, the total volume of the forebays should equal 20%. When more than one forebay is needed, the volume of each individual forebay is weighted by the area draining to the inlet discharging to the forebay. For example, if the drainage area to one inlet is 30% of the entire stormwater pond drainage area, then the forebay volume at that inlet is 0.3 x 0.2 of permanent pool volume, or 0.06 (6%) of the permanent pool volume.

The forebay sedimentation zone is typically separated from the main permanent pool using an earthen berm, concrete structure, gabions, or riprap (Illinois Urban Manual Partnership, 2022). Velocity of flows from the forebay should not erode the main permanent pool area. Hardening the forebay bottom with concrete, paver blocks, and so forth may make sediment removal easier (Atlanta Regional Commission 2016).

Permanent Pool and Temporary Storage Volume

A water balance should be conducted to ensure that sufficient precipitation and runoff are available to maintain the permanent pool. If a stormwater pond is to be used for irrigation, the water balance should account for the water that will be taken from the pond.

A length-to-width ratio of at least 1.5:1 increases the time that stormwater remains in the pond and reduces short-circuiting, thereby, increasing pollutant removal. The flow path can be lengthened through the pond by incorporating underwater berms. A vegetated buffer around the stormwater pond provides shading and cooling of the pond water. If ponds are expected to stratify in the summer, consider installing a fountain or other mixing mechanism.

For wet pond designs, temporary storage volume above the permanent pool can be used to reduce peak flows from rainfall events greater than 1 inch. During the design, the peak pond elevation for all design storms should be evaluated to ensure that water levels do not flood nearby properties or structures.

A vegetated shelf will provide for diverse emergent wetland vegetation that enhances pollutant removal, provides wildlife habitat, protects the shoreline from erosion, and improves sediment trapping efficiency. A minimum 10-ft-wide vegetated shelf should be designed around the perimeter of the stormwater pond. Half of the required shelf width is 6 inches or above the normal water level. For a 10-ft-wide shelf, the resulting slope is 10:1, creating a rim of shallow water around the deeper permanent pool. The vegetated shelf is a safety feature designed to prevent people from falling into deep water if they get too close to the edge. **Appendix A** includes a list of plants suitable for the vegetated shelf growing conditions.

Outlet Structure

A wet pond outlet structure should be designed to safely convey flows to the conveyance system. A wet extended detention pond outlet structure should be designed to release the volume of runoff from the 1-inch rainfall over a period of 1–2 days (24–48 hours) and safely convey larger flows. Longer detention times typically do not improve settling efficiency significantly, and the temporary pool volume must be available for the next storm. In addition, a prolonged period of inundation can adversely affect the wetland vegetation growing on the vegetated shelf.

Submerged orifice outlets simplify maintenance and reduce the potential for obstruction. They consist of an orifice opening at the bottom end of a vertical PVC pipe connected to a tee. The tee is connected to a horizontal pipe stubbed into the outlet riser. The orifice is below the permanent pool elevation and the elevation of the horizontal pipe invert is equal to the permanent pool elevation. This configuration reduces the likelihood that the orifice will clog. The designer must calculate flotation force for any outlet design subject to flotation forces. The design should include an emergency overflow spillway to safely pass large flows.

Other non-clogging outlets include reverse-slope pipe or weir outlet with trash rack. A reverse-slope pipe draws from below the permanent pool extending in a reverse angle up to a riser and establishes the water elevation of the permanent pool. Because these outlets draw water from below the permanent pool, they are less likely to be clogged by floating debris.

A filter diaphragm and drain system should be provided along the barrel of the principal spillway to prevent piping. If reinforced concrete pipe is used for the principal spillway, O-ring gaskets (ASTM C361) should be used to create watertight joints and should be inspected during installation.

Safety Features

Incorporate safety considerations into the stormwater pond design. Trash racks and other debris control structures should be sized to prevent entry by children. Consider using fences around the spillway structure, embankment, and stormwater pond slopes, with shallow safety benches around the stormwater pond permanent pool. The contours of the stormwater pond should eliminate sharp drop-offs.

5.10.3. Construction Considerations

Even moderate rainfall events during the construction of a stormwater pond can cause extensive damage if proper precautions are not taken. Protective measures should be employed both in the contributing drainage area and at the stormwater pond itself. Temporary drainage or erosion control measures should be used to reduce the potential for damage to the stormwater pond before the site is stabilized.

5.10.4. Maintenance

Maintenance access should be provided to allow for maintenance equipment to access the pond and outlet structure. Immediately after the stormwater pond is established, the plants on the vegetated shelf and perimeter of the basin should be watered twice weekly, if needed, until the plants become established (typically 6 weeks). No portion of the stormwater pond should be fertilized after the first initial fertilization that is required to establish the plants on the vegetated shelf. Stable groundcover should be maintained in the drainage area to reduce the sediment load to the stormwater pond.

If the stormwater pond is not adequately maintained (e.g., by periodic excavation of the captured sediment), storm flows may resuspend sediments and deliver them to the stream. If the basin must be drained for an emergency or to perform maintenance, flushing of sediment through the emergency drain should be minimized to the maximum extent practicable. Once a year, a dam safety expert should inspect the embankment.

With the presence of standing water, stormwater ponds have the potential to escalate mosquito populations. Stocking stormwater ponds with mosquitofish is proving to be an effective method of controlling mosquito populations (RNJAES 2022).

6. Incorporating Practices into Existing Development — Retrofits

In the past, stormwater management for developed areas focused on impervious conveyance methods and detention for flood control purposes. In addition, these areas might not have been developed with established stream buffers. Modifying older developments to include sustainable drainage elements helps to improve water quality. This can be accomplished by modifying existing detention basins or conveyances originally designed for flood prevention to include features that improve water quality. For example, modifying existing dry detention basins to incorporate pretreatment and increase detention time will enhance pollutant removal and maintain flood control benefits. Another method of improving the quality of stormwater from existing developed areas is to incorporate smaller LID/GI into public open spaces, large parking lots, or alongside street parking areas. Because of the large impervious areas and frequent redevelopment often associated with commercial areas, they present a unique opportunity to reduce impervious areas and incorporate sustainable stormwater management practices. Upon redevelopment of commercial areas, impermeable driveways and parking lots can be reconstructed using permeable pavements with LID/GI features and rain gardens, bioretention cells, and other BMPs.

Streambanks and stream buffer conditions in existing developments can often be improved to increase pollutant reduction and increase stream stability. These practices include stabilizing streambanks, maintaining and restoring adequate buffer vegetation, and inspection and repair of energy dissipating structures. Section 2.2.7 describes how to incorporate these practices into new development and the material also is applicable to existing developments with streams. The following discussion focuses on two of the most common approaches to improving the quality of stormwater from existing development: retrofitting dry detention basins and redevelopment and retrofit of commercial areas.

6.1. Retrofitting Existing Dry Detention Basins

Modifying existing dry detention basins may be one of the most cost-effective approaches to enhancing water quality treatment for existing developments. Dry detention basins are commonly designed and used for flood prevention and they may be converted to other BMPs with improved pollutant removal, such as stormwater ponds, stormwater wetlands, or extended dry detention basins. When retrofitting existing dry detention basins for water quality treatment, it is important to preserve the flood control performance of the original design.

The CWP published *Urban Stormwater Retrofit Practices* (Schueler et al. 2007), which includes comprehensive guidance on identifying retrofit opportunities and various ways to modify dry detention basins for water quality benefits, including highlighting potential cost efficiencies. For example, retrofits of dry detention basins can cost around 40% less than new basin construction.

Common ways to retrofit dry detention are to:

- Increase storage volume within the basin by excavating to a deeper elevation, raising the embankment height, or expanding the basin footprint;
- Extend the internal flow path;
- Add wetland elements; and
- Add a pretreatment forebay.

Dry detention basin retrofits are often favorably viewed by the community because they can address maintenance problems and improve basin appearance (Schueler et al. 2007). Retrofit of dry basins that have been constructed with a dual purpose, such as functioning as a soccer field when dry, may be more difficult because of their use constraints. Other difficult retrofit situations include basins with utilities under the bottom, older basins with minimal flood storage capacity caused by upstream development or sedimentation, and basins with limited access for construction equipment.

6.2. Redeveloping and Retrofitting Commercial Areas

Redevelopment refers to redesigning and constructing infrastructure on properties that already have been developed. Redevelopment of commercial areas is fairly common. Commercial sites are likely to be covered with impervious surface, providing opportunity to reduce those surfaces and incorporate LID/GI into the redevelopment design. Another value of redevelopment is the opportunities it provides to conserve natural areas in the surrounding community that might otherwise be subject to greater development pressure (CWP 1998).

Sustainable drainage design of commercial redevelopment properties is challenging because of common land constraints, including irregularly shaped properties, small lots, possible legacy contamination, and noncompliant building features and footprints. These constraints can influence the selection of BMPs used to manage the project's stormwater. The BMPs chosen for redevelopment need to consider the unique circumstances of the project. Bioretention, permeable pavement for sidewalks and parking areas, impervious cover disconnection, and stormwater planters are often recommended for urban areas.

Communities that choose to upgrade and improve stormwater treatment as part of redevelopment should try to keep BMP costs and permit review requirements in line with those typical of new development. Because redevelopment is often more complex than new development, design and building costs can be higher. Where infrastructure upgrades are needed, the costs can be considerable, particularly where treatment capacity or aging infrastructure is the limiting factor. In many cases, however, redevelopment projects can command a premium price and some or all the costs can be recovered.

Parking lots are good retrofit opportunities and often include extensive underground pipes, inlets, and outfalls. A typical retrofit of a large parking lot is to provide storage at a centralized location downstream from the parking lot if space is available (Schueler et al. 2007). Other on-site retrofit alternatives include installing surface BMPs within the lot, reducing impervious cover and providing water quality treatment. Common on-site parking lot BMPs include permeable pavements, bioretention, filter strips, and grassed swales.

Street retrofits to reduce impervious surface and include stormwater BMPs are common in commercial developments. Rain gardens within curb extensions treat stormwater near the source, improve aesthetics, and slow down traffic. Care should be taken when retrofitting BMPs into commercial streets to continue to provide a sufficient number of on-street parking spaces and travel lane width. Select BMP locations that do not interfere with bike lanes.

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Appendix A. Native Plants for Stormwater Management

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Appendix B. Model Ordinance: Post-Construction Runoff Management

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Appendix C. Model Ordinance: Stream and Wetland Buffers

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