PART 2B – Nationwide Review of Best Management Practices for Stormwater Management (Post-Construction Phase)

Florida Board of Professional Engineers
Approved Course No. 0010329

4 PDH Hours

A test is provided to assess your comprehension of the course material – 24 questions have been chosen from each of the above sections. You will need to answer at least 17 out of 24 questions correctly (>70%) in order to pass the overall course. You can review the course material and re-take the test if needed.

You are required to review each section of the course in its entirety. Because this course information is part of your Professional Licensure requirements it is important that your knowledge of the course contents and your ability to pass the test is based on your individual efforts.

Course Description:

Uncontrolled stormwater runoff from construction sites can significantly impact rivers, lakes, and estuaries. Sediment in waterbodies from construction sites can reduce the amount of sunlight reaching aquatic plants, clog fish gills, smother aquatic habitat and spawning areas, and impede navigation.

This course is part of a 4 course, 2-PART Series of a compilation of nationwide Best Management Practices (BMPs) published by the U.S. Environmental Protection Agency (EPA). The course includes BMP fact sheets describing practices that engineers involved with stormwater management may want to consider and the fact sheets generally provide applicability, implementation, and effectiveness information. Overall this series offers a total of 16 PDH credit hours (Parts 1A, 1B, and 2A, 2B)

Part 1 is further separated into 2 courses (Part 1A and 1B) and covers **Stormwater BMPs related to the Construction Phase** of projects and will cover areas of interest including:

- Construction Site Planning and Management
- Erosion Control
- Runoff Control
- Sediment Control
- Good Housekeeping/Materials Management

Part 2 is further separated into 2 courses (Part 2A and 2B)Part 2 is covers **Stormwater BMPs related to the Post-Construction Phase** of projects and will cover areas of interest including:

- Innovative BMPs for Site Plans
- Infiltration
- Filtration
- Retention/Detention

How to reach Us …

If you have any questions regarding this course or any of the content contained herein you are encouraged to contact us at Easy-PDH.com. Our normal business hours are Monday through Friday, 10:00 AM to 4:00 PM; any inquiries will be answered within 2 days or less. Contact us by:

EMAIL: bajohnstonpe@aol.com
Phone: 813-398-9380

Refer to Course No. 0010329

PART 2B – Nationwide Review of Best Management Practices for Stormwater Management (Construction Phase)

How the Course Works…

What do you want To do?	LOOK For This!
Search for Test Questions and the relevant review section	Q1 Search the PDF for: Q1 for Question 1, Q2 for Question 2, Q3 for Question 3, Etc… (Look for the icon on the left to keep you ON Target!)

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24 QUESTIONS

Q1:	A grasses swale helps improve stormwater quality by doing what function as the water flows along the channel:

(A)	Vegetation slows the flow down
(B)	Allows for sedimentation
(C)	Allows for filtration into the underlying soils
(D)	All of the Above

Q2:	Grassed channels are generally used to treat smaller drainage areas of what size:

(A)	1 acre of less
(B)	2 acres or less
(C)	3 acres of less
(D)	More than 3 acres

Q3:	An infiltration basin is a shallow impoundment that infiltrates stormwater into the soil and are not appropriate which regions:

(A)	Arid regions
(B)	Karst regions
(C)	Mountain regions
(D)	Coastal regions

Q4:	Infiltration basins should be scraped to remove accumulated sediment how often:

(A)	Monthly
(B)	Semi-Annually
(C)	Annually
(D)	Every 5 years

Q5:	An infiltration trench is a shallow impoundment that infiltrates stormwater into the soil. Infiltration trenches are less feasible in which region:

(A)	Arid regions
(B)	Karst regions
(C)	Coastal regions
(D)	B and C

Q6:	For maintenance of infiltration trenches how often should the pretreatment basin bottom be aerated de-thatched:

(A)	Monthly
(B)	Semi-Annually
(C)	Annually
(D)	Every 5 years

Q7:	**Permeable pavements allow stormwater to infiltrate to the ground below. Typical Types of permeable pavements include all of the following EXCEPT:**

(A)	Porous asphalt
(B)	Impervious concrete
(C)	Permeable interlocking concrete pavement
(D)	Pervious concrete

Q8:	**Proper design of subsurface components is as important part of installation of Permeable Pavements. The choker or bedding course provides a level and stabilized bed surface that is typically how thick:**

(A)	0.5 to 1.0 inches thick
(B)	1.0 to 1.5 inches thick
(C)	1.0 to 2.0 inches thick
(D)	2.0 to 2.5 inches thick

Q9:	**Bioretention practices are well suited to small sites in urbanized settings and typically need a footprint of what percentage of the surrounding drainage area:**

(A)	5 to 10 percent
(B)	10 to 15 percent
(C)	15 to 20 percent
(D)	20 to 25 percent

Q10:	**Typical maintenance activities for bioretention practices include annual removal of dead plants. It can be expected that within the first year what percentage of plants can die :**

(A)	5 percent
(B)	10 percent
(C)	15 percent
(D)	20 percent

Q11:	**Sand filters are suitable for most regions of the country and most types of sites but may not be as effective during what periods:**

(A)	Fall months
(B)	Winter months
(C)	Spring months
(D)	Summer months

Q12:	For sand filters, if it is observed that there is prolonged periods of pooling water over the filter bed during dry weather, what maintenance activity is necessary:

(A)	Replace the filter media
(B)	Clear sediment from sediment chamber
(C)	Remove trash and debris
(D)	Inspect system for erosion

Q13:	Sand filters effectively remove most pollutants, what is the expected percent reduction of total suspended solids:

(A)	88 percent
(B)	84 percent
(C)	56 percent
(D)	62 percent

Q14:	Vegetated filter strips are vegetated surfaces that treat sheet flow from adjacent surfaces and are also commonly referred to as:

(A)	Grassed filter strips
(B)	Filter strips
(C)	Grassed Filters
(D)	All of the Above

Q15:	Filter strips also have the potential to reduce stormwater but are less for very large storm events or when flow velocities exceed:

(A)	1.0 feet per second
(B)	1.3 feet per second
(C)	1.8 feet per second
(D)	2.1 feet per second

Q16:	Dry detention ponds are appropriate for detaining stormwater from large drainage areas of what size:

(A)	10 acres
(B)	5 acres
(C)	3 acres
(D)	1 acre

Q17:	Dry detention pods require regular maintenance, what design features are suggested to reduce the burden of such maintenance:

(A)	Installation of a micropool at the outlet
(B)	Appropriate perimeter fencing
(C)	Maintenance access to the forebay and micropool
(D)	A and C

Q18:	Of the most common stormwater controls for on-lot treatment for residential homes, which is the simplest:

(A)	Cisterns and rain barrels
(B)	Rain gardens
(C)	Dry wells
(D)	Detention ponds

Q19:	On-lot treatment for residential lots can be relatively inexpensive. Typical costs for a rain barrel is:

(A)	75.00 dollars
(B)	100.00 dollars
(C)	150.00 dollars
(D)	200.00 dollars

Q20:	Stormwater wetlands (or constructed wetlands) are similar to wet ponds and are widely used in most regions of the US except:

(A)	Arid regions
(B)	Karst regions
(C)	Mountain regions
(D)	Coastal regions

Q21:	A typical annual maintenance activity for wetlands is:

(A)	Inspect all components for cracking, subsidence, spalling, etc
(B)	Inspect vegetated areas for erosion, scour
(C)	Inspect components that receive or trap debris
(D)	A and B

Q22:	From stormwater wetlands, the typical expected effluent concentration rate for total suspended solids is:

(A)	3.20 mg/L
(B)	12.0 mg/L
(C)	16.0 mg/L
(D)	20.0 mg/L

Q23:	Wet ponds are constructed basins that have a permanent pool of water throughout the year and have limited application in:

(A)	Urban settings
(B)	Arid Climates
(C)	Coastal Areas
(D)	A and B

Q24:	**After the first year of installation, an inspection of the plant survival rate in the littoral zone of a wet pond should be:**

(A)	25 percent
(B)	35 percent
(C)	50 percent
(D)	66 percent

End of Test Questions

Stormwater Best Management Practice

Grassed Swales

Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment
Subcategory: Infiltration

Description

In the context of stormwater controls to improve water quality, a grassed swale is a vegetated, open-channel management practice that treats and reduces stormwater flows for a specified water quality volume. As stormwater flows along these channels, the vegetation slows it down, allowing for sedimentation, soil filtration and/or infiltration into the underlying soils. Variations of the grassed swale include the grassed channel, dry swale, bioswale and wet swale. The specific design features and methods of treatment differ in each of these designs, but all are improvements on the traditional drainage ditch. They incorporate modified geometry and other features for use of the swale as a treatment and conveyance practice.

Applicability

Planners can use grassed swales in most situations with some restrictions. Swales are linear practices, well-suited for treating stormwater from highways or residential roads. A swale is also useful as one stormwater control in a series of stormwater controls known as a treatment train: for instance, conveying water to a rain garden and receiving water from filter strips. Furthermore, swales can be integral parts of green infrastructure and better site design approaches[1]; see the Site Design and Planning Strategies fact sheet for more information.

Regional Applicability

Planners can use grassed swales in most regions of the United States. In arid and semi-arid climates, however, planners should weigh the value of the practice against any water irrigation needs.

Urban Areas

Dense development in urban areas leaves little pervious surface. Grassed swales may not be well-suited to urban areas because they require a relatively large area of pervious surface.

A grassed swale directs the flow of stormwater and allows stormwater to infiltrate.

Stormwater Hot Spots

Stormwater hot spots are areas where certain land uses or related activities generate highly contaminated discharges with pollutant concentrations exceeding those typically found in stormwater. Typical examples include gas stations and industrial areas. Grassed swales should not receive stormwater from hot spots as they either infiltrate stormwater or intersect the groundwater table, so using them for treatment or conveyance of hot spot discharges could threaten groundwater quality.

[1] Better site design is a design strategy that aims to reduce impervious cover, preserve natural lands and capture stormwater on-site. See the Site Design and Planning Strategies fact sheet for more information.

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Stormwater Retrofit

A stormwater retrofit is a stormwater management practice (usually structural) that property owners put into place after development to improve water quality, protect downstream channels, reduce flooding or meet other specific objectives such as achieving compliance with a total maximum daily load waste load allocation.

One retrofit opportunity to consider involves incorporating grassed swale design features, such as flatter longitudinal slopes, to enhance the stormwater management functions of existing drainage ditches. Designers have traditionally planned ditches to rapidly convey stormwater. In ditches with high flow rates, it may be possible to incorporate features such as check dams (i.e., small dams along the ditch that trap sediment, slow stormwater flow, reduce erosion and promote infiltration) that effectively reduce the channel slope, thus reducing flow velocities and enhancing pollutant removal or infiltration.

Grassed swales may be a suitable retrofit opportunity in areas with ample space, such as lower-density residential areas or roadways with wire shoulders. However, using only grassed swales to retrofit an entire watershed would be expensive—grassed swales cannot treat large drainage areas, so installing a large number of them would be necessary.

Cold Water (Trout) Streams

Grassed swales are a good treatment option in watersheds that drain to cold water streams. They do not pond water for long and often infiltrate water. As a result, they do not typically subject standing water to solar warming.

Siting Considerations

Although grassed swales are generally broadly applicable, designers should consider the site conditions that come with different regions and land uses. These can restrict the choice of grassed swales (e.g., steep slopes, highly impermeable soils) and necessitate adaptations. Designers should also consider these site factors to ensure that this management practice is feasible at the site in question.

Drainage Area

Grassed swales should generally treat stormwater from drainage areas smaller than 1 acre. If they treat larger areas, the flows become too large to allow for any stormwater treatment. For larger drainage areas, consider using wet/dry swales (see “Design Variations”), which generally have a higher level of engineering and can handle larger flows and pollutant loadings.

Slope

Sites with relatively flat slopes work best for grassed swales. Design documents generally recommend a 1 to 2 percent slope. Stormwater velocities within the channel become too high on steeper slopes, causing erosion and preventing infiltration or filtering in the swale. When site conditions require installing swales in areas with steeper slopes, designers can use check dams to reduce velocities and allow for temporary ponding.

Soils/Topography

Design engineers should evaluate the hydrologic soil group of the site during the design phase. Most soils are suitable for grassed swales, with some restrictions on the most impermeable soils (hydrologic soil group D). For impermeable soils, variations such as the dry swale (see “Design Variations”) replace on-site soils with a fabricated soil bed to ensure that stormwater infiltrates as it travels through the swale.

Groundwater

The required depth to groundwater depends on the type of swale (see “Design Variations”). In dry swales and grassed channels, design engineers should position the bottom of the swale at least 2 feet above the groundwater table to prevent prolonged saturation. In areas where groundwater contamination is a concern, designers may want to offset the swale from any water wells to provide a buffer from pollutants infiltrating nearby water sources. Conversely, the design of wet swales depends on standing water or a slow-flowing wet pool, which is achieved by intersecting the groundwater.

Design Considerations

Designers should consider several features to improve longevity and performance while minimizing maintenance burden. Although there are variations, some considerations are common to all grassed swale designs. An overriding similarity between the types of swales is cross-sectional geometry. Swales often have a trapezoidal or parabolic cross section with relatively flat side slopes (flatter than 3:1), though they can also have rectangular and triangular channels. Flat side slopes increase the wetted perimeter—the length along the edge of the swale cross section where stormwater flowing through the swale contacts the vegetated sides and bottom. This design slows stormwater, and the added contact with vegetation encourages sorption, filtering and infiltration. Flat side slopes also let stormwater entering from the sides of the swale receive some pretreatment along the side slope.

In addition to treating stormwater for water quality, it is important that grassed swales convey flows from larger storms safely. Typical designs allow the stormwater from the 2-year storm to flow through the swale without causing erosion. Swales should also have the capacity to convey larger storms (typically a 10-year storm) safely (Philadelphia Water, 2018).

Design Variations

The subsections below discuss three variations of open channel practices: grassed channels, dry swales and wet swales. Grassed channels are the smallest variation, and design engineers can implement them as a standalone practice. Dry and wet swales are larger and, due to their size, should include pretreatment in the form of a small forebay or filter strip at the front of the swale to trap incoming sediments. For pretreatment of stormwater entering the sides of a dry or wet swale, designers can incorporate a pea gravel diaphragm (a small trench that contains river-run gravel) along the length of the swale. Other features that enhance the performance of grassed swales are a flat longitudinal slope (generally between 1 and 2 percent) and a dense vegetative cover in the channel. The flat slope helps to reduce the flow velocity within the channel. The dense vegetation also helps reduce velocities, protects the channel from erosion, and acts as a filter to treat stormwater. When selecting vegetation, consider native plants, flow velocities, sunlight, deicing material tolerance, ponding depth and ponding duration.

Grassed Channel

Q2

Grassed channels generally treat smaller drainage areas of 1 acre or less. Compared to design variations that treat larger drainage areas, they typically require flatter slopes and do not require pretreatment. Of all the options, grassed channels are the least expensive and require the least engineering, but they also provide the least reliable pollutant removal. Designers use grassed channels effectively as pretreatment to other structural stormwater practices. A major difference between the grassed channel and many other structural practices is the method designers use to size the practice. Design engineers size most stormwater management practices by volume, whereas they typically size grassed channels to limit peak flow velocities from a design storm. Maximum velocity and design storms vary by region, but they are often 1 foot per second for the 10-year, 24-hour storm event (e.g., MDE, 2009).

Dry Swale

Dry swales are larger than grassed swales and similar in design to bioretention practices; see the Bioretention (Rain Gardens) fact sheet for more information. Practitioners typically use these designs to treat drainage areas of 1 to 5 acres. They generally incorporate fabricated soil beds, unless native soils have high enough infiltration rates (e.g., hydrologic soil group A or B). When using a fabricated soil bed, a sand/soil mix meeting minimum permeable requirements replaces the native soil. Drawdown requirements vary regionally but required drain time is typically 24 to 48 hours. Design engineers may specify an underdrain system, which consists of a perforated pipe encased by a gravel layer under the soil bed. After the soil bed treats the stormwater, the stormwater flows into the underdrain, which routes it to the storm drain system or receiving waters. Installers can also amend the soil bed with materials that enhance pollutant removal, such as compost or media with high adsorption capacities (Hirschman et al., 2017).

Bioswales are a dry swale variation suitable for smaller drainage areas (generally less than 0.5 acres) and therefore do not need pretreatment. They are similar in design to a rain garden (a smaller version of a bioretention practice), with the main difference being that they infiltrate and convey stormwater, rather than solely infiltrating. Bioswales are typically vegetated and used by designers in urban areas. Accordingly, they have become a common green infrastructure alternative, where they not only provide for stormwater conveyance and treatment, but also increase aesthetic appeal.

Wet Swale

Wet swales intersect the groundwater and function similarly to a linear wetland cell (see the Stormwater Wetland fact sheet). Planners typically use wet swales to treat drainage areas of 1 to 5 acres. This design variation incorporates a shallow permanent pool and wetland vegetation to provide stormwater treatment. When possible, designers should consider using native vegetation in the swale. In some cases, a companion or cover crop may be appropriate to help establish native species. There is also evidence that this design results in potentially high pollutant removal. Wet swales are not common in residential or commercial settings because standing water may facilitate mosquito breeding.

Arid Climates

In arid or semi-arid climates, consider using drought-tolerant vegetation. It is necessary to balance the value of vegetated practices for water quality treatment against the cost of the irrigation water necessary to maintain them in arid and semi-arid regions.

Limitations

Grassed swales have some limitations, including the following:

- Grassed swales cannot treat a very large drainage area.
- Wet swales may become nuisances due to mosquito breeding if they take 3 or more days to drain. Allowing for constant flow, a permanent pool with natural predators (e.g., fish) or timely drainage reduces the chance of the swale becoming a mosquito breeding habitat (MPCA, 2018).
- Improper design or maintenance (e.g., not achieving proper slopes or failing to establish vegetation), grassed swales may result in very little to no pollutant removal.
- Generally, grassed swales reduce peak pollutant concentrations, but depending on their design, they may have very limited capacity to reduce total loadings in the long term.

Maintenance Considerations

Maintenance of grassed swales mostly involves litter control and maintaining the grass or wetland plant cover. Table 1 lists maintenance activities recommended by typical design documents. Some general recommendations include:

- Not using too much salt or sand around the swale during the winter months.
- Not applying fertilizer (consult a local nursery or botanist if plants aren't thriving).
- Not piling snow that can crush plants or leach deicing materials into the system.

Table 1. Typical maintenance activities for grassed swales.

Activity	Schedule
■ Inspect pretreatment areas, such as a pea gravel diaphragm, for clogging. Make corrections as necessary. ■ Inspect grass along slopes for erosion and formation of rills or gullies. Make corrections as necessary. ■ Remove accumulated trash and debris. ■ Inspect and correct erosion problems in the sand/soil bed of dry swales. ■ Plant an alternative grass species if the original grass cover does not become established. ■ Evaluate vegetation health and replant if the vegetation is not sufficiently established or healthy.	Annual (semiannual the first year)
■ Rototill or cultivate the surface of the sand/soil bed of a dry swale if ponded water does not draw down within 48 hours. ■ Remove sediment buildup from the bottom of the swale if accumulation reaches 25 percent of the original design volume.	As needed (infrequent)
■ Mow grass to maintain a height of 3 to 4 inches.	As needed (frequent seasonally)

Source: Claytor & Schueler, 1996

Effectiveness

Structural stormwater management practices can achieve four broad resource protection goals: pollutant removal, flood control, channel protection and groundwater recharge. Depending on the design variation, grassed swales can help meet groundwater recharge and pollutant removal goals.

Groundwater Recharge

Grassed channels and dry swales can provide some groundwater recharge through infiltration. Note that wet swales generally make little, if any, contribution to groundwater recharge. Either high surrounding water tables limit infiltration or debris settled on the bottom of the swale impedes flow. When infiltration losses are a large portion of total incoming flow, analysts should interpret pollutant removal data accordingly. For example, even if effluent concentrations remain the same as influent concentrations, losses to infiltration represent removal of pollutant mass from surface water discharge pathways.

Pollutant Removal

The pollutant removal performance of swales depends on several factors, including velocity reduction, volume reduction and pollutant loading. In all cases, infiltration provides some amount of pollutant removal through volume reduction. Additionally, slowing flow velocity allows sediments, metals and bacteria to settle out of the water column. However, evidence suggests that while it is possible to reduce peak stormwater concentrations, the filter layer may not permanently bind pollutants. Long-term pollutant removal performance may therefore be negligible if stormwater flows can re-mobilize settled pollutants (Bäckström, 2006). Table 2 summarizes the results of several studies looking at the effectiveness of design variations.

Table 2. Grassed swale pollutant removal efficiency (percent removal) data.[a]

Design Variations	Total Suspended Solids	Total Phosphorus	Total Nitrogen	Metals	Bacteria	Source
Grassed channel	16–81	(67)–29	(12)–38[b]	(60)–62	(50)–100	Goldberg, 1993; Cook, 2007; Clary et al., 2017
Dry swale	87	5–83	46–84	88–90	—	Harper, 1990; Carey et al., 2012
Wet swale	23–67	12–39	9–42[b]	(35)–64	33	Koon, 1995; Carey et al., 2012; Clary et al., 2017

[a] Values in parentheses indicate negative removal rates.
[b] Some results only reflect nitrate concentrations.

While it is difficult to draw conclusions from such variable performances, grassed channels generally have poorer and less consistent removal rates than wet and dry swales. This is due in part to design standards focusing on flow conveyance rather than pollutant removal.

The removal efficiencies of metals and bacteria can be variable, as they are highly dependent on surrounding conditions. Swales often treat adjacent roadway discharge, which can be a significant source of metals from wear and tear of vehicle components like tires and brake pads. Swales may also be sources of bacteria, which can thrive in warm soils. Another factor that many studies do not account for is alternative sources of bacteria, such as local wildlife or pet waste. Signs identifying swales as stormwater controls leading to local receiving waters might encourage pet owners to pick up pet waste. Some municipalities have implemented ordinances requiring pet owners to remove pet waste from public areas and stormwater conveyances. Cost Considerations[2]

Data to estimate the difference in cost between various swale designs are limited. One study (Carey et al., 2012) estimated the construction cost of grassed channels as being between $0.85 to $2.30 per cubic foot of storage capacity. Another study estimated total initial costs, including design and construction, as $25,000 to $50,000 per acre of impervious surface treated, with higher costs reflecting smaller practices such as bioswales (King & Hagan, 2011). In any case, pre-construction costs including design and permitting can be 20 to 40 percent of construction costs (Brown & Schueler, 1997; King & Hagan, 2011).

Long-term maintenance costs should be a consideration, since proper upkeep of the swale is critical to both its designed flow capacity and pollutant removal. Although

[2] Prices updated to 2019 dollars. Inflation rates obtained from the Bureau of Labor Statistics CPI Inflation Calculator Web site: https://data.bls.gov/cgi-bin/cpicalc.pl.

annual maintenance costs depend on the design variation, planners generally estimate them to be around 3 percent of construction costs or $500 to $1,500 per acre of impervious surface treated (King & Hagan, 2011).

It is important to assess construction costs in the context of larger design goals. Most development projects require some type of stormwater conveyance. The construction of grassed swales is less expensive than concrete ditches or sewers and can also provide stormwater management benefits.

Additional Information

Additional information on related practices and the Phase II MS4 program can be found at EPA's National Menu of Best Management Practices (BMPs) for Stormwater website

References

Bäckström, M., Viklander, M., & Malmqvist, P. A. (2006). Transport of stormwater pollutants through a roadside grassed swale. *Urban Water Journal, 3*(2), 55–67.

Brown, W., & Schueler, T. (1997). *The economics of stormwater BMPs in the mid-Atlantic region: Final report*. Center for Watershed Protection, Maryland.

Carey, R. O., Hochmuth, G. J., Martinez, C. J., Boyer, T. H., Nair, V. D., Dukes, M. D., Toor, G. S., Shober, A. L., Cisar, J. L., Trenholm, L. E., & Sartain, J. B. (2012). Regulatory and resource management practices for urban watersheds: The Florida experience. *HortTechnology, 22*(4), 418–429.

Clary, J., Jones, J., Leisenring, M., Hobson, P., & Strecker, E. (2017). *International Stormwater BMP Database: 2016 summary statistics*. Water Environment & Reuse Foundation.

Claytor, R. A., & Schueler, T. R. (1996). *Design of stormwater filtering systems*. Center for Watershed Protection.

Cook, E. A. (2007). Green site design: Strategies for storm water management. *Journal of Green Building, 2*(4), 46–56.

Goldberg, J. S. (1993). *Dayton Avenue swale biofiltration study*. Seattle Engineering Department.

Harper, H. (1990). *Effects of stormwater management systems on groundwater quality*. Florida Department of Environmental Regulation.

Hirschman, D. J., Seipp, B., & Schueler, T. (2017). *Enhancing devices for stormwater best management practices: Final report*. Center for Watershed Protection.

King, D. & Hagen, P. (2011). *Costs of Stormwater Management Practices in Maryland Counties.* Prepared for Maryland Department of the Environment by the University of Maryland Center for Environmental Services.

Koon, J. (1995). *Evaluation of water quality ponds and swales in the Issaquah/East Lake Sammamish Basins*. King County Surface Water Management and Washington Department of Ecology.

Maryland Department of the Environment (MDE). (2009). *Maryland stormwater design manual, volumes I and II*.

Minnesota Pollution Control Agency (MPCA). (2018). *Operation and maintenance of a wet swale*.

Philadelphia Water Department (Philadelphia Water). (2018). *Philadelphia stormwater management guidance manual*.

Wisconsin Department of Natural Resources (WDNR). (2017). *Technical Standard: Vegetated swale 1005*.

Stormwater Best Management Practice

Infiltration Basin

Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment
Subcategory: Infiltration

Description

An infiltration basin is a shallow impoundment that infiltrates stormwater into the soil. This control is effective at increasing groundwater recharge (thus increasing baseflow to nearby streams) and can also help remove pollutants from stormwater. Infiltration basins have specific underlying soil requirements, which can preclude them from being feasible on all sites. Pretreatment design and regular inspection and maintenance procedures are crucial to ensure they do not fail.

Applicability

While most regions of the country use infiltration basins, Q3 soil infiltration rate, groundwater contamination concerns, spatial constraints and shallow groundwater tables can limit their application.

Regional Applicability

Infiltration basins apply in most places, with some design modifications in cold and arid climates. They are often inappropriate in karst (i.e., limestone) regions due to concerns of sinkhole formation and groundwater contamination.

Urban Areas

Infiltration basins are generally not appropriate for dense urban areas largely due to space requirements, the potential of infiltrated water to interfere with existing infrastructure and the relatively poor infiltration capacity of most urban soils.

Stormwater Hot Spots

Infiltration basins should not receive discharges from stormwater hot spots, unless another control has already treated the stormwater. Direct infiltration of discharges from stormwater hot spots can lead to groundwater contamination.

Infiltration pond in a natural area. The infiltration portion consists of sand with a high infiltration rate.

Cold Water (Trout) Streams

Infiltration basins are an excellent option for cold water streams because they encourage infiltration of stormwater and maintain dry weather flow. Because stormwater travels underground to the stream, it has little opportunity to increase in temperature.

Common Terms

Stormwater hot spots are areas where land use or activities generate highly contaminated stormwater discharges, with concentrations of pollutants in excess of those typically found in stormwater. Examples include gas stations, vehicle repair areas and waste storage areas.

Siting Considerations

Designers need to carefully locate infiltration basins and ensure that the soils on-site are appropriate for infiltration and that the potential for groundwater contamination and long-term maintenance problems are minimal.

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Drainage Area

Municipalities and site developers have historically used infiltration basins as large-scale facilities, serving for both quantity and quality control. In some regions of the country, they are feasible, particularly if the soils are sandy. In most areas, infiltration basins experience high rates of failure when treating too large a drainage area. In general, they best apply to relatively small drainage areas. Less than 5 acres is ideal, but less than 10 can be acceptable under the right conditions (MDE, 2009).

Slope

Infiltration pond in a natural area. Pond is filled with water and surrounded by vegetation

The bottom of an infiltration basin needs to be completely flat to allow infiltration throughout the entire basin bottom. Side slopes should be flat enough to prevent erosion of the sides of the basin.

Infiltration basin in an urban area. The basin has two gravel areas for infiltration. The remainder of the basin bottom and its slopes are planted with sod.
Credit: Massachusetts Department of Transportation

Soils

Soils are the most important factor when locating infiltration basins. Soils should be significantly permeable to ensure that the basin can infiltrate stormwater quickly enough. Soils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for groundwater contamination. The infiltration rate should range between 0.5 and 3 inches per hour. In addition, the soils should have no greater than 20 percent clay content and less than 40 percent silt/clay content (MDE, 2009). Designers should confirm the infiltration rate and textural class of the soil in the field with approved testing methods; they should only use generic information such as soil surveys for preliminary siting considerations. Finally, infiltration basins may not be suitable in karst regions due to the potential for sinkhole formation or groundwater contamination.

Groundwater

Construction staff should maintain at least 4 feet of separation between the bottom of the infiltration basin's trench and the seasonal high groundwater table. For areas close to large waterbodies, this minimum distance may be as low as 2 feet. In either case, construction staff should follow local standards. Additional variables to consider may include the location of nearby drinking wells or sites with groundwater contamination.

Design Considerations

Specific designs may vary considerably, depending on local design requirements, site constraints or preferences of the designer or community. Designers should incorporate pretreatment, treatment, conveyance, maintenance reduction and landscaping into most infiltration basin designs.

Pretreatment

Pretreatment is important for all stormwater controls, but it is particularly important for infiltration basins. To ensure that pretreatment systems are effective, designers can consider a treatment train approach using multiple controls such as grassed swales, vegetated filter strips, rock swales, detention basins or plunge pools in series.

Treatment

Treatment design features enhance the effectiveness of a control. During the construction process, construction staff should stabilize the upland soils of an infiltration basin to ensure that it does not become clogged with sediment. Also, staff should size the treatment component itself so that the treatment volume can infiltrate into surrounding soils within 48 hours (ideally within 24 hours). Infiltration basins on less permeable soils can be significantly larger than those on more permeable soils.

Conveyance

It is important to convey stormwater through post-construction stormwater controls safely and in a way that minimizes erosion. Designers should ensure that channels leading to an infiltration basin minimize erosion and can use a flow spreader or riprap to minimize erosion from water entering the infiltration basin. If a main conveyance system delivers stormwater to the basin, an offline design is recommended.

Common Terms

Offline design refers to using a flow separator structure in order to divert only a portion of flow to a stormwater control.

Pretreatment plays an important role in stormwater treatment. Pretreatment structures, installed immediately upgradient to a stormwater control, reduce flow rates and remove sediment and debris before stormwater enters the stormwater control. This helps to improve the stormwater control's pollutant removal efficiency and reduces maintenance requirements.

Maintenance Reduction

In addition to specifying regular maintenance activities, designers should incorporate features into the design to reduce the maintenance burden of a stormwater control. In infiltration basins, designers should provide access to the basin for regular maintenance. Where possible, the basin should include a drainage mechanism, such as an underdrain, in case the bottom becomes clogged, water begins ponding for too long or sediment needs removal.

Landscaping

Landscaping can enhance the aesthetic value of post-construction stormwater controls and improve their function. In an infiltration basin, the most important purpose of vegetation is to reduce the basin's tendency to clog. Construction staff should properly stabilize upland drainage with a thick layer of vegetation, especially following construction. In addition, providing a thick turf at the basin bottom helps encourage infiltration and prevent the formation of rills.

Arid or Semiarid Climates

In arid regions, infiltration basins are often highly recommended because of the need to recharge groundwater. Designers should strongly emphasize pretreatment to ensure that an infiltration basin in an arid region does not clog due to relatively high sediment concentrations in these environments. In addition, construction staff may plant the basin bottom with drought-tolerant species and/or cover it with an alternative material such as coarse sand or gravel.

Cold Climates

In extremely cold climates (i.e., regions that experience permafrost), infiltration basins may be infeasible. They are feasible in most cold climates, but there are some challenges to their use. First, a basin may become inoperable during portions of the year when its surface becomes frozen. Designers may also need to increase the treatment capacity to accommodate the additional volume of stormwater associated with spring snowmelt.

Another option is to use a seasonally operated facility (Oberts, 1994). A seasonally operated infiltration/detention basin combines several techniques to improve performance in cold climates. Two of these features are underdrain systems and level control valves:

- At the beginning of the winter season, construction staff open the level control valve and drain the soil.
- As the snow begins to melt in the spring, construction staff close the underdrain and the level control valves. The snowmelt fills the basin until the soil reaches capacity. Then the facility acts as a detention facility, providing storage for particles to settle.

Other design features can help to minimize problems associated with winter conditions, particularly concerns that chlorides from deicing roads, parking lots and sidewalks may contaminate groundwater. If infiltration basins treat stormwater from roadsides or parking lots, construction staff may disconnect them during the winter to prevent chlorides from contaminating groundwater. If disconnection is infeasible or the basin provides snow storage, construction staff should plant the basin bottom with salt-tolerant vegetation.

Maintenance Considerations

Regular maintenance is critical to the successful operation of infiltration basins (see Table 1) and prevents sedimentation that could clog infiltration basins and lead to their failure (MDOT, 2018).

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Table 1. Typical maintenance activities for infiltration basins

Activity	Schedule
▪ Replace pea gravel or topsoil (when clogged)	As needed
▪ Ensure inlets are clear of debris, including sediment and oil/grease ▪ Stabilize the surrounding area ▪ Mow grass and remove grass clippings of filter strip areas, if applicable ▪ Repair undercut and eroded areas at inflow/outflow structures	Monthly
▪ Inspect pretreatment devices and diversion structures for debris accumulation and structural integrity; take corrective action as needed	Semiannually
▪ Aerate the pretreatment basin bottom or de-thatch it, if applicable	Annually
▪ Scrape the pretreatment bottom to remove accumulated sediment and re-seed ground cover, if applicable	Every 5 years
▪ Perform total rehabilitation of the basin and restore design storage capacity Excavate the basin bottom to expose clean soil	Upon failure

Source: MPCA, 2016

Limitations

Infiltration basins are not appropriate for areas with compacted or poorly infiltrating soils, typically limiting their use in urban environments. They are also not suitable for areas with a high groundwater table or where groundwater contamination is a concern. Infiltration basins are not generally aesthetically pleasing, particularly if they clog. If an infiltration basin becomes clogged and takes more than 3 days to drain, the basin could become a source for mosquitoes. Finally, regular maintenance is key to the effectiveness of infiltration basins.

Effectiveness

Infiltration basins reduce stormwater discharge volume by enhancing groundwater recharge. In doing so, they address problems of low groundwater tables, flood control, channel erosion and pollutant removal to varying degrees.

Groundwater Recharge

Urbanization often changes the movement of water through the landscape by increasing stormwater and reducing groundwater recharge. Infiltration basins are effective at reversing these impacts, reducing stormwater by enhancing groundwater recharge.

Pollutant Removal

By reducing the volume of stormwater, infiltration basins also reduce the amount of pollutants that discharge directly to surface waters. In addition, by routing stormwater to underlying soils, infiltration basins use the soil as a filter, which can be an effective removal mechanism for pollutants like sediment, phosphorus and metals. Unfortunately, because the “outlet” of an infiltration basin is underlying soil, measuring effluent concentrations is impractical, and data are scarce on actual pollutant removal performance.

Instead, performance data for infiltration stormwater controls are generally related to the volume of stormwater that the basin captures and infiltrates, as well as the presumed level of filtration the soil provides for individual pollutants. For example, in pollutant loading guidance for infiltration basins, the New Hampshire Department of Environmental Services allows for an assumed removal efficiency of 90 percent for total suspended solids (TSS), 65 percent for total phosphorus, and 10 to 60 percent for total nitrogen for a 90 percent reduction in stormwater volume (NHDES, 2011). The TSS removal efficiency is due to TSS being composed of relatively large particles that the soil physically filters with high effectiveness. Total phosphorus removal is slightly lower and more due to soil adsorption processes, which can be effective but vary by soil type. Nitrogen is generally not well filtered or adsorbed to natural soil, causing a lower removal efficiency.

Cost Considerations[1]

Infiltration basins can be relatively cost-effective post-construction stormwater controls because their construction requires minimal infrastructure. Typical construction costs, including contingency and design costs, can range from $55,000 to $85,000 per acre of impervious surface treated (King & Hagan, 2011). As with many other stormwater controls, economies of scale may lower this unit cost when treating larger areas.

[1]Prices updated to 2019 dollars. Inflation rates obtained from the Bureau of Labor Statistics CPI Inflation Calculator website: https://data.bls.gov/cgi-bin/cpicalc.pl.

Additional Information

Additional information on related practices and the Phase II MS4 program can be found at EPA's National Menu of Best Management Practices (BMPs) for Stormwater website

References

King, D., & Hagan, P. (2011). *Costs of stormwater management practices in Maryland counties*. University of Maryland Center for Environmental Science.

Maryland Department of the Environment (MDE). (2009). *2000 Maryland stormwater design manual.*

Minnesota Department of Transportation (MDOT). (2018). *Infiltration basins: Standards and procedures to ensure performance.*

Minnesota Pollution Control Agency (MPCA). (2016). Operation and maintenance of infiltration basin. In *Minnesota stormwater manual*.

New Hampshire Department of Environmental Services (NHDES). (2011). Pollutant removal efficiencies for best management practices for use in pollutant loading analysis.

Oberts, G. (1994). Performance of stormwater ponds and wetlands in winter. *Watershed Protection Techniques, 1*(2), 64–68.

Stormwater Best Management Practice

Infiltration Trench

Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment
Subcategory: Infiltration

Description

An infiltration trench typically consists of a gravel-filled trench that allows stormwater to soak into the ground. Various infiltration trench designs exist; a design may include an overflow, an underdrain or vegetation. To reduce clogging, design engineers often use settling basins or other pretreatment components in conjunction with the infiltration trench.

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Applicability

Infiltration trenches are appropriate for most regions of the country, but site-specific conditions—such as soil type, water table, drainage area and slope—may restrict their use. Also, infiltration may be less feasible in tidal areas (due to high water tables) or in karst regions (due to concerns with sinkhole formation).

Urban Areas

Infiltration trenches are sometimes suitable for the urban environment, particularly when paired with other stormwater controls. Two site characteristics that can restrict their use are the potential for infiltrated water to interfere with existing infrastructure and the relatively poor infiltration capacity of most urban areas. Additionally, infiltration trenches may need more frequent maintenance in urbanized areas, where they can become clogged with trash and debris.

Stormwater Hot Spots

Infiltration trenches should not receive discharge from stormwater hot spots, unless another stormwater control has already treated the stormwater. Direct infiltration of discharge from stormwater hot spots may lead to groundwater contamination.

Siting and Design Considerations

Design engineers need to site infiltration trenches carefully. They should ensure that the soils on-site are appropriate for infiltration and that there is minimal

Infiltration trenches at Einstein Hospital in East Norriton.
Photo Credit: Montgomery County Planning Commission/Flickr CC

potential for groundwater contamination and long-term maintenance problems.

Design engineers generally use infiltration trenches for drainage areas smaller than 5 acres and with relatively high impervious cover (MDE, 2009). For larger applications, designers should consider infiltration basins. An infiltration trench should be on flat ground, but the slopes of the site draining to the trench can be as steep as 15 percent.

Common Terms

Stormwater hot spots are areas where land use or activities generate highly contaminated stormwater discharges, with concentrations of pollutants exceeding those typically found in stormwater. Examples include gas stations, vehicle repair areas and waste storage areas.

Soils are a strongly limiting factor in the siting of infiltration trenches. Soils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for groundwater contamination. The infiltration rate should

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range between 0.5 and 3 inches per hour. In addition, the soils should have no greater than 20 percent clay content and less than 40 percent silt/clay content (MDE, 2009). Design engineers should confirm the infiltration rate and textural class of the soil in the field; generic information such as soil surveys is only suitable for preliminary siting considerations. Finally, design engineers should not use infiltration trenches in regions of karst topography due to the potential for sinkhole formation or groundwater contamination.

Design engineers should design infiltration trenches to maintain at least 4 feet of separation between the bottom of the trench and the seasonal high groundwater table. For areas close to large waterbodies, this minimum distance may be as low as 2 feet. In either case, designers should follow local standards. Additional variables to consider may include the location of nearby drinking wells or sites with groundwater contamination.

Pretreatment

Pretreatment is particularly important for infiltration-based stormwater controls. To ensure that pretreatment systems are effective, designers can consider a treatment train approach using multiple stormwater controls—such as grassed swales, vegetated filter strips, rock swales, detention basins or plunge pools—in series.

Common Terms

Pretreatment plays an important role in stormwater treatment. Pretreatment structures, installed immediately upgradient to a stormwater control, reduce flow rates and remove sediment and debris before stormwater enters the stormwater control. This helps to improve the stormwater control's pollutant removal efficiency and reduces maintenance requirements.

Offline design Offline design refers to using a flow separator structure in order to divert only a portion of flow to a stormwater control.

Treatment

Treatment design features enhance the effectiveness of an infiltration trench. During the construction process, construction staff need to stabilize the upland soils of an infiltration trench to ensure it does not clog with sediment. They should size the treatment component itself so that the treatment volume can infiltrate into surrounding soils within 48 hours (ideally within 24 hours).

Conveyance

Stormwater needs to pass safely through stormwater controls, and design engineers should ensure that channels leading to an infiltration trench minimize erosion. They should expect an infiltration trench to treat only small storms (and thus consider an offline design that uses a structure to divert only a portion of flow to the trench). If needed, design engineers can specify the sides of an infiltration trench be lined with a geotextile fabric to prevent flow from causing rills along the edge of the trench.

Arid or Semiarid Climates

Infiltration trenches are often highly suitable for arid regions because they can recharge groundwater. One concern in these environments is the potential for infiltration trenches to clog due to relatively high sediment concentrations. Design engineers need to emphasize pretreatment more heavily in drier climates.

Cold Climates

In extremely cold climates (i.e., regions that experience permafrost), infiltration trenches may be infeasible. They can be feasible in most cold climates, but there are some challenges to their use. Design engineers may need to increase a trench's capacity to accommodate additional stormwater volume from snowmelt. In addition, for a trench that controls stormwater from areas treated with deicing materials, it may be desirable to divert flow around the trench in winter to prevent the infiltration of chlorides. Finally, design engineers should set the trench back a minimum distance from roads to ensure that it does not cause frost heaving.

Maintenance Considerations

In addition to specifying regular maintenance activities, design engineers should incorporate features to reduce the infiltration trench's maintenance burden. Maintenance may be difficult if it follows an irregular schedule. The most frequent maintenance challenge with infiltration trenches is clogging. Table 1 provides a general schedule for infiltration trench maintenance.

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Table 1. Typical maintenance activities for infiltration trenches.

Activity	Schedule
Replace pea gravel and topsoil (when clogged).	As needed
Clear inlets of debris, including sediment and oil/grease.	Monthly
Stabilize the surrounding area.	
Mow grass and remove grass clippings from filter strip areas, if applicable.	
Repair undercut and eroded areas at inflow/outflow structures.	
Inspect pretreatment devices and diversion structures for debris accumulation and structural integrity; take corrective action as needed.	Semiannually
Aerate pretreatment basin bottom or de-thatch basin bottom, if applicable.	Annually
Scrape pretreatment basin bottom to remove accumulated sediment and re-seed ground cover, if applicable.	Every 5 years
Totally rehabilitate the trench and restore its design storage capacity.	Upon failure
Excavate trench walls to expose clean soil, if applicable.	

Source: MPCA, 2016

As with all post-construction stormwater controls, infiltration trenches should have an access path for maintenance activities. An observation well (i.e., a perforated PVC pipe that leads to the bottom of the trench) can enable inspectors to monitor the drawdown rate. Where possible, a trench should have a feature to drain clogs, such as an underdrain. An underdrain is a perforated pipe system in a gravel bed, installed on the bottom of filtering controls to collect and convey filtered stormwater. An underdrain pipe with a shutoff valve can act as an overflow in an infiltration trench in case of clogging.

Landscaping

The pretreatment components of an infiltration trench are typically the only areas with vegetation, such as a grass channel. Still, it is important to properly stabilize pretreatment components and upland drainage areas with thick vegetation, particularly after construction. When possible, design engineers should specify native vegetation to maximize rapid establishment.

Limitations

Although infiltration trenches can be a useful post-construction stormwater control, they have several limitations. While they do not detract visually from a site, infiltration trenches generally provide no visual enhancements. Their application can be limited due to concerns with groundwater contamination and other soil requirements. Finally, maintenance can be burdensome, and infiltration trenches can have a relatively high rate of failure without regular maintenance or adequate pretreatment.

Effectiveness

Performance data for infiltration-based stormwater controls are generally related to the volume of captured and infiltrated stormwater, as well as the presumed level of filtration that the soil provides for individual pollutants. For example, the New Hampshire Department of Environmental Services provided data showing that, for a 90 percent reduction in stormwater volume, stormwater trenches achieve an assumed removal efficiency of 90 percent for total suspended solids (TSS), 60 percent for total phosphorus (TP) and 10 to 55 percent for total nitrogen (NHDES, 2011). The high TSS removal efficiency is because TSS consists of relatively large particles that soil physically filters with great effectiveness. TP removal is slightly lower and is more due to soil adsorption processes, which can be effective but vary by soil type. Last, natural soil (especially soil with low organic content) generally does not filter or adsorb nitrogen well, resulting in a lower removal efficiency.

Cost Considerations[1]

Infiltration trenches can be somewhat expensive when compared to other post-construction stormwater controls like stormwater wetlands and bioretention systems (Weiss et al., 2007). Typical construction costs, including contingency and design costs, can range from $60,000 to $70,000 per acre of impervious surface treated (King & Hagan, 2011).

Using land efficiently can help save money. Infiltration trenches are typically small, taking up only about 2 to 3 percent of the site draining to them. In addition, they can fit into thin, linear areas. Thus, they can generally fit into relatively unusable portions of a site.

If improperly maintained, infiltration trenches have a high failure rate (see "Maintenance Considerations"). In general, maintaining them costs an estimated 5 to 20 percent of their construction cost. More realistic values are probably closer to the 20 percent range to ensure long-term functionality.

[1]Prices updated to 2019 dollars. Inflation rates obtained from the Bureau of Labor Statistics CPI Inflation Calculator website: https://data.bls.gov/cgi-bin/cpicalc.pl.

Additional Information

Additional information on related practices and the Phase II MS4 program can be found at EPA's National Menu of Best Management Practices (BMPs) for Stormwater website

References

King, D., & Hagan, P. (2011). *Costs of stormwater management practices in Maryland counties*. University of Maryland Center for Environmental Science.

Maryland Department of the Environment (MDE). (2009). *2000 Maryland stormwater design manual.*

Minnesota Pollution Control Agency (MPCA). (2016). Operation and maintenance of infiltration trench. In *Minnesota stormwater manual*.

New Hampshire Department of Environmental Services (NHDES). (2011). Pollutant removal efficiencies for best management practices for use in pollutant loading analysis.

Weiss, P. T., Gulliver, J. S., & Erickson, A. J. (2007). Cost and pollutant removal of storm-water treatment practices. *Journal of Water Resources Planning and Management, 133*(3), 218–229.

Disclaimer

This fact sheet is intended to be used for informational purposes only. These examples and references are not intended to be comprehensive and do not preclude the use of other technically sound practices. State or local requirements may apply.

Permeable Pavements

Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment
Subcategory: Infiltration

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Description

Permeable pavements are a stormwater control that allows stormwater to infiltrate through the surface of the pavement to the ground below—a green infrastructure alternative to traditional impervious surfaces. Types of permeable pavements include porous asphalt, pervious concrete and permeable interlocking concrete pavement (PICP).

Porous asphalt (sometimes called pervious, permeable, popcorn or open-graded asphalt) and pervious concrete (sometimes called porous, gap-graded or enhanced porosity concrete) are versions of traditional asphalt or concrete with reduced sand and fines to allow for greater porosity and infiltration. PICP consists of manufactured concrete units (pavers) with small openings between permeable joints that contain highly permeable, small-sized aggregates.

As with traditional pavement or concrete, construction staff install permeable pavements on a crushed stone aggregate bedding layer and base, which can also temporarily detain stormwater that has passed through the permeable surface layer. With proper installation, permeable pavements can serve as durable, low-maintenance and low-cost alternatives to traditional impermeable pavements.

Permeable pavement can reduce the impervious area in an urban landscape without losing the functionality of impervious surfaces.
Credit: Anthony D'Angelo for USEPA, 2015

Applicability

Permeable pavements can help achieve multiple benefits since they provide surfaces to move vehicular and pedestrian traffic and reduce stormwater discharges. They are suitable for municipal stormwater management programs and private development applications. For municipal applications, permeable pavements can reduce pavement ponding and local flooding by infiltrating stormwater on-site. Similarly, private development projects can use them to meet post-construction stormwater quantity and quality requirements. Permeable pavements can be especially helpful in developed areas with little open space that cannot accommodate post-construction stormwater controls requiring dedicated surface area. They can also reduce the need for additional expenditures and land use associated with conventional collection, conveyance and stormwater management infrastructure.

Permeable pavements can generally replace traditional impervious pavement in local roadway, pedestrian walkway, sidewalk, driveway, parking lot and bike path applications. They may not be appropriate for certain high-volume and high-speed roadways, although permeable friction course overlays can reduce road ponding, splash and noise on these types of roadways. Some permeable concrete can handle heavier loads; however, the increased surface abrasion can cause the pavement to deteriorate more quickly than conventional concrete, and the eroded material can create a clogging concern.

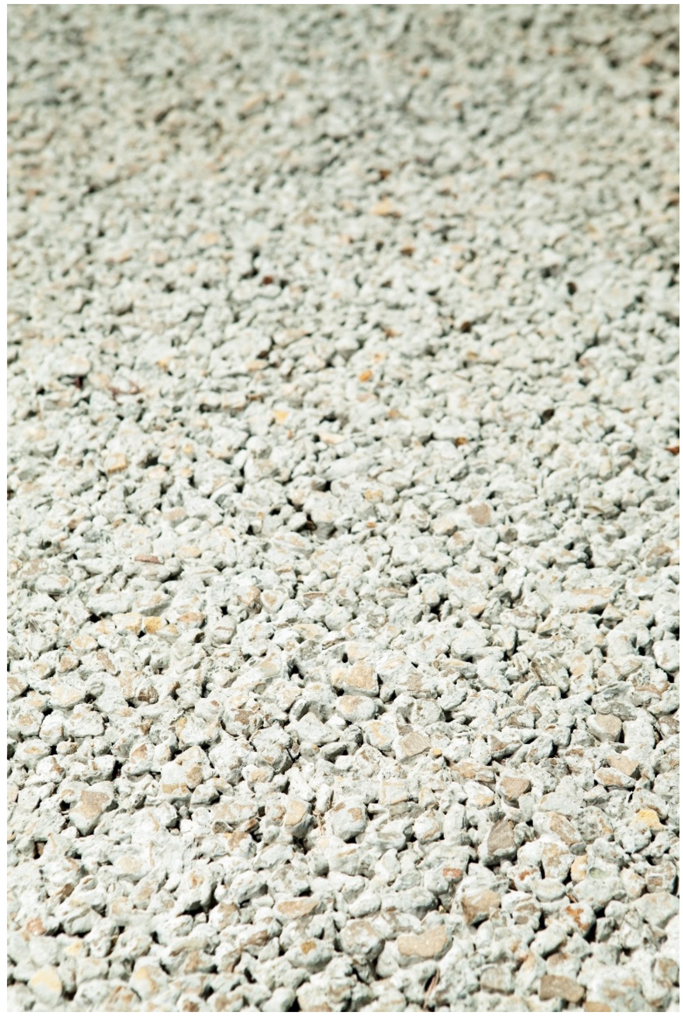
Individual permeable pavement types also have unique characteristics and offer additional benefits. Porous asphalt and pervious concrete have slightly rougher surfaces than their traditional counterparts, providing more traction to vehicles and pedestrians. Amending pervious concrete with photocatalytic compounds can help remove harmful air pollutants (Shen et al., 2012). Researchers have also found ways to increase the conductivity of permeable pavement, which not only improves infiltration capacity but also wicks moisture from the ground to improve evaporation. This process, along with the generally lighter colors of permeable pavement compared to asphalt, may help to reduce the urban heat island effect under certain conditions (Yong et al., 2018). The gridded surface texture of PICP also tends to slow traffic and can even provide an aesthetic amenity. Additionally, PICP reduces the risk of ponding on the roadway surface, which in turn reduces the chance of vehicles hydroplaning and reduces splashing of vehicle undercarriages that can release pollutants.

PICP differs from concrete grid pavements (i.e., concrete units with cells that typically contain topsoil and grass). These paving units can infiltrate water but at rates lower than PICP. Unlike PICP, concrete grid pavement designs generally lack a crushed stone base, which limits water storage. Moreover, grids are more typical in areas with intermittent traffic, such as overflow parking areas and emergency fire lanes.

Siting and Design Considerations

The purpose of permeable pavements is to intercept, evaporate, detain, filter and infiltrate stormwater on-site. Site developers can install permeable pavements across an entire street width, across an entire parking area or within a portion of a larger impervious area. For example, designers can use permeable pavements in parking lot lanes or parking spaces to treat stormwater flow from adjacent upgradient impermeable pavements and roofs. Designers can also incorporate inlets to accommodate overflows from extreme storms. The area of a permeable pavement installation depends on the infiltration capacity of the particular type of pavement or paver system (with an appropriate allowance for clogging); its depth or storage capacity; and the stormwater volume that the permeable pavement will need to capture, store or infiltrate.

Permeable pavements consist of surface and subsurface layers that each have a specific material composition and thickness depending on the desired application (FHWA, 2016). As with traditional pavements, surface layers are generally less than 4 inches thick. Porous asphalt consists of open-graded coarse aggregate that bituminous asphalt bonds together. Adding polymers to



Close-up view of permeable concrete.

the mix can also increase its strength for heavier load applications. The thickness of porous asphalt ranges from 2 to 4 inches depending on the traffic loads that design engineers expect. Pervious concrete consists of cement, open-graded coarse aggregate and water. Adding admixtures to the concrete mixture can enhance strength, increase setting time or add other properties. The thickness of pervious concrete ranges from 4 to 8 inches depending on the traffic loads that design engineers expect. PICP pavers consist of precast modular units of various shapes and sizes. They are typically 80 millimeters (3⅛ inches) thick for vehicular areas and 60 millimeters (2⅜ inches) thick for pedestrian areas.

For any application, proper design of subsurface components is as important as the design of the permeable surface itself. Not every permeable pavement application needs each subsurface layer. In all cases, designers should follow any state or local codes and guidance. Typical subsurface components are described below, from top to bottom (MDE, 2009; NAPA, 2008; UNHSC, 2009). Note that the descriptions provide a typical thickness range for each layer, but actual thicknesses can vary substantially depending on project-specific requirements, such as desired storage capacity, pavement strength or subgrade composition.

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- **Choker course.** Also called a bedding course for PICP, this permeable layer is usually 1 to 2 inches thick and provides a level and stabilized bed surface for the permeable surface layer. It consists of small, uniformly sized (also sometimes called poorly graded) aggregate.
- **Filter course or base reservoir.** This layer sits immediately beneath the choker or bedding course and serves as a high-infiltration-rate transition layer between the bedding and subbase layers. It also provides additional storage and can provide some filtration. Sometimes it is necessary to place filter fabric at the base of this layer to reduce the migration of fines. This base reservoir is typically 3 to 4 inches thick and, depending on local design requirements, can consist of uniformly sized crushed stone (e.g., No. 57 stone) or bank run gravel. It is typically of an intermediate size between bedding and subbase aggregate, often ¾ to 3⁄16 of an inch in diameter.
- **Subbase reservoir.** The subbase layer or reservoir serves as the main water storage and support layer. The stone is uniformly graded and sizes are larger than the base, typically ¾ of an inch to 2½ inches in diameter. The thickness of the subbase layer depends on project-specific factors such as water storage requirements, traffic loads, subgrade soils and the need for frost heave protection. This layer often has a specific minimum thickness of 4 inches, but the total thickness can be greater than 24 inches in some cases. A subbase layer may not be a requirement in pedestrian or residential driveway applications. In such instances, the base layer is larger to provide water storage and support.
- **Underdrain (optional).** In instances where design engineers install porous asphalt over soils with poor infiltration rates, an underdrain facilitates water removal from the base and subbase. The underdrain is a perforated pipe that ties into an outlet structure. The pipes also provide additional storage volume beyond the stone base.
- **Geotextile (optional).** Geotextile can separate the subbase from the subgrade and keep soil from migrating into the aggregate subbase or base.
- **Subgrade.** The subgrade layer of soil is immediately beneath the aggregate base or subbase. The infiltration capacity of the subgrade determines how much water can exfiltrate from the aggregate into the surrounding soils. Construction staff should not compact the subgrade soil.
- **Liner.** Some permeable pavements and PICP installations may include liners and underdrain systems where infiltration is not feasible or desirable due to the presence of underground utilities, contaminated soils that could pollute groundwater if those contaminants mobilize, or surface contaminants (e.g., chlorides) that might negatively affect receiving waters.

Site slopes and soils are important considerations during the design phase. For slopes greater than 2 percent, the soil subgrade base may need terracing to prevent stormwater from flowing through the pavement structure. Alternatively, designers can dig lined trenches with underdrains across the slope to intercept flow through the subbase (ACPA, 2006). For soils that are weak or have poor infiltration capacity, designers should take certain measures to accommodate pervious pavements. For example, clay soils exhibit both of these problematic characteristics. To compensate for the lower structural support capacity of clay soils, permeable pavements often need greater subbase depth—which also adds storage volume to compensate for the lower infiltration rate of the clay subgrade. Underdrains can increase drainage over clay soils. Designers may install an impermeable liner between the subbase and the subgrade to limit water infiltration when clay soils have a high shrink-swell potential (Hunt & Collins, 2008).

For pervious concrete, consistent porosity through the concrete structure is critical to prevent freeze-thaw damage. Cement paste and smaller aggregate can settle to the bottom of the structure during consolidation and seal the pores. Trapped water can freeze, expand and break apart the pavement. In general, larger aggregate size helps improve permeability and reduce freeze-thaw damage (Thompson Materials Engineers, Inc., 2008).

Installation Considerations

For all surface types, proper installation is key to ensuring long-term effectiveness. While construction staff can generally use much of the same equipment to mix and lay permeable and conventional versions of asphalt and concrete, the mixtures are slightly different and have different handling and installation requirements.

During compaction of porous asphalt, contractors should use minimal pressure to avoid closing pore space. They should avoid vehicular traffic for 24 to 48 hours after pavement installation.

Pervious concrete has a lower water content than traditional concrete, greatly reducing its handling time. Contractors should pour pervious concrete within 1 hour of mixing unless they use admixtures to extend the handling time. A screed—which construction staff use to level concrete—is a manual or mechanical device typically set ½ inch above the finished height. Construction staff should not use floating and troweling because these may close the surface pores. Consolidation of the concrete, usually with a non-vibratory steel roller, typically happens within 15 minutes of placement. For all permeable pavements, designers should take measures to protect these surfaces from high sediment loads. When contributing areas are large, designers should consider pretreatment practices such as filter strips and swales. Preventing sediment from entering the base of permeable pavement during construction is critical for ensuring that permeable pavements retain a high infiltration rate. Construction staff should divert stormwater flow from disturbed areas away from the permeable pavement until stabilization is complete, which can take up to a week for concrete systems.

Limitations

Several factors may limit permeable pavement use. Permeable pavements are not as strong as conventional asphalt and are not appropriate for applications with high volumes and extreme loads. Permeable pavements are also not appropriate for stormwater hot spots where hazardous material loading, unloading or storage occurs, or in areas where spills and fuel leakage are possible.

PICP designs also have limitations. Most pavers comply with the Americans with Disabilities Act. However, designers may want to limit units with large openings containing aggregate for paths or parking areas that disabled persons, bicycles, pedestrians with high heels and the elderly use. Such areas can use solid interlocking concrete pavements (ICPI, 2019).

Maintenance

The most prevalent maintenance concern for permeable pavements is clogging, which can limit infiltration rates. Fine particles that may clog permeable pavements can come from vehicles, the atmosphere and stormwater discharge from adjacent land surfaces—the more frequent (e.g., vehicle use) or large (e.g., drainage area) these sources are, the faster that clogging will occur. Although clogging increases with age and use, it generally does not lead to complete impermeability. Long-term studies have found that permeable pavements have high initial infiltration rates that then decrease and eventually level off with time (Bean et al., 2007a). Compared to initial infiltration rates of hundreds of inches per hour, long-term infiltration rates decrease but usually remain well above 1 inch per hour, which may be sufficient in most circumstances to infiltrate stormwater from intense storm events (ICPI, 2000). A study of 11 pervious concrete sites found infiltration rates ranging from 5 inches per hour to 1,574 inches per hour, with the lowest rates coming from sites receiving discharge from areas with poor maintenance or earth disturbance activities. However, the infiltration rates were still high relative to rainfall intensities (Bean et al., 2007a).

Key Siting and Maintenance Issues:

- Do not install in areas where hazardous material loading, unloading or storage occurs.
- Avoid high sediment loading areas.
- Divert stormwater from disturbed areas until the areas stabilize.
- Do not use sand for snow or ice treatment.
- Perform periodic maintenance to remove fine sediments from paver surface and optimize permeability.

Vacuum sweeping can increase permeability. Also, in cases of isolated clogging of porous asphalt and permeable concrete, construction staff can drill ½-inch holes through the pavement surface to allow stormwater to drain to the aggregate base. In cases of extreme clogging of PICP, construction staff can replace aggregate between the pavers (Clark et al., 2008; TRCA & CVCA, 2010). Placing a stone apron around the pavement and connecting it hydraulically to the aggregate base and subbase can provide a backup to surface clogging or pavement sealing.

Porous asphalt and concrete generally need less maintenance for cracks or potholes than traditional pavement surfaces, mostly due to effective draining of the stone bed, deep structural support and a better ability to withstand freeze-thaw stress. When cracking and potholes do occur, construction staff can use a conventional patching mix to repair them. The life span of porous alternatives can also be greater for similar reasons. The life span of a conventional pavement parking lot in a cold climate is typically 15 years, whereas porous asphalt parking lots can have life spans of more than 30 years due to the reduced freeze-thaw stress (Gunderson, 2008). Permeable concrete with proper construction can last 20 to 40 years because of its ability to handle temperature impacts (Gunderson, 2008).

Maintenance requirements for permeable pavements in cold climates are slightly different than those for traditional pavements. In cold climates, roadway managers should not use sand around permeable pavement. Snow plowing can occur similarly to plowing on conventional pavements, and deicing material use is acceptable in moderation. Plowed snow pile storage should not be above permeable surfaces, as melting snow can increase sediment loads and lead to clogging.

Compared to traditional pavements, permeable pavements generally need less road salt or deicing materials because the rapid surface drainage reduces the occurrence of freezing puddles and black ice (Gunderson, 2008). This benefit can be considerable, as deicing treatments are a significant expense, chlorides in stormwater have substantial environmental impacts, and no post-construction stormwater control can effectively reduce chloride concentrations. For example, a porous asphalt lot installed at the University of New Hampshire required 75 percent less deicing material than other impervious asphalt lots for equivalent deicing effects. In addition, the porous pavement required no deicing material application because it had a higher frictional resistance than conventional pavement (UNHSC, 2007).

Effectiveness

Permeable pavements can be effective at reducing stormwater discharges and pollutant concentrations, though their effectiveness can be variable and depends more on the design of underlying layers and surrounding environmental conditions than surface type. The choice of surface type is relevant to user needs, cost, material availability, constructability and maintenance, but it has minimal impact on the overall stormwater retention, detention and treatment of pollutants by the system.

Reduction in stormwater volume is generally a function of subsoil infiltration rate and base storage capacity. However, depending on site constraints, some designers may include liners and underdrain systems that would not infiltrate runoff. Both infiltrating and noninfiltrating systems provide ecological benefits—through detention, retention, evaporation and pollutant removal, all to varying degrees—so many entities treat them both as pervious surfaces. Permeable pavements with deeper subsurface layers can detain greater volumes of stormwater, while the high infiltration rates of surrounding soils allow subsurface layers to drain more rapidly—also improving detention capacity. Although pavement infiltration rate is important, it is rarely the limiting factor, as the infiltration rates of surface and base layers with proper construction tend to exceed peak rainfall and stormwater rates. Overall, permeable pavements have demonstrated stormwater reduction effectiveness from 25 to 100 percent, reflecting the range of design approaches and site conditions (Bean et al., 2007a, 2007b; Booth & Leavitt, 1999; Brattebo & Booth, 2003; Cahill et al., 2003; Collins et al., 2008; Fassman & Blackbourn, 2007; Legret & Colandini, 1999; Roseen & Ballestero, 2008; Pratt et al., 1999).

Permeable pavements reduce pollutant concentrations through several processes. The media layers filter stormwater and promote pollutant removal through physical filtration and biological processes. The subgrade soils are also a major factor in treatment. Sandy soils infiltrate more stormwater but have less treatment capability. Clay soils can hold and capture more pollutants, but they infiltrate less. Table 1 provides measured pollutant removals from pervious pavement systems.

Table 1. Permeable pavement pollutant removals.

Surface Type	Total Suspended Solids	Metals	Nutrients
Porous asphalt	94–99%	76–97%	42–43%
Pervious concrete	91%	75–92%	N/A
PICP	67–81%	13–88%	34–72%

Sources: Barrett et al., 2006; Bean et al., 2007b; Clausen & Gilbert, 2006; Rushton, 2001; UNHSC, 2007; Van Seters, 2007

Permeable pavement and paver systems are considered green infrastructure as defined under the Clean Water Act. Permeable pavements may provide stormwater volume reductions, detention and pollutant removal depending on the design of the systems.

Permeable pavements with water quantity and pollutant reduction characteristics (e.g., 80 percent total suspended solids reductions) can earn credits under voluntary standards, i.e., green or sustainable building evaluation systems such as Leadership in Energy and Environmental Design (LEED) and Green Globes. They can also earn credits for water conservation, conservation of materials through the use of recycled materials, and regional manufacturing and resource use.

Cost Considerations[1]

Permeable pavement can be a cost-effective alternative to traditional pavement. Although it typically costs more than traditional pavement to construct initially, savings in maintenance and stormwater management costs can make it more economical in the long term (U.S. EPA, 2013).

As with other green infrastructure practices, permeable pavement costs depend on site conditions and the level of stormwater management necessary. Subgrade soils such as clay may need more base material for structural support or more stormwater storage volume. Areas that have low infiltration capacity or that need a high level of stormwater treatment may need deeper base layers for greater detention capacity or require components like underdrains. Each of these factors may increase overall costs.

Construction costs range from $1 to $1.50 per square foot for porous asphalt, $3 to $9 per square foot for pervious concrete and $7 to $14 per square foot for PICP (VDEQ, 2013). In comparison, asphalt alone costs around $1 to $2 per square foot depending on the thickness and type (RSMeans, 2019), while typical road construction can cost more than $15 per square foot when considering full construction costs, including stormwater management (ARTBA, 2019; FDOT, 2019). Still, it is difficult to compare costs if not looking at a single site. A study from Olympia, Washington, evaluated the life cycle cost of traditional versus permeable concrete sidewalks and found the total cost to be $8 per square foot for the permeable alternative and $15 per square foot for the traditional, impermeable alternative. Greater costs for the traditional alternative were due to the cost of a stormwater pond that would have been needed to treat discharge from the impervious surface (U.S. EPA, 2008). Similarly, in a life cycle cost analysis of permeable versus traditional pavement, the city of West Union, Iowa, found that despite greater upfront costs, installation of permeable pavement would result in savings over the life span of the project owing to lower maintenance and repair costs for deicing (U.S. EPA, 2013). EPA's Green Infrastructure Cost-Benefit Resources page offers more examples of successful, economically viable permeable pavement and other green infrastructure projects.

[1] Prices updated to 2019 dollars. Inflation data obtained from the Bureau of Labor Statistics CPI Inflation Calculator Web site: https://data.bls.gov/cgi-bin/cpicalc.pl.

Additional Information

Additional information on related practices and the Phase II MS4 program can be found at EPA's National Menu of Best Management Practices (BMPs) for Stormwater website

References

American Concrete Pavement Association (ACPA). (2006). *Stormwater management with pervious concrete.* Publication IS334P.

American Road and Transportation Builders Association (ARTBA). (2019). *Funding, financing and cost frequently asked questions*.

Barrett, M., Kearfott, P., & Malina, J. (2006). Stormwater quality benefits of a porous friction course and its effect on pollutant removal by roadside shoulders. *Water Environment Research*, *78*(11), 2177–2185.

Bean, E., Hunt, W., & Bidelspach, D. (2007a). A field survey of permeable pavement surface infiltration rates. *ASCE Journal of Irrigation and Drainage Engineering, 133*(3), 249–255.

Bean, E., Hunt, W., & Bidelspach, D. (2007b). Evaluation of four permeable pavement sites in eastern North Carolina for runoff reduction and water quality impacts. *ASCE Journal of Irrigation and Drainage Engineering, 133*(6), 583–592.

Booth, D. B., & Leavitt, J. (1999). Field evaluation of permeable pavement systems for improved stormwater management. *American Planning Association Journal*, *65*(3), 314–325.

Brattebo, B. O., & Booth, D. B. (2003). Long-term stormwater quantity and quality performance of permeable pavement systems. *Water Resources, 37*(18), 4369–4376.

Cahill, T. H., Adams, M., & Marm, C. (2003, September/October). Porous asphalt: The right choice for porous pavements. *Hot Mix Asphalt Technology*, *8*, 26–40.

Clark, M., Acomb, G., Bean, E. (2008). Permeable surfaces. In *Florida field guide to low impact development.* University of Florida IFAS Extension Program for Resource Efficient Communities.

Clausen, J. C., & Gilbert, J. K. (2006). Stormwater runoff quality and quantity from asphalt, paver, and crushed stone driveways in Connecticut. *Water Research, 40*, 826–832.

Collins, K. A., Hathaway, J. M., & Hunt, W. F. (2008). Hydrologic comparison of four types of permeable pavement and standard asphalt in Eastern North Carolina. *Journal of Hydrologic Engineering, 13*(12), 1146–1157.

Fassman, E., & Blackbourn, S. (2007, March). *Permeable pavement performance for use in active roadways in Auckland, New Zealand*. Presented at the 2nd National Low Impact Development Conference, Wilmington, NC.

Federal Highway Administration (FHWA). (2016). *Tech brief: Permeable concrete pavements*.

Florida Department of Transportation (FDOT). (2019). *Cost per mile models for long range estimating*.

Gunderson, J. (2008, September). Pervious pavements: New findings about their functionality and performance in cold climates. *Stormwater Magazine*.

Hunt, W., & Collins, K. (2008). *Permeable pavement: Research update and design implications.* Publication # AGW-588-14. North Carolina State University Cooperative Extension.

Interlocking Concrete Pavement Institute (ICPI). (2000). *Permeable interlocking concrete pavements: Design, specification, construction, maintenance* (3rd ed.).

Interlocking Concrete Pavement Institute (ICPI). (2019). *Permeable pavement FAQ*.

Legret, M., & Colandini, V. (1999). Effects of a porous pavement with reservoir structure on runoff water: Water quality and fate of heavy metals. *Water Science and Technology*, *39*(2), 111–117.

Maryland Department of the Environment (MDE). (2009). *2000 Maryland stormwater design manual volumes I & II*.

National Asphalt Pavement Association (NAPA). (2008). *Porous asphalt pavements for stormwater management: Design, construction, and maintenance guide*. IS-131.

Roseen, R. M., & Ballestero, T. P. (2008, May/June). Porous asphalt pavements for stormwater management in cold climates. *Hot Mix Asphalt Technology*.

RSMeans. (2019). RSMeans data from Gordian [Online database]. Gordian.

Rushton, B. (2001). Low impact parking lot design reduces runoff and pollutant loads. *Journal of Water Resources Planning and Management*, *127*(3), 172–179.

Shen, S., Burton, M., Jobson, B., & Haselbach, L. (2012). Pervious concrete with titanium dioxide as a photocatalyst compound for a greener urban road environment. *Construction and Building Materials*, *35*, 874–883.

Thompson Materials Engineers, Inc. (2008). *Pervious concrete evaluation materials investigation, Denver, Colorado.* Project # CT14, 571-356. Urban Drainage and Flood Control District.

Toronto and Region Conservation Authority (TRCA) and Credit Valley Conservation Authority (CVCA). (2010). *Low impact development stormwater management planning and design guide.* Version 1.0.

University of New Hampshire Stormwater Center (UNHSC). (2007). *University of New Hampshire Stormwater Center 2007 annual report*.

University of New Hampshire Stormwater Center (UNHSC). (2009). *UNHSC design specifications for porous asphalt pavement and infiltration beds*.

U.S. Environmental Protection Agency (U.S. EPA). (2008). *Managing wet weather with green infrastructure: Municipal handbook—Green Streets*. EPA-833-F-08-009.

U.S. Environmental Protection Agency (U.S. EPA). (2013). *Case studies analyzing the economic benefits of low impact development and green infrastructure programs*. EPA 841-R-13-004.

Van Seters, T. (2007). *Performance evaluation of permeable pavement and a bioretention swale, Seneca College, King City, Ontario (Interim Report #3)*. Toronto and Region Conservation Authority.

Virginia Department of Environmental Quality (VDEQ). (2013). *Virginia DEQ stormwater design specification no. 7—Permeable pavement* (2nd ed.).

Yong, L., Tian, L., & Hangyu, P. (2018). A new structure of permeable pavement for mitigating urban heat island. *Science of the Total Environment*, *634*, 1119–1125.

Stormwater Best Management Practice

Bioretention (Rain Gardens)

Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment
Subcategory: Filtration

Description

Bioretention practices, such as rain gardens, are landscaped depressions that treat on-site stormwater discharge from impervious surfaces such as roofs, driveways, sidewalks, parking lots and compacted lawns. They are used to collect stormwater and filter it through a mixture of soil, sand and/or gravel. The designs of bioretention practices mimic volume reduction and pollutant removal mechanisms that work in natural systems. The filtered stormwater soaks into the ground, provides water to plants and can help recharge the local groundwater supply. Through these processes, bioretention practices reduce peak flows within downstream sewer systems and allow pollutant removal through filtration and plant uptake.

Applicability

Q9

Bioretention practices are well suited to small sites in urbanized settings and can filter stormwater from small to medium storms. Designers generally bypass stormwater discharges from larger storms past a bioretention practice to a larger stormwater control or the storm drain system.

Urban Areas

Developers can easily install bioretention practices in densely developed urban areas with few pervious surfaces. Bioretention practices can fit into existing parking lot islands, along roads, at intersections or in other landscaped areas as part of a retrofit, redevelopment or new construction. Bioretention practices generally need a footprint of approximately 5 to 10 percent of the surrounding drainage area (Tetra Tech, Inc., 2011).

Stormwater Hot Spots

Stormwater hot spots are areas where certain land uses or related activities generate highly contaminated discharges with pollutant concentrations exceeding those typical of stormwater. Typical examples include gas stations and some industrial areas. Design engineers can tailor a bioretention practice to treat a stormwater hot spot by adding an impervious liner to the bottom of the gravel layer to prevent groundwater or surface water contamination.

A bioretention practice in a suburban road median, capturing stormwater during a rain event.

Photo Credit: Image reproduced with permission from Montgomery County, MD Department of Environmental Protection

Cold Water (Trout) Streams

Heat from paved surfaces like parking lots and roads can increase the temperature of stormwater discharge as it flows into nearby surface waters. Some wildlife species in cold water streams like trout are sensitive to temperature changes. Bioretention practices can decrease the temperature of stormwater by temporarily detaining stormwater discharge beneath the ground surface.

Regional Applicability

Bioretention practices are applicable almost anywhere in the United States. A three-year study in the Twin Cities, Minnesota, region concluded that bioretention practices perform well in cold climate conditions (LeFevre et al., 2009). In this study, soil type was the most important design consideration. In addition, the presence of frost only influenced performance in cases where pore spaces became frozen, halting infiltration.

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In arid and semiarid climates, drought-tolerant plants are the best landscaping option for bioretention practices. Houdeshel et al. (2015) evaluated the effectiveness of three bioretention practices in a semiarid climate and concluded that by increasing native vegetation densities or by using gray water to irrigate vegetation during dry periods, nutrient retention performance in this climate was similar to that of other wetter climates.

Siting Considerations

Important site conditions to consider when designing bioretention practices include the size of the drainage area, slopes, soil and subsurface conditions, and the depth of the seasonal high groundwater table. Design engineers can incorporate design features that improve the longevity and performance of the bioretention practice while minimizing maintenance.

Drainage Area

Design engineers typically use bioretention practices to treat small drainage areas that are less than 5 acres. When treating areas larger than one-half acre, bioretention practices often use pretreatment systems such as forebays or filter strips to prevent clogging. In addition, it can be difficult to convey flow from a large drainage area to a bioretention practice. In these cases, multiple successive bioretention practices may work better than a single large system.

Slope/Topography

Parking lots or residential landscaped areas with gentle slopes around 5 percent are ideal for bioretention practices. A design engineer should include sufficient elevation difference between the bioretention practice inflow and outflow to ensure that water can flow through the filtering media in a specified amount of time, typically less than 24-48 hours (design requirements vary by location). Depending on the design variation, the bioretention practice may need 2 to 6 feet of elevation difference to meet this requirement.

Soils

Design engineers can use bioretention practices with almost any soil type. In soils with poor infiltration rates, adding underdrains allows stormwater to percolate through the media and move downstream. In soils with naturally high infiltration rates, design engineers may exclude underdrains from the plans. In all cases, preliminary design steps should include site-specific soil testing by a qualified professional and should adhere to local design standards that specify when conditions warrant an underdrain.

Groundwater

Design engineers should separate the bottom layer of a bioretention practice from the seasonal high groundwater table by a minimum of 2 feet. This separation ensures that the groundwater table does not intersect with the bed of the bioretention practice, maintains infiltration rates throughout the system, and prevents possible groundwater contamination from contaminated stormwater. In areas where groundwater contamination is a concern, design engineers should add an impervious liner around the bottom of the bioretention practice. Bioretention practices without underdrains and with high infiltration rates may also help maintain groundwater recharge rates.

Design Considerations

Bioretention practice designs can vary considerably, depending on site constraints or preferences of the design engineer or community. Some consistent design features fall into five basic categories described below: pretreatment, treatment, conveyance, maintenance reduction and landscaping.

Pretreatment

Bioretention practices that treat large drainage areas greater than one-half acre use pretreatment, which includes design features that settle coarse sediment particles and their associated pollutants. Pretreatment can reduce the maintenance burden and the likelihood that the soil bed will clog over time. Design engineers can use several different mechanisms to provide pretreatment in bioretention practices, including grass channels or filter strips and pea gravel diaphragms. The system directs stormwater to these pretreatment features to reduce flow rates and filter out coarse materials before the stormwater flows into the filter bed. Larger systems often use wet or dry forebays as pretreatment.

Treatment

Treatment design features help enhance a bioretention practice's ability to remove pollutants. Design engineers should consider several basic design features to enhance the bioretention practice's pollutant removal:

1. A footprint whose size is between 5 and 10 percent of the impervious area draining to it (Tetra Tech, Inc., 2011).

2. A soil bed that is a sand/soil matrix to serve as plant growing media.
3. A design to temporarily pond a small amount of water (typically 6 to 12 inches) above the filter bed.

In addition to the standard features above, design engineers may add various media amendments to the soil bed layer to enhance specific pollutant removal performance. For example, a literature review by Hirschman et al. (2017) found that adding iron and aluminum amendments can reduce total phosphorus in bioretention practice effluent.

Conveyance

Stormwater flow into and through a bioretention practice is a critical component of its design. If surrounding soils have low infiltration rates, bioretention practices should include a perforated underdrain system to collect and convey filtered stormwater to the storm drain system. Design engineers should place the underdrain in a gravel bed at the bottom of the filter bed. Design engineers should also provide an overflow structure to convey flows that are too large for the system to handle.

Landscaping

Landscaping with appropriate plants is vital to the function and aesthetic value of bioretention practices. Using native plants that also provide wildlife habitat provides multiple benefits and can help boost plant survival, given these plants should tolerate the local hydrologic regime. For example, plants on the bottom of the bioretention practice should tolerate both wet and dry conditions. At the edges, upland species used to dry conditions can thrive. Finally, it is best to plant a combination of shrubs and herbaceous vegetation where site conditions allow. Design engineers can include trees after considering any overhead or underground infrastructure such as power lines or pipes.

Design Variations

Design engineers can implement multiple design variations for bioretention practices to serve different objectives. Some variations promote percolation into the native soil and groundwater recharge, while others exclusively focus on filtration. The Minnesota Pollution Control Agency offers examples of bioretention design variations. The main differences pertain to the presence or absence of an underdrain, an impermeable liner or an internal water storage chamber. One common design variation is the rain garden, a shallow depression containing a layer for planting media. However, rain gardens do not have sand or gravel layers to treat stormwater through infiltration.

Limitations

Bioretention practices are not suitable for treating large drainage areas. Surface soil layers can clog over time in areas with excessive sediment loadings. Although bioretention practices typically have small footprints, incorporating them into a parking lot design may reduce the number of parking spaces available if the design did not previously include islands. In addition, bioretention practices should leave space between the system and permanent structures, including buildings (with the exception of the bioretention planter box design variation).

Bioretention practices can reduce local flooding but may not provide flood control during extreme storms. They can, however, alleviate the stress on other flood control measures by reducing peak flows and stormwater volumes within their drainage areas.

Maintenance Considerations

Bioretention practices require landscaping maintenance as well as measures to ensure that the practice is functioning properly. Bioretention practices may initially require more labor for maintenance than a traditional landscaped island, but maintenance needs generally decrease over time. If they contain appropriate vegetation, landscaping maintenance may require fewer resources than traditional landscaped islands in parking areas.

Table 1 below provides a general overview of the typical maintenance activities, frequency and maintenance notes for bioretention practices. Local stormwater manuals often include specific maintenance considerations.

Bioretention Planter Box

A *bioretention planter box* can be designed to infiltrate stormwater and act as a bioretention practice. This type of practice is typically a concrete box that contains planting media, sand and gravel layers that promote infiltration. Bioretention planter boxes can be used in rights of way. If used beside buildings, then designers should consider potential impacts of infiltration on building foundations.

Q10

Table 1. Typical maintenance activities for bioretention practices (consult local stormwater manuals for specific considerations).

Activity	Frequency	Maintenance Notes
Pruning	1 to 2 times per year	Vegetation often grows vigorously during rainy seasons. Prune vegetation to maintain capacity and flow rates.
Mowing	2 to 12 times per year	Frequency depends on location and desired aesthetic appeal. Providing clarity as to the timing is important so that maintenance staff do not include these areas as part of more regular mowing procedures.
Watering	Once every 2 to 3 days for first 1 to 2 months; sporadically after establishment	If drought conditions exist, plants may need watering after the initial year. Native vegetation may flourish without watering.
Fertilization	Once initially	One-time spot fertilization for *first-year* vegetation.
Dead plant removal and replacement	Once per year	Within the first year, 10 percent of plants can die. Survival rates increase with time. Removing dead plants also removes nutrients that would otherwise enter the system.
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the bioretention practice is as designed. Remove any accumulated sediment.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for erosion at the outlet, and remove any accumulated mulch or sediment.
Miscellaneous upkeep	Once per month	Tasks include collecting trash, checking plant health, spot weeding, removing invasive species and removing mulch from the overflow device.
Replacement of top few inches of filter media	If ponding occurs for more than 48 hours	Replace top few inches of filter media. Sediment accumulation reduces the bioretention practice's performance and the facility's ability to drain.

Sources: Tetra Tech, Inc., 2011; MDE, 2009

Effectiveness

Effective bioretention practices reduce stormwater flows and remove pollutants. Bioretention practices reduce stormwater discharge from smaller-storm events, though they can also remove a limited amount of pollutants from larger events under the right conditions. Like most stormwater treatment systems, bioretention practices by design capture a specific treatment volume associated with local climate conditions. For example, Maryland defined this volume as the stormwater produced from a 1-inch storm event (MDE, 2009). Treatment performance generally diminishes for larger storm events above the design capacity, though these events tend to be less frequent and often make up a small fraction of the total annual rainfall and stormwater discharge to a given location.

Bioretention practices reduce stormwater discharge by enhancing infiltration and evapotranspiration. Infiltration enhancement depends on the design variation. Figure 1 shows the results of an analysis looking at the volume reduction performance of 20 different bioretention practices with underdrains (left) and without underdrains (right) (Geosyntec Consultants and Wright Water Engineers, Inc., 2012). Both design variations consistently provided volume reduction, though systems without underdrains (right) provided greater volume reduction (as measured by zero-discharge events) due to increased infiltration losses. Systems with underdrains provided an average volume reduction of 56 percent across all measured storm events, while those without underdrains provided an average volume reduction of 89 percent.

These areas enhance evapotranspiration (the sum of evaporation and vegetation transpiration) by providing prolonged storage of stormwater discharge within bioretention media and gravel layers where plant roots have greater access.

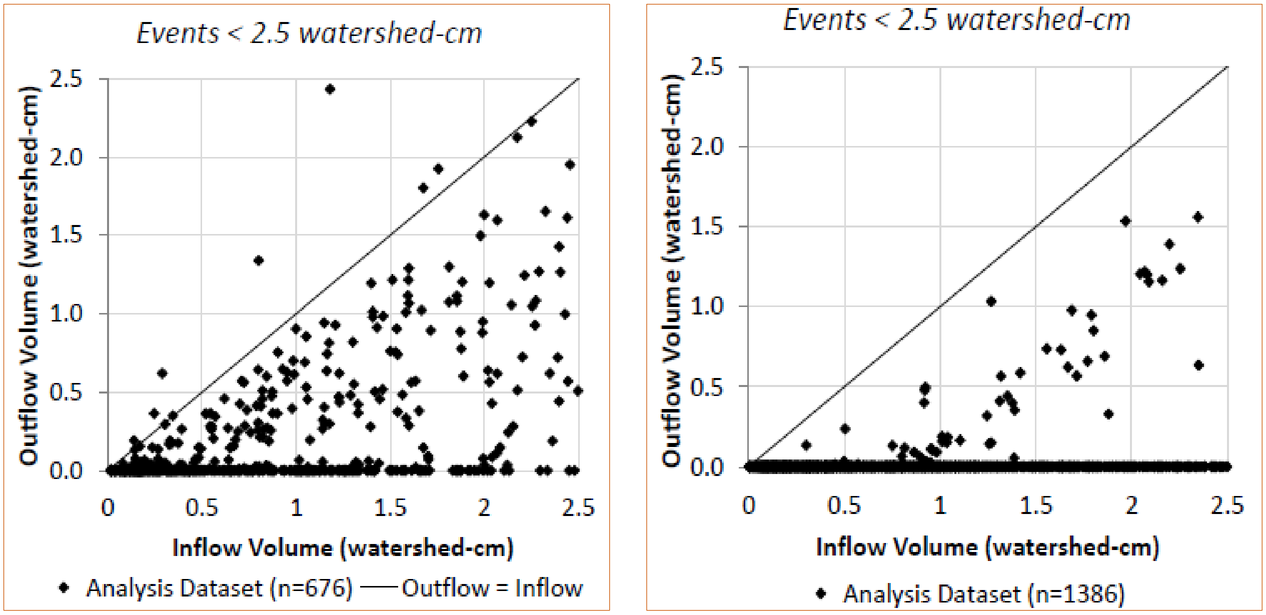

Figure 1. Discharge volume versus inflow volume for bioretention areas with and without underdrains. Tile A shows results for 676 monitored events across 14 individual systems with underdrains. Tile B shows results for 1,386 monitored events across six individual systems without underdrains.

Source: Geosyntec Consultants and Wright Water Engineers, Inc. 2012. Reprinted with permission. © Water Environment Research Foundation.

Pollutant removal performance is more variable and, due to volume losses described above, can be misleading when looking at influent and effluent concentrations. For example, data summaries in the National Pollutant Removal Database (Clary et al., 2017) indicate positive removals for metals, bacteria, total suspended solids and total nitrogen but negative removals for total phosphorus when measured using concentration. However, to determine actual mass removal performance, analysts should incorporate the volume reduction performance discussed above. For example, in a detailed assessment of a subset of the same National Pollutant Removal Database data, Leisenring et al. (2013) found that bioretention systems with underdrains showed statistically significant removal of total suspended solids but not total nitrogen or total phosphorus.

Cost Considerations

Bioretention practices can vary depending on size, maintenance required and cost of materials. Costs can range from $50,000 to $200,000 per acre of impervious surface treated,[1] with smaller systems being more expensive per acre. In addition, retrofits with complex existing infrastructure may be more expensive than new construction (King and Hagan, 2011).

An important consideration when evaluating bioretention practice maintenance costs is that they are often in areas that already require landscape maintenance, such as parking lot islands or rights-of-way. Maintenance activities for bioretention practices are similar to traditional landscaping and may cost less than typical vegetative cover—such as turfgrass or ornamental vegetation—because they require less watering and less frequent mowing.

Like other volume reduction practices, bioretention practices can save costs compared to the use of traditional structural stormwater conveyance systems. For example, the use of bioretention practices can decrease the cost of constructing stormwater conveyance systems and reduce the required size of traditional stormwater detention ponds.

Helpful EPA Resources

- What is Green Infrastructure?
- What is EPA Doing to Support Green Infrastructure?
- Green Infrastructure Modeling Tools
- Green Infrastructure Design and Implementation
- Green Infrastructure Funding Opportunities
- Tools, Strategies and Lessons Learned from EPA Green Infrastructure Technical Assistance Projects
- Manage Flood Risk
- Build Resiliency to Drought
- Green Infrastructure Webcast Series

Additional Information

Additional information on related practices and the Phase II MS4 program can be found at EPA's National Menu of Best Management Practices (BMPs) for Stormwater website

References

Clary, J., Jones, J., Leisenring, M., Hobson, P., & Strecker. E. (2017). *Final report—International stormwater BMP database: 2016 summary statistics*. Water Environment & Reuse Foundation.

Hirschman, D. J., Seipp, B., & Schueler, T. (2017). *Performance enhancing devices for stormwater best management practices*. Center for Watershed Protection.

[1] Prices updated to 2019 dollars. Inflation rates obtained from the Bureau of Labor Statistics CPI Inflation Calculator Web site https://data.bls.gov/cgi-bin/cpicalc.pl. Reference dates for the calculation are October 2011 and September 2019.

Houdeshel, C. D., Hultine, K. R., Johnson, N. C., & Pomeroy, C. A. (2015). Evaluation of three vegetation treatments in bioretention gardens in a semi-arid climate. *Landscape and Urban Planning*, *135*, 62–72.

Geosyntec Consultants and Wright Water Engineers, Inc. (2012). *International Stormwater Best Management Practices (BMP) Database: Addendum 1 to Volume Reduction Technical Summary (January 2011): Expanded Analysis of Volume Reduction in Bioretention BMPs.* Water Environment Research Foundation, Federal Highway Administration, American Society of Civil Engineers, and U.S. Environmental Protection Agency.

King, H., and Hagan, P. (2011). *Costs of stormwater management practices in Maryland counties*. University of Maryland Center for Environmental Science.

LeFevre, N., Davidson, J., & Oberts, G. (2009). Bioretention of simulated snowmelt: Cold climate performance and design criteria. *Cold Regions Engineering 2009*, 145–154.

Leisenring, M., Hobson, P., Clary, J., Krall, J. (2013). *International Stormwater Best Management Practices (BMP) Database Advanced Analysis: Influence of Design Parameters on Achievable Effluent Concentrations*. International Stormwater BMP Database.

Maryland Department of the Environment (MDE). (2009). *2000 Maryland stormwater design manual volumes I & II*.

Tetra Tech, Inc. (2011). *San Diego low impact development design manual* (Document No. PITS070111-01). Prepared for the City of San Diego Storm Water Division.

Stormwater Best Management Practice

Sand and Organic Filters

Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment
Subcategory: Filtration

Description

Sand and organic filters provide water quality improvements through settling and filtration. A sand filter typically consists of two chambers: a settling chamber and a filter bed with sand or other filtering media. As stormwater flows into the settling chamber, large particles settle out, and the filtering media then remove finer particles and other pollutants. There are several modifications of the basic sand filter design, including the surface sand filter, underground sand filter, perimeter sand filter and various organic media filters. Some versions even have distinct names, like the Austin Sand Filter, the Washington D.C. Sand Filter and the Delaware Sand Filter. These filters operate on the same basic design of settling, then filtration. Design engineers have modified the traditional surface sand filter to fit sand filters into more challenging sites (e.g., underground and perimeter filters) or to improve pollutant removal (e.g., organic media filter).

A sand filter under construction.

Applicability

Q11

Sand filters are suitable for most regions of the country and most types of sites. Some site constraints favor specific versions over others (see “Siting and Design Considerations” below).

Regional Applicability

Sand filters are suitable for cold climates, but surface or perimeter filters will not be effective during the winter months. Using an alternative conveyance measure such as a weir system between the settling chamber and filter bed may avoid freezing associated with the traditional standpipe. Where possible, the filter bed should be below the frost line. Some sand filter variations (e.g., organic filters) should not operate during the winter, as organic media can become completely impervious when frozen. Using a larger underdrain system to encourage rapid draining in winter may help limit freezing of the filter bed.

In cold and arid climates, design engineers should also consider the size of the settling chamber. In cold climates that practice road sanding, this additional sediment load can take up as much as half the storage volume. In arid climates, sand filters are not widely used; in these climates, designers may need to make similar accommodations to account for the naturally higher sediment loads in these regions.

Urban Areas

Urban areas are usually densely developed places in which little pervious surface is present. Sand filters are generally good options in these areas because they consume little space, particularly if they are underground.

Stormwater Hot Spots

Sand filters that incorporate liners or sit on poorly infiltrating soils are often a good option to treat discharge from stormwater hot spots due to the treatment they provide and their limited potential to contaminate groundwater. Organic media are an effective adsorbent of many hotspot pollutants, such as metals and hydrocarbons. In all cases, design engineers should follow local regulations regarding treatment requirements for stormwater hotspots.

Stormwater Retrofit

Sand filters are a good option to achieve water quality goals in retrofit studies where space is limited, because they take up very little surface space and have few physical site restrictions. However, they are not suitable for treating stormwater flows from large drainage basins, as they often have limited hydraulic capacity.

Common Terms

Stormwater hot spots are areas where land use or activities generate highly contaminated stormwater discharge, with pollutant concentrations exceeding those typically found in stormwater. Examples include gas stations, vehicle repair areas and waste storage areas.

A **stormwater retrofit** is a stormwater management practice (usually structural) put into place after development or construction of a stormwater control to improve water quality, protect downstream channels, reduce flooding or meet other specific objectives that did not exist at the time of original construction.

Pretreatment plays an important role in stormwater treatment. Pretreatment structures, installed immediately upgradient to a stormwater control, reduce flow rates and remove sediment and debris before stormwater enters a stormwater control. This helps to improve the stormwater control's pollutant removal efficiency and reduces maintenance requirements.

Cold Water (Trout) Streams

Some aquatic species in cold water streams, notably trout, are extremely sensitive to changes in temperature. Sand filters may be a good treatment option for cold water streams. However, design engineers should consider site-specific placement, as the sun can warm pooling water within a surface sand filter. To protect aquatic life, designers may consider shortening the detention time for surface sand filters that discharge to cold waterbodies. Underground and perimeter sand filter designs have little potential for warming because they are not exposed to the sun.

Siting and Design Considerations

Drainage Area

Sand filters are best for smaller sites: up to 10 acres for surface sand filters, up to 5 acres for organic filters, and up to 2 acres for underground and perimeter filters (MDE, 2009). Designers have used sand filters for larger drainage areas (up to 100 acres), but these systems tend to clog easier, causing stormwater to overwhelm or bypass the system entirely.

Slope

Sand filters are suitable for sites with mild to moderate slopes, as they generally require 4 to 8 feet of head (elevation drop) to promote flow through the system. Smaller versions, sometimes called "pocket filters," can function with as little as 2 feet of head, though their capacity is lower. Sand filters can be challenging or impractical to construct on flat terrain.

Soils/Topography

Design engineers can install sand filters on almost any soil, including poorly infiltrating soils. In soils with high infiltration rates, engineers can design sand filters to exfiltrate into the surrounding soil to promote groundwater recharge. If groundwater contamination is a concern or if soils have low infiltration rates, design engineers can incorporate an impermeable liner with an underdrain. All options provide water quality treatment.

Groundwater

Designers should provide at least 2 feet of separation between the bottom of the filter and the seasonally high groundwater table. This design feature allows for sufficient hydraulic head within the system and prevents structural damage from prolonged inundation.

Pretreatment

Pretreatment is an important part of the sand filter. It happens in the sedimentation chamber, where the coarsest particles settle out and thus do not reach the filter bed. A common practice is to provide at least 25 percent of the water quality volume in a dry or wet sedimentation chamber as pretreatment to the filter system. (The water quality volume is the amount of stormwater from a single storm event that the control measure will treat. Although regulations vary by location, most approximate this quantity as the volume the control measure receives from a 1-inch storm event.)

Although pretreatment is highly recommended, not all locations require it, especially for smaller sand filters (e.g., at sites smaller than half an acre) (City of Portland, 2016; MDE, 2009; SPU, 2017. Design engineers should always follow local specifications.

Treatment

Treatment design features help enhance the ability of a stormwater control to mitigate or remove pollutants of concern. Design engineers may choose media based the desired hydraulic conductivity, desired pollutant removal performance, or targeting of specific pollutants. Custom media blends are now available in many locations that provide very specific performance characteristics. For example, certain organic amendments can promote denitrification and provide sorption sites to bind pollutants like phosphorus, metals and hydrocarbons (Hirschman et al., 2017). Design engineers should consult local stormwater authorities to identify approved media sources for specific applications.

The volume of the treatment component generally depends on the water quality volume, with the requirement that it be able to temporarily store a certain percentage. For example, in Maryland, the pretreatment and treatment components together should be able to store at least 75 percent of the water quality volume (MDE, 2009), while in Seattle the requirement is 91 percent (SPU, 2017). The design engineer should size the filter bed area using Darcy's law or an approved equivalent method, which relates the velocity of fluid through a medium to the hydraulic head and the medium's hydraulic conductivity. Designers may use multiple layers of different media in a sand filter, depending on the targeted flow rate and targeted pollutants. They should also incorporate a factor of safety to account for a possible decrease in permeability over time (e.g., NJDEP, 2014).

Conveyance

A properly designed sand filter should convey stormwater in a manner that minimizes erosion and provides for the design flow rate through the system. Ideally, vegetated filter strips or grass swales can achieve some stormwater treatment during conveyance to and from the filter. In many cases, sand filters are offline systems, meaning they use flow splitters to divert part of the stormwater flow from the main conveyance feature. One exception is the perimeter filter: all flows enter the system in this design, but larger flows overflow to an outlet chamber and are not treated. Every sand filter (with the rare exception of pure exfiltration filters) has an underdrain below the filter bed. An underdrain is a perforated pipe system in a gravel bed, installed on the bottom of the filter, that collects and conveys filtered stormwater.

Maintenance

Table 1 presents typical maintenance requirements. Design engineers can incorporate certain features to make regular maintenance easier. They should provide easy access to filtering systems, especially pretreatment components to allow for regular sediment removal. For underground sand filters, they should also follow the Occupational Safety and Health Administration's confined space rules.

Q12

Table 1. Typical maintenance activities for sand filters.

Activity	Timeframe
Remove trash and debris, including clippings from regular landscaping activities	After storm events or as needed, at least semi-annually
Inspect for structural damage and leaks	Annually
Inspect for evidence of erosion	After storm events or as needed, at least annually
Inspect to ensure stormwater is not bypassing the unit	After storm events or as needed, at least annually
Repair or replace damaged parts	As necessary
Clear sediment from sediment chamber	If sediment accumulates to half the chamber volume
Replace filter media	As necessary, as indicated by prolonged periods of pooling water over the filter bed during dry weather

Sources: MassDEP, 2008; MDE, 2009

Landscaping

Landscaping can add to both the aesthetic value and the treatment ability of stormwater controls. Sand filters generally need minimal landscaping, although surface sand filters and organic media filters may have a grass cover. In all filters, designers need to ensure that the contributing drainage has dense vegetation to reduce sediment loads and that debris from regular landscaping activities (e.g., grass or shrub clippings) do not flow into the filter.

Limitations

Sand filters are not appropriate for large drainage areas, do not provide flood control and generally do not protect stream channels from erosion. Sand filters that do promote groundwater recharge are not suitable in areas with high groundwater tables. In addition, sand filters need frequent maintenance, and underground and perimeter versions are out of sight so can be easy to forget.

Effectiveness

Filters typically provide pollutant removal rather than retention or detention. In some cases, where local soil and groundwater conditions allow, they can also achieve groundwater infiltration. Sand filters effectively remove most pollutants with the exception of nitrates which can both pass through the filter untreated or even be produced within the filter through the mineralization of organic nitrogen (various media amendments can remedy this; see Hirschman et al., 2017). Table 2 summarizes removal efficiencies for sand filters.

Table 2. Percent reductions in pollutant concentrations for sand filters. Q13

Parameter	Units	Median Influent EMC	Median Effluent EMC	Percent Reduction
Total suspended solids	mg/L	56	9.0	84%
Fecal coliform	MPN/100 mL	900	400	56%
Total arsenic	µg/L	0.91	0.74	19%
Total cadmium	µg/L	0.30	0.08	73%
Total chromium	µg/L	2.0	1.0	50%
Total copper	µg/L	10	5.5	45%
Total iron	µg/L	642	210	67%
Total lead	µg/L	10	1.7	83%
Total nickel	µg/L	3.3	2	39%
Total zinc	µg/L	63	14	78%
Total phosphorus	mg/L	0.15	0.09	40%
Total nitrogen	mg/L	1.2	1.1	14%
Nitrate+nitrite (as nitrogen)	mg/L	0.35	0.57	-63%

Source: Clary et al., 2017
EMC = event mean concentration

Cost Considerations[1]

Table 3 summarizes average costs from multiple projects for installing and maintaining surface and underground sand filters. Costs are in terms of acres of impervious surface treated. The initial costs include pre-construction (site discovery, surveying, design, planning) and construction (labor, materials, installation) costs. The cost of maintenance activities includes regular maintenance, intermittent repair and associated inspection/monitoring costs.

[1] Prices updated to 2019 dollars. Inflation rates obtained from the Bureau of Labor Statistics CPI Inflation Calculator website: https://data.bls.gov/cgi-bin/cpicalc.pl.

Table 3. Average sand filter costs per acre of impervious surface treated.

Stormwater Control	Total Initial Cost	Annual Maintenance Costs
Surface sand filter	$56,000	$1,700
Underground sand filter	$64,000	$1,900

Source: King & Hagan, 2011

Additional Information

Additional information on related practices and the Phase II MS4 program can be found at EPA's National Menu of Best Management Practices (BMPs) for Stormwater website

References

City of Portland. (2016). *2016 City of Portland stormwater management manual.*

Clary, J., Jones, J., Leisenring, M., Hobson, P., & Strecker, E. (2017). *International Stormwater BMP Database: 2016 summary statistics*. Alexandria, VA: Water Environment and Reuse Foundation.

Hirschman, D. J., Seipp, B., & Schueler, T. (2017). *Performance enhancing devices for stormwater best management practices*. Prepared for the Chesapeake Stormwater Network.

King, D., & Hagan, P. (2011). *Costs of stormwater management practices in Maryland counties*. University of Maryland Center for Environmental Science.

Maryland Department of the Environment (MDE). (2009). *2000 Maryland stormwater design manual*.

Massachusetts Department of Environmental Protection (MassDEP). (2008). *Massachusetts stormwater handbook and stormwater standards.*

New Jersey Department of Environmental Protection (NJDEP). (2014). *Stormwater BMP manual: Sand filters*.

Seattle Public Utilities (SPU). (2017). *City of Seattle stormwater manual* (Vol. 2).

Stormwater Best Management Practice

Vegetated Filter Strip

Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment
Subcategory: Filtration

Q14

Description

Vegetated filter strips (grassed filter strips, filter strips and grassed filters) are vegetated surfaces that treat sheet flow from adjacent surfaces. Filter strips function by slowing stormwater velocities, filtering out sediment and other pollutants, and providing some infiltration into underlying soils. Filter strips were originally an agricultural treatment practice and have more recently evolved into an urban practice. With proper design and maintenance, filter strips can provide relatively high pollutant removal. However, for the filter strip to be effective, stormwater should maintain sheet flow throughout the length of the filter strip. This creates a challenge, as heavier, concentrated flows that receive little or no treatment can overwhelm the practice.

A vegetated filter strip can infiltrate and treat stormwater flow from adjacent surfaces using a variety of plants.

Photo Credit: Steven Chase for USEPA, 2019

Common Terms

Stormwater hot spots are areas where land use or activities generate highly contaminated stormwater discharges, with pollutant concentrations exceeding those typically found in stormwater. Examples include gas stations, vehicle repair areas and waste storage areas.

A **stormwater retrofit** is a stormwater management practice (usually structural) put into place after development or construction of a stormwater control to improve water quality, protect downstream channels, reduce flooding or meet other specific objectives that did not exist at the time of original construction.

Pretreatment plays an important role in stormwater treatment. Pretreatment structures, installed immediately upgradient to a stormwater control, reduce flow rates and remove sediment and debris before stormwater enters a stormwater control. This helps to improve the stormwater control's pollutant removal efficiency and reduces maintenance requirements.

Applicability

Filter strips are applicable in most regions but are restricted in some situations because they consume a large amount of space relative to other practices. Filter strips are most suitable for treating stormwater discharge from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. They are also ideal components of the "outer zone" of a stream buffer (see Riparian/Forested Buffer fact sheet) or as pretreatment to a structural practice. For example, the *Maryland Stormwater Design Manual* does not consider the filter strip a treatment practice, but does encourage the use of filter strips to supplement other practices (MDE, 2009).

Regional Applicability

Filter strips are applicable in most regions of the country. However, they may be impractical in arid areas where the cost of irrigating the grass on the filter strip will most likely outweigh its water quality benefits.

Urban Areas

Urban areas are areas with dense development in which little pervious surface exists. Filter strips are impractical in urban areas because they require a large amount of space.

Stormwater Hot Spots

Filter strips should not receive hot spot stormwater because the practice has minimal pollutant removal ability and encourages infiltration, both of which may encourage dispersal of hot spot pollutants. Similarly, filter strips should not slope toward or convey stormwater over septic drain fields or contaminated groundwater plumes.

Stormwater Retrofit

Filter strips are generally a poor retrofit option because they take up a relatively large amount of space and cannot treat large drainage areas.

Cold Water (Trout) Streams

Some cold water species, such as trout, are sensitive to changes in temperature. While some treatment practices, such as wet ponds (see Wet Ponds fact sheet), can warm stormwater substantially, filter strips do not pond water and are therefore not likely to increase stormwater temperatures. Thus, these practices are good for protecting cold water streams, as the *Massachusetts Stormwater Handbook* suggests (MDEP, 2008).

Siting and Design Considerations

Siting Considerations

In addition to assessing the applicability of filter strips for different regions and land uses, designers need to ensure that this management practice is feasible at the site in question. The following section provides basic guidelines for siting filter strips.

Drainage Area

Typically, filter strips treat very small drainage areas such as roads, sidewalks and small parking lots. Although some guidelines include area-based limits—for example, the Pennsylvania Department of Environmental Protection recommends the ratio of drainage area to filter strip area be less than 6:1 (PDEP, 2006)—most limiting design factors refer to the length of flow leading to the practice. As stormwater flows over the ground's surface, it changes from sheet flow to concentrated flow. Rather than moving uniformly over the surface, the concentrated flow forms rivulets that are slightly deeper and cover less area than the sheet flow. When flow concentrates, it moves too rapidly for a grassed filter strip to effectively treat it. Furthermore, this concentrated flow can lead to scouring. To prevent this, the length of the filter strip (with length measured normal, or parallel, to flow) should span at least the length of the drainage area. The recommended maximum flow length (the length of the drainage area, measured normal to flow) depends on the drainage area's permeable and impermeable surface areas. Generally, flow lengths should not exceed 75 feet for impervious surfaces and 150 feet for pervious surfaces (Battiata et al., 2014).

Slope

To encourage sheet flow, filter strips should have slopes of at least 2 percent, with a maximum slope of 5 to 6 percent (Battiata et al., 2014; MDEP, 2008). However, certain combinations of filter strip length, soil type and vegetation can allow for slightly steeper slopes (PDEP, 2006). Slopes that are too steep can encourage the formation of concentrated flow.

Soils

Topsoil depth and composition are important for the establishment and maintenance of healthy vegetation, as well as the proper functioning of the filter strip. Topsoil should be at least 8 to 18 inches deep (PDEP, 2006; Battiata et al., 2014). The soil should be native or amended with organic compost to allow for water retention and infiltration. Soils with high clay content are not suitable for filter strips, as they prevent infiltration. An ideal soil infiltration rate is between 0.5 and 12 inches per hour (Cahill et al., 2018). The *Pennsylvania Stormwater Best Management Practices Manual* recommends a time of 48 to 72 hours maximum for the filter strip to filter standing water; if standing water doesn't drain in that time, reexamine the soil composition and consider a lower-density soil (PDEP, 2006).

Groundwater

Filter strips should be separate from the groundwater or any confining layer (e.g., bedrock) by between 2 and 4 feet to prevent contamination and to ensure that the filter strip can adequately drain between storms (MDEP, 2008; PDEP, 2006).

Design Considerations

Filter strips appear to be a minimal design practice because they are basically a grassed slope. However, certain design features can improve the filter strip's ability to provide a small amount of water quality treatment. The following are design variations or features that can improve the function of a filter strip:

- The top layer of a vegetated filter strip can consist of turf grasses, meadow grasses, shrubs, native vegetation or trees. The planting of the vegetation should be dense to increase infiltration, withstand relatively high-velocity flows and prevent soil erosion.

- For larger versions of the practice, a pea gravel diaphragm, level spreader or concrete curb stop at the top of the slope can maintain sheet flow into the practice. A pea gravel diaphragm (a small, gravel-filled trench running along the top of the filter strip) also acts as a pretreatment device, settling out sediment particles before they reach the practice. A typical pea gravel diaphragm is 12 inches long and 24 to 36 inches deep (PDEP, 2006).
- To help reduce ponding, the filter strip design can incorporate a pervious berm of vegetated sand and gravel at the toe of the slope. This berm should be 6 to 12 inches tall and resistant to erosion. The berm should allow for the infiltration of ponded water within 24 hours (PDEP, 2006).
- The filter strip length (normal, or parallel, to flow) should be a function of slope, vegetation cover, soil type, stream sensitivity and contamination level (PDEP, 2006). Lengths are often 50 to 200 feet (Cahill et al., 2018), though the *Minnesota Stormwater Best Management Practices Manual* recommends a minimum length of 25 feet and a maximum length of 300 feet (MPCA, 2000). As the slope increases and the soil composition becomes less permeable (i.e., higher clay or silt fractions), the length should increase to maintain sheet flow and infiltration. For examples of specific recommendations, see the *NJ Stormwater Best Management Practices Manual* (NJDEP, 2014) and Pennsylvania's stormwater manual (PDEP, 2006).
- Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion. The top of the slope should be directly next to the pea gravel diaphragm.

Regional Variations

In cold climates, filter strips provide a convenient area for snow storage and treatment. If serving this purpose, vegetation in the filter strip should be salt-tolerant, and a maintenance schedule should include the removal of sand built up at the bottom of the slope (PDEP, 2006). In arid or semiarid climates, designers should specify drought-tolerant grasses to minimize irrigation requirements.

Limitations

Filter strips have several limitations related to their performance and space consumption:

- Sheet flow is difficult to maintain, and concentrated flow will limit the practice's effectiveness.
- Filter strips are not suitable for the treatment of high-velocity flows.
- Filter strips require a large amount of space, typically equal to the impervious area they treat, often making them infeasible in urban environments where land prices are high.
- If standing water remains for 3 days or more, filter strips can allow mosquitos to breed.
- Proper design requires careful planning and execution. Slight problems in the design, such as improper grading, can render the practice ineffective in terms of pollutant removal or sediment buildup.

For treating large volumes of stormwater, a more suitable treatment control, such as a bioretention, should follow filter strips.

Maintenance Considerations

Filter strips require similar maintenance to other vegetative practices (e.g., see Grassed Swales fact sheet). Maintenance is very important for filter strips, particularly to ensure that concentrated flow does not short-circuit the practice. Maintenance practices include:

- Monitoring of recently planted vegetation to ensure the filter strip is establishing it properly.
- Regular mowing, trimming, watering, fertilizing and reseeding of the vegetation, as applicable to the local conditions.
- Regular inspection of the vegetation for damage from foot or vehicle traffic. To prevent pollution, sediment buildup and damage to the vegetation, municipalities should discourage public use of the strips.
- Removal of accumulated sediment and debris at the toe, the berm and the strip itself. This monitoring is important to make sure preferential flow paths haven't developed and sheet flow is consistent. This should happen at least biannually, or when sediment accumulates to a height of 2 inches or greater.
- Soil aeration if the drainage time of the filter strip becomes significantly slower than the original drainage time due to soil compaction.

Effectiveness

Filter strips can provide a small amount of groundwater recharge as stormwater flows over the vegetated surface and ponds at the toe of the slope. Through this infiltration, or stormwater reduction, filter strips can provide some pollutant removal. Based on a review of multiple studies, a report by the Center for Watershed Protection calculated an average stormwater reduction of 51 percent and average load reductions for total nitrogen, total phosphorus and total solids of 56, 66 and 86 percent, respectively (Battiata et al., 2014).

Filter strips also have the potential to reduce stormwater by 20 to 85 percent via infiltration by soil and plants. Filter strips are most effective during 80 to 95 percent of annual storm events. However, effectiveness is less for very large storm events or when flow velocities exceed 1.3 feet per second (Battiata et al, 2014).

A North Carolina study observed four different urban vegetative filter strip systems (two 25-foot, two 50-foot) for the removal of pollutants by infiltration. Although both sizes were effective at removing total suspended solids, only the 50-foot systems were able to consistently remove nitrogen and phosphorus (Winston et al., 2011).

Cost Considerations[1]

Filter strip costs depend on a number of factors, the first and most important of which is the land available for the practice. In some situations, this land is available as wasted space beyond backyards or adjacent to roadsides, but this practice is cost-prohibitive when land prices are high and land could serve other purposes.

Q15

In addition to land costs, construction costs can vary depending on the size, type and complexity of the practice. Costs can be low when the practice only includes seeding or planting for small, simple variations. For more complex variations that require grading, level spreaders, pea gravel diaphragms or toe berms, additional excavation, grading and material costs will be necessary. Due to these variations, cost estimates range from $0 to $65,000 per acre of practice (PDEP, 2006), with other estimates falling closer to the middle of the range at $25,000 to $35,000 per acre (King & Hagan, 2011).

Annual maintenance costs include mowing, weeding, inspection and litter removal, which can be $130 to $1,800 per acre of the filter strip. The cost may be toward the lower end of the range if maintenance needs are already part of the site's existing landscape maintenance routine or if local vegetation growth rates or landscaping labor rates are low (PDEP, 2006).

[1] Prices updated to 2020 dollars. Inflation rates obtained from the Bureau of Labor Statistics CPI Inflation Calculator Web site https://data.bls.gov/cgi-bin/cpicalc.pl.

Additional Information

Additional information on related practices and the Phase II MS4 program can be found at EPA's National Menu of Best Management Practices (BMPs) for Stormwater website

References

Battiata, J., Clagett, S., Crafton, S., Follansbee, D., Gasper, D., Greer, R., Hardman, C., Jordan, T., Stewart, S., Todd, A., Winston, R., & Zielinski, J. (2014). *Recommendations of the expert panel to define removal rates for urban filter strips and stream buffer upgrade practices*. Chesapeake Bay Program.

Cahill, M., Godwin, D., & Tilt, J. (2018). *Vegetated filter strips: Low-impact development fact sheet* (EM 9208). Oregon State University.

King, D., & Hagan, P. (2011). *Costs of stormwater management practices in Maryland counties*. University of Maryland Center for Environmental Science. Prepared for the Maryland Department of the Environment Science Services Administration.

Maryland Department of the Environment (MDE). (2009). *Maryland stormwater design manual*.

Massachusetts Department of Environmental Protection (MDEP). (2008). Vegetated filter strips. In *Volume 2, chapter 2: Structural BMP specifications for the Massachusetts stormwater handbook*.

Minnesota Pollution Control Agency (MPCA). (2000). *Stormwater best management practices manual*.

Pennsylvania Department of Environmental Protection (PDEP). (2006). BMP 6.4.9: Vegetated filter strip. In *Pennsylvania Stormwater Best Management Practices Manual*.

State of New Jersey Department of Environmental Protection (NJDEP). (2014). *NJ stormwater best management practices manual*.

Winston, R. J., Hunt III, W. F., Osmond, D. L., Lord, W. G., & Woodward, M. D. (2011). Field evaluation of four level spreader-vegetated filter strips to improve urban storm-water quality. *Journal of Irrigation and Drainage Engineering, 137*(3), 170-182.

Stormwater Best Management Practice

Dry Detention Ponds

Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment
Subcategory: Retention/Detention

Description

Dry detention ponds (also called dry ponds, extended detention basins, detention ponds and extended detention ponds) are basins that detain stormwater for some minimum time (e.g., 24 hours) to allow particles and pollutants to settle and reduce peak flow rates. They do not have large permanent pools of water—unlike wet ponds—though they often have small pools at the inlet and outlet of the basin. Although dry detention ponds were once popular for flood control, they are less so now, given their limited ability to provide water quality treatment.

Q16

Dry detention pond with security fencing.
Credit: Jared Richardson for USEPA, 2012

Applicability

Dry detention ponds have traditionally been one of the most widely used stormwater controls. They are appropriate for detaining stormwater from large drainage areas (typically 10 or more acres). They require a large area to construct, so other stormwater controls are more appropriate for smaller sites (see Grassed Swales, Infiltration Basin, Infiltration Trench, Bioretention (Rain Gardens), Permeable Pavements, or Green Roofs). If pollutant removal efficiency is an important consideration, dry detention ponds may not be the most appropriate choice.

Common Terms

Stormwater hot spots are areas where land use or activities generate highly contaminated stormwater discharges, with pollutant concentrations exceeding those typically found in stormwater. Examples include gas stations, vehicle repair areas and waste storage areas.

A **stormwater retrofit** is a stormwater management practice (usually structural) put into place after development or construction of a stormwater control to improve water quality, protect downstream channels, reduce flooding or meet other specific objectives that did not exist at the time of original construction.

Regional Applicability

Dry detention ponds can work in all regions of the United States. Design engineers might need to make minor changes in cold or arid climates or in regions with karst (i.e., limestone) topography.

Stormwater Hot Spots

Dry detention ponds can accept flow from stormwater hot spots, but to do so need a liner or significant separation from groundwater.

Stormwater Retrofit

As noted above, dry detention ponds were common stormwater controls in the past but have become less popular given their limited ability to address water quality concerns (see “Limitations” below). They can be useful stormwater retrofit options, though, given their existing prevalence and the fact that they already offer certain stormwater management benefits such as flood control. In retrofit scenarios, it is possible to modify these facilities to incorporate features that address additional objectives such as water quality treatment and channel protection. This could be a more cost-effective option than constructing an entirely new stormwater control—as could combining a dry detention basin with other

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stormwater treatment options to address water quality impacts.

Cold Water (Trout) Streams

Dry detention ponds can increase the temperature of stormwater they receive (UNHSC, 2011). Generally, the only way to mitigate this effect is to decrease the detention time. Alternative stormwater controls may therefore be more appropriate in areas discharging to cold water streams.

Siting Considerations

Designers need to ensure that the dry detention pond is feasible at the site in question. This section provides basic guidelines for siting dry detention ponds.

Drainage Area

In general, dry detention ponds are appropriate for sites with a minimum area of 10 acres. On smaller sites, it can be challenging to provide proper discharge control because the orifice diameter at the outlet needed to control relatively small storms becomes very small and thus prone to clogging (City of Portland, 2016). For smaller sites, green infrastructure practices and on-lot treatment controls are better options given their smaller footprint and effectiveness.

Slope

Dry detention ponds can operate at sites with slopes up to about 15 percent. The local slope needs to be relatively flat: this allows the pond's side slopes to be reasonably flat, which keeps safety risks low.

There is no minimum slope requirement, though there needs to be enough elevation drop from the pond inlet to the pond outlet to ensure that flow can move through the system.

Soils

Dry detention ponds can function with almost all soils and geology, with minor design adjustments for karst areas or in rapidly percolating soils such as sand. In such areas, extended detention ponds need impermeable liners to prevent groundwater contamination or sinkhole formation.

Standing Water

To limit standing water, the base of the extended detention facility should not intersect the groundwater table. The persistence of standing water for more than 3 days in dry detention facilities makes them ideal breeding grounds for mosquitoes (Metzger et al., 2002).

Design Considerations

Specific designs may vary considerably, depending on site constraints, preferences of the designer or community, or local regulations. Common recommended features fall into five basic categories: pretreatment, treatment, conveyance, maintenance reduction and landscaping. For any project, design engineers should follow local requirements.

Pretreatment

Removing coarse sediment particles from stormwater before they reach the large permanent pool reduces a pond's maintenance burden. Pretreatment features help settle out these particles. For a pond, the appropriate pretreatment feature is a sediment forebay, a small pool at the entrance to the pond (typically about 10 percent of the volume of water that the pond will treat for pollutant removal).

Treatment

Treatment design features enhance a stormwater control's ability to remove pollutants. To allow for enough settling time, the pond should be large enough to detain the volume of stormwater it treats for between 12 and 48 hours. Designing dry ponds with a high length-to-width ratio (i.e., at least 1.5:1) and incorporating other design features to maximize the flow path effectively increases the detention time in the system by keeping flow from short-circuiting the pond. Designing ponds with relatively flat side slopes can also help to lengthen the effective flow path. Last, as dry detention ponds alone do not provide a high degree of pollutant removal, adding filtration at the outlet improves water quality before discharging to receiving waters.

Conveyance

The conveyance system should carry stormwater to and from dry ponds safely, in a manner that minimizes erosion potential. It is also important to stabilize the outfall of pond systems to prevent scouring. To convey low flows through the system, designers should incorporate a small, shallow pilot channel, as well as an emergency spillway to safely convey water from large floods. To help mitigate the warming of water at the outlet channel, designers should provide shade around the channel at the pond outlet, if possible.

Maintenance Reduction

Stormwater controls need regular maintenance. Design features can ease this maintenance burden. In a dry detention pond, a micropool at the outlet can prevent resuspension of sediment and outlet clogging. A good design includes maintenance access to the forebay and micropool.

Another design feature that can reduce maintenance needs is a non-clogging outlet. Typical examples include a reverse-slope pipe or a weir outlet with a trash rack. A reverse-slope pipe draws from below the permanent pool, extending in a reverse angle up to the riser, and determines the water elevation of the micropool. Because these outlets draw water from below the level of the permanent pool, floating debris is less likely to clog them.

Landscaping

Designers should maintain a vegetated buffer around the dry detention pond and should select plants within the detention zone (i.e., the portion of the pond up to the elevation where it detains stormwater) that can withstand both wet and dry periods.

Storage Pipes and Tanks

Another variation of the dry detention pond design is the use of storage tanks, storage pipes or underground vaults. This approach is most common in urban environments on small sites with limited opportunity to provide flood control—where underground storage for a large drainage area would generally be costly. Because the drainage area contributing to tank or pipe storage is typically small, the outlet diameter needed to reduce the flow from very small storms would be very small. A very small outlet diameter, along with the underground location of the tanks or pipes, creates the chance that debris will build up in the outlet and cause maintenance problems.

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Arid or Semiarid Climates

In arid and semiarid regions, design engineers might need to make changes to conserve scarce water resources. Any landscaping plans should prescribe drought-tolerant vegetation wherever possible. In addition, the design engineer can replace the wet forebay with an alternative dry pretreatment, such as a detention cell. In regions with distinct wet and dry seasons—as in many arid regions—detention ponds can have recreation uses in the dry season (e.g., as ball fields).

Cold Climates

In cold climates, some additional design features can help to treat spring snowmelt. One such modification is to increase the volume available for detention to help treat this relatively large flow event. As well, it may be necessary to remove sediment from the forebay more often than in warmer climates (see “Maintenance Considerations” below for guidelines) to account for sedimentation due to road sanding.

Maintenance Considerations

In addition to incorporating features into the dry detention pond design to minimize maintenance, site operators will need to carry out some regular maintenance and inspection practices. Table 1 outlines some of these practices.

Table 1. Typical maintenance activities for dry ponds

Activity	Schedule
▪ Note erosion of pond banks or bottom	Semiannual inspection
▪ Inspect for damage to the embankment ▪ Monitor for sediment accumulation in the facility and forebay ▪ Examine to ensure that inlet and outlet devices are free of debris and operational	Annual inspection
▪ Repair undercut or eroded areas ▪ Mow side slopes ▪ Manage pesticide and nutrients ▪ Remove litter and debris	Standard maintenance
▪ Seed or sod to restore dead or damaged ground cover	Annual maintenance (as needed)
▪ Monitor sediment accumulations in the forebay; remove sediment when the forebay capacity has been reduced by 50 percent	2- to 7-year maintenance
▪ Monitor sediment accumulations; remove sediment when the pond volume has been reduced by 25 percent	25- to 50-year maintenance

Source: Modified from MPCA, 2017

Limitations

Although dry detention ponds are widely applicable, they have some limitations that might make other stormwater controls preferable:

- Dry detention ponds have limited water quality treatment capacity compared to other structural stormwater controls and are ineffective at removing soluble pollutants (see “Effectiveness”).
- Dry extended detention ponds may become a nuisance due to mosquito breeding if improperly maintained or if shallow pools of water form for more than 3 days.
- Dry ponds may detract from the value of a home (see “Cost Considerations”).

Dry detention ponds on their own only provide peak flow reduction and do little to control stormwater volume, which could result in adverse downstream impacts.

Effectiveness

Structural stormwater controls can achieve four broad resource protection goals: flood control, channel protection, groundwater recharge and pollutant removal. Dry detention basins can provide flood control and channel protection, as well as some limited pollutant removal. They are not typically designed to provide groundwater recharge (for a similar control that does provide groundwater recharge, see Infiltration Basin). However, some infiltration to surrounding soils may occur, particularly in soils with high infiltration rates.

Flood Control

One objective of stormwater controls can be to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. One of the main purposes of dry detention basins is to slow stormwater and reduce peak flow rates. Dry detention ponds therefore provide effective flood control, especially in conjunction with other peak flow reduction controls throughout a watershed.

Channel Protection

One result of urbanization is the geomorphic changes that occur in response to modified hydrology. Traditionally, dry detention basins have provided control of the 2-year storm for channel protection. However, it appears that this control has been relatively ineffective for channel protection. Research suggests that control of a smaller storm, such as the 1-year storm, might be more appropriate (MacRae, 1996; Tillinghast et al., 2011). Most current channel protection standards are based on the 1-year storm event (e.g., MDE, 2009).

Pollutant Removal

Dry detention basins provide some pollutant removal, provided that the design features described in the "Siting Considerations" and "Design Considerations" sections are incorporated. Although they are effective at removing some pollutants through settling, they are less effective at removing soluble pollutants because of the absence of a permanent pool. Pollutant loading information for dry detention basins provided by the New Hampshire Department of Environmental Services allows for an assumed removal efficiency of 80 percent for total suspended solids, 55 percent for total nitrogen removal and 68 percent for total phosphorus removal (NHDES, 2011).

Cost Considerations[1]

The construction costs associated with dry detention ponds can range considerably depending on the type of construction and size. Adjusted for inflation, a reported range for dry detention ponds and dry extended detention ponds is $45,000 to $80,000 per acre of impervious surface treated (King & Hagan, 2011). As with most other stormwater controls, economies of scale suggest that larger systems are at the lower end of this range.

Maintenance costs can be slightly higher than comparable wet ponds, mostly due to the greater area needing regular mowing. For ponds, the annual cost of routine maintenance is typically about 2 to 6 percent of the construction cost (King & Hagan, 2011). Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section.

Another economic concern associated with dry ponds is that they can detract from the value of adjacent properties, especially compared to wet ponds and mixed recreational use stormwater facilities (Lee & Li, 2009). One study found that dry ponds detract from the perceived value of adjacent homes by between 3 and 10 percent (Emmerling-Dinovo, 1995).

Additional Information

Additional information on related practices and the Phase II MS4 program can be found at EPA's National Menu of Best Management Practices (BMPs) for Stormwater website

[1] Prices updated to 2019 dollars. Inflation rates obtained from the Bureau of Labor Statistics CPI Inflation Calculator website: https://data.bls.gov/cgi-bin/cpicalc.pl.

References

City of Portland. (2016). *2016 City of Portland stormwater management manual.*

Emmerling-Dinovo, C. (1995). Stormwater detention basins and residential locational decisions. *Water Resources Bulletin, 31*(3), 515–521.

King, D., & Hagan, P. (2011). *Costs of stormwater management practices in Maryland counties*. University of Maryland Center for Environmental Science.

Lee, J. S., & Li, M. H. (2009). The impact of detention basin design on residential property value: Case studies using GIS in the hedonic price modeling. *Landscape and Urban Planning*, *89*(1–2), 7–16.

MacRae, C. (1996). Experience from morphological research on Canadian streams: Is control of the two-year frequency runoff event the best basis for stream channel protection? In L. Roesner (Ed.), *Effects of watershed development and management on aquatic ecosystems* (pp. 144–162). Snowbird, UT: American Society of Civil Engineers.

Maryland Department of the Environment (MDE). (2009). *2000 Maryland stormwater design manual.*

Metzger, M. E., Messer, D. F., Beitia, C. L., Myers, C. M., & Kramer, V. L. (2002). The dark side of stormwater runoff management: Disease vectors associated with structural BMPs. *Stormwater*, *3*(2), 24–39.

Minnesota Pollution Control Agency (MPCA). (2017). Operation and maintenance of stormwater ponds. In *Minnesota stormwater manual.*

New Hampshire Department of Environmental Services (NHDES). (2011). *Pollutant removal efficiencies for best management practices for use in pollutant loading analysis.*

Tillinghast, E. D., Hunt, W. F., & Jennings, G. D. (2011). Stormwater control measure (SCM) design standards to limit stream erosion for Piedmont North Carolina. *Journal of Hydrology*, *411*(3–4), 185–196.

University of New Hampshire Stormwater Center (UNHSC). (2011). *Examination of thermal impacts from stormwater best management practices.*

Stormwater Best Management Practice

On-Lot Treatment

Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment
Subcategory: Retention/Detention

Description

The term "on-lot treatment" refers to a range of stormwater controls that treat discharges from individual residential lots. The primary purpose of most stormwater controls for on-lot treatment is to manage discharges from rooftops and, to a lesser extent, driveways and sidewalks. On-lot treatment reduces surface discharge, either by enhancing infiltration or by temporarily storing the water for irrigation or infiltration during dry times. Although the volume of stormwater that individual lots generate is small and its quality is generally good compared to other urban stormwater (NAS, 2016), the cumulative effect of untreated stormwater from thousands of households can be a major contributor to problems like water quality pollution and erosive flows in urban streams (Walsh et al., 2005). Treating residential discharges at the source is therefore one of the best and easiest ways to restore a community's natural hydrology.

There are many options for on-lot treatment stormwater controls. The best option depends on a community's goals, local laws, the feasibility at a specific site and the property owner's preferences. Table 1 summarizes common practices. Additional information can be found in the individual links.

A rain barrel decorated by a homeowner and used for watering a garden.
Credit: Alisha Goldstein, USEPA

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Table 1. Common stormwater controls for on-lot treatment for residential homes

Stormwater Control	Description and Siting Considerations
Bioretention (rain gardens)	▪ Consists of a shallow depression with multiple layers, including soil mix media, a mulch layer and native vegetation. ▪ Provides landscaping and aesthetic benefits. ▪ Requires regular maintenance.
Cisterns and rain barrels	▪ Cisterns and rain barrels are the simplest on-lot treatment method. ▪ Property owners can retrofit existing roof drains to lead into rain barrels. ▪ Sites can use harvested rainwater to water plants during dry weather. ▪ Their effectiveness depends on storage volume and seasonal rainfall rates.
Dry wells	▪ Subsurface storage facilities can receive and temporarily store stormwater from roof structures.

Stormwater Control	Description and Siting Considerations
	▪ Property owners can retrofit existing roof drains to connect to dry wells. ▪ Wells help store stormwater with high flow and encourage groundwater recharge. ▪ They are only practical in areas with high soil infiltration rates.
Grassed swales or filter strips	▪ Strips of grass or vegetation can transport stormwater to a larger pervious area for infiltration. ▪ They are most effective in conjunction with other stormwater controls.
Infiltration trenches	▪ Property owners fill trenches with various-sized rocks to reduce the stormwater flow rate and encourage infiltration. ▪ They are most effective in areas with highly permeable soils. ▪ They require regular maintenance.

Application and Design Considerations

With very few exceptions (e.g., very small lots or lots with no landscaping), some sort of on-lot treatment applies to most sites. Traditionally, municipalities have encouraged but not widely adopted on-lot treatment of residential stormwater discharge, as the property owner is responsible for initial and maintenance costs. However, more local governments are offering financial incentives for on-lot treatment, such as reducing fees and supporting public outreach (see “Cost Considerations” below).

Although simpler than other types of stormwater controls, on-lot treatment still has certain design elements common to all practices. Pretreatment is important to ensure the controls do not clog with leaf litter or debris. For rainwater collection systems, a settling tank, first flush diverter, or debris-trapping grate or filter in the downspout is recommended.

Common Terms

Pretreatment plays an important role in stormwater treatment. Pretreatment structures, installed immediately upgradient to a stormwater control, reduce flow rates and remove sediment and debris before stormwater enters the stormwater control. This helps to improve the stormwater control’s pollutant removal efficiency and reduces maintenance requirements.

Both infiltration- and storage-based on-lot treatment stormwater controls typically incorporate some type of bypass to direct heavy stormwater discharges away from buildings. In many cases, this simply entails allowing for an overflow route that will not cause erosion or flooding. For cisterns or rain barrels, emptying the container before large storm events helps prevent the container from overfilling. For example, property owners typically mount a hose at the bottom of the barrel or cistern to irrigate gardens or for landscaping; owners can use the hose to manually empty the tank or connect the hose to a drip tape to allow for slow drawdown after each rain event. In infiltration-based on-lot treatment, an aboveground opening in the downspout can serve as the bypass. Additionally, design engineers can design grassed swales and bioretention cells to absorb all but the largest of stormwater flows. In extreme cases, flows generally pass untreated over these stormwater controls.

When designing infiltration-based on-lot treatment stormwater controls, it is important to locate the infiltration area far enough away from the building’s foundation to prevent the undermining of the foundation or basement seepage. The infiltration area should be at least 10 feet away from the house.

Limitations

Limitations to the use of on-lot treatment include the following:

- Property owners should perform some basic maintenance.
- Property owners who do not enjoy landscaping may struggle to find uses for water stored in rain barrels or cisterns, since the water is not potable.
- Some of these stormwater controls may be impractical on very small lots.

- Rainwater harvesting may have restrictions in some arid states, where water rights laws apply. Always consult local limitations.
- Even if every property in a watershed uses on-lot treatment, these stormwater controls would only treat a portion of the watershed imperviousness, because they would not address roads and parking areas (see the Right-Sized Residential Streets and Green Parking fact sheets).

Maintenance Considerations

Bioretention practices, infiltration trenches, filter strips and grassed swales require regular maintenance to ensure that the vegetation remains in good condition and clogging does not occur; see the Bioretention (Rain Gardens), Vegetated Filter Strip and Grassed Swales fact sheets for more detailed information. Infiltration-based stormwater controls require regular removal of sediment and debris that settle in the pretreatment or treatment area (see the Bioretention and Infiltration Trench fact sheets). Property owners might also need to replace the media if they become clogged.

Rain barrels and cisterns require minimal maintenance, but the property owner should maintain the rain barrel and any apparatus to prevent freezing or cracking. In addition, the property owner should clean the tank about once per year and periodically check that rain barrels and cisterns are properly sealed to prevent mosquito breeding.

Effectiveness

On-lot treatment is most effective at reducing the volume of stormwater that individual lots generate. Pollutant removal may not be as high as larger-scale stormwater controls—see the Infiltration Trench, Bioretention (Rain Gardens), Vegetated Filter Strip and Grassed Swales fact sheets—because the pollutant concentrations entering the systems are generally low. Still, benefits can be significant if implemented on many lots throughout a watershed. Even if only 10 to 20 percent of properties adopt on-lot treatment, these controls can measurably reduce peak discharge rates and total discharge volumes (Jarden, Jefferson, & Grieser, 2016).

> In an assessment of three watersheds in the Mid-Atlantic region, sub-watersheds with over 10 percent adoption of rain gardens, detention ponds, bioswales and green roofs showed a 26 to 44 percent reduction in peak flow, a reduced frequency of discharge-generating events and up to a 50 percent reduction in stormwater nitrogen export (Pennino et al., 2016).

Many on-lot treatment stormwater controls also promote groundwater recharge, helping address typical urban stream problems such as reduced baseflow and increased frequency of erosive flows (Walsh et al., 2005). Finally, landscaped areas such as rain gardens beautify the landscape and may also provide habitat for pollinators and other native wildlife.

Cost Considerations and Local Incentivization Programs

Q19 On-lot treatment can be relatively inexpensive. Typical costs are $100 for a rain barrel and $500 for a dry well. The property owner is usually directly responsible for the cost, which can make adoption rates low. For dry wells, rain barrels and cisterns, property owners can reduce costs by making their own rather than purchasing a commercial product. Incentive and rebate programs are also becoming more popular, which can offset nearly all installation costs. Currently, some municipalities offer credits or other incentives for installing stormwater controls on residential properties. Consult local agencies to determine if these incentives are available.

> The city of Seattle, Washington, developed the RainWise program for residents, offering up to $4 per square foot of controlled rooftop discharge, with an average rebate of $4,800 to each qualifying household in the Seattle area (City of Seattle, n.d.).
>
> Montgomery County, Maryland, has a similar program, called RainScapes, which provides a variety of incentives for installing and maintaining on-lot treatment stormwater controls. These incentives include a rebate of $1 per gallon for cisterns and rain barrels, $10 per square foot of rain garden total area, and $3 to $7 per square foot of pavement removal (MCDEP, n.d.).

Additional Resources

- Soak Up the Rain: Rain Barrels
- What is Green Infrastructure?
- What is EPA Doing to Support Green Infrastructure?
- Green Infrastructure Modeling Tools
- Green Infrastructure Design and Implementation
- Green Infrastructure Funding Opportunities
- Tools, Strategies and Lessons Learned from EPA Green Infrastructure Technical Assistance Projects
- Manage Flood Risk
- Build Resiliency to Drought
- Green Infrastructure Webcast Series

Additional Information

Additional information on related practices and the Phase II MS4 program can be found at EPA's National Menu of Best Management Practices (BMPs) for Stormwater website

References

City of Seattle. (n.d.) *The rebate process.*

Jarden, K. M., Jefferson, A. J., & Grieser, J. M. (2016). Assessing the effects of catchment-scale urban green infrastructure retrofits on hydrograph characteristics. *Hydrological Processes, 30*(10), 1536–1550.

Montgomery County Department of Environmental Protection (MCDEP). (n.d.). *Types of stormwater management facilities.*

National Academies of Sciences, Engineering, and Medicine (NAS). (2016). *Using graywater and stormwater to enhance local water supplies: An assessment of risks, costs, and benefits.* Washington, DC: National Academies Press.

Pennino, M. J., McDonald, R. I., & Jaffe, P. R. (2016). Watershed-scale impacts of stormwater green infrastructure on hydrology, nutrient fluxes, and combined sewer overflows in the mid-Atlantic region. *Science of the Total Environment, 565,* 1044–1053.

Walsh, C. J., Roy, A. H., Feminella, J. W., Cottingham, P. D., Groffman, P. M., & Morgan, R. P. (2005). The urban stream syndrome: Current knowledge and the search for a cure. *Journal of the North American Benthological Society, 24*(3), 706–723.

Stormwater Best Management Practice

Stormwater Wetland

Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment
Subcategory: Retention/Detention

Description

Stormwater wetlands (or constructed wetlands) are structural post-construction stormwater controls similar to wet ponds (see the Wet Ponds fact sheet) whose design incorporates shallow zones and vegetation. As stormwater flows through the wetland, it removes pollutants through settling and biological uptake. Wetlands are among the most effective post-construction stormwater controls in terms of pollutant removal and also offer aesthetic and habitat value. Stormwater wetlands are fundamentally different from natural wetland systems. Engineers design them specifically to treat stormwater, and they typically have less biodiversity than natural wetlands in terms of both plant and animal life. Several variations of stormwater wetlands exist, differing in relative amounts of dry, shallow and deep water zones.

Planners should distinguish between using a constructed wetland for stormwater management and diverting stormwater into a natural wetland. They should avoid the latter: altering the hydrology of a natural wetland can in turn alter and, in many cases, degrade the existing system. In most cases, local regulations also prohibit this practice. In all circumstances, communities should protect natural wetlands from the adverse effects of development, including impacts from increased stormwater discharge. This is especially important because natural wetlands provide stormwater and flood control benefits on a regional scale.

Applicability

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Constructed wetlands are widely applicable. They can have limited applicability in highly urbanized settings and arid climates, but they have few other restrictions.

Regional Applicability

Most regions of the United States can apply stormwater wetlands, except those with arid climates. In arid and semiarid climates, it is difficult to design stormwater controls with permanent pools. Stormwater wetlands are shallow, so large portions of them are subject to evaporation. This makes maintaining the permanent pool in wetlands more challenging than maintaining the pool of a wet pond (see the Wet Ponds fact sheet).

Stormwater wetlands provide a reduction in stormwater pollutants as well as provide wildlife habitat.

Urban Areas

It is difficult to use stormwater wetlands in urban environments because of the large continuous land area they require. However, they can work in an urban environment if a relatively large area is available downstream of a site.

Stormwater Hot Spots

Stormwater hot spots are areas where certain land uses or related activities generate highly contaminated stormwater, with higher-than-usual pollutant concentrations. Typical examples include gas stations and industrial areas. Wetlands can accept stormwater discharge from hot spots—but, if they do, they need significant separation from groundwater. If designers use these practices to develop wildlife habitat, they should be careful to ensure that pollutants in stormwater discharge do not enter the food chain for organisms living in or near the wetland.

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Stormwater Retrofit

A stormwater retrofit is a stormwater control (usually structural) that a community puts into place after development to improve water quality, protect downstream channels, reduce flooding or meet other specific objectives.

When designers retrofit an entire watershed, stormwater wetlands have the advantage of providing both educational and habitat value. One disadvantage of stormwater wetlands is the difficulty of storing large amounts of stormwater without taking up a large amount of land.

It is also possible to incorporate wetland elements, such as enhanced littoral zones (i.e., nearshore and shallow environments) and wetland plantings, into other existing practices (see the Wet Ponds and Dry Detention Ponds fact sheets).

Cold Water (Trout) Streams

Stormwater wetlands could pose a risk to cold water systems because of their potential for stream warming. Several factors affect wetland temperature and need careful consideration. Kadlec and Wallace (2009) recommend a set of design equations to predict wetland outlet temperature as a function of climate, wetland size, wetland depth and loading rate. They found that small, shallow wetlands tend toward ambient temperatures and show 24-hour trends, while deeper wetlands show similar but dampened patterns. For shallow wetlands, this can translate to warm effluent, particularly during the warmest parts of the day. Where thermal limits are in place, designers should use additional measures—such as outlet channel shading—to reduce warming effects. Conversely, in dry climates where evaporative cooling effects are significant, wetland temperatures may be as much as 5°C to 10°C lower than ambient temperatures. Where warming concerns exist, designers should conduct a thorough thermal analysis in the design stage.

Siting and Design Considerations

Siting Considerations

In addition to the broad applicability concerns described above, designers need to consider site-specific conditions such as drainage area, slope, soils/topography and groundwater and incorporate design features that improve the longevity and performance of the practice while minimizing maintenance needs.

Drainage Area

A stormwater wetland needs enough drainage area to maintain a permanent pool. In humid regions, the drainage area needed is typically about 5 to 25 acres, but regions with less rainfall may need a larger area. In some instances, such as in areas with high water tables or regularly high rainfall, smaller systems can be feasible. However, they generally should undergo thorough hydrologic analysis to show that the practice will be viable.

Slope

Sites with an upstream slope of up to about 15 percent can use stormwater wetlands. However, the local slope should be relatively shallow to maintain permanent pool volumes. Construction on steeper slopes is possible through use of a step-pool system.

Soils/Topography

Almost all soils and geology can support stormwater wetlands, with minor design adjustments for regions of karst (i.e., limestone) topography. Designers can include liners for soils with high infiltration rates if water loss is a concern.

Groundwater

Similar to natural wetlands, constructed wetlands often have direct contact with shallow groundwater tables, unless hot spots or excessive infiltration concerns necessitate preventing such contact. This contact generally minimizes infiltration losses and maintains saturation during periods of low rainfall. In extreme cases where groundwater inflow is large relative to surface water area, the shorter detention time can reduce pollutant removal. Groundwater infiltration can decrease the temperature of the water flowing through the wetland, thereby reducing the biological activity that contributes to pollutant removal (Kill et al., 2018). However, groundwater flows are typically small, and the benefit to wetland hydrology is far greater than any reductions in pollutant removal efficiency.

Design Considerations

Specific designs may vary considerably, depending on site constraints or the preferences of the designer or community. Most constructed wetlands, however, should incorporate certain design features. These fall into five basic categories: pretreatment, treatment, conveyance, maintenance reduction and landscaping.

Pretreatment

Pretreatment features remove coarse sediment particles by settling. By removing these particles from stormwater before they reach the treatment area, pretreatment reduces the maintenance burden of the wetland. A wetland typically pretreats using a sediment forebay: a small pool, usually about 10 percent of the volume of the permanent pool. Coarse particles stay trapped in the forebay, and crews perform maintenance on this smaller pool, eliminating the need to dredge and replant the entire treatment area.

Treatment

The treatment area, or permanent pool, helps a stormwater wetland remove pollutants by increasing the detention time of stormwater within the wetland. Some typical design features include the following:

- The surface area of stormwater wetlands should make up at least 1 percent of the area draining to the practice.
- Wetlands should have a length-to-width ratio of at least 1.5:1. Making the wetland longer than it is wide ensures that water entering the wetland receives adequate treatment.
- An effective wetland design displays “complex microtopography”—underwater earth berms creating both very shallow (<6 inches) and moderately shallow (<18 inches) water zones. This design provides a longer flow path through the wetland that encourages settling and biological pollutant removal processes. It also promotes greater biological diversity, allowing a range of microbial and vegetation communities to flourish, which tends to increase both health and pollutant removal performance.

Intermittent flooding/drying cycles can promote mosquito breeding through predator reduction (e.g., mosquitofish, insects and amphibians) during cycles (Walton, 2012). Designs that incorporate a permanent pool and more stable hydrologic conditions are better able to maintain these predator communities, as well as more biological diversity in general, which helps promote better wetland health and function.

Conveyance

A stormwater wetland should convey stormwater safely and in a manner that minimizes erosion potential. Designers should always stabilize the wetland’s outfall to prevent scour, as well as possibly providing an emergency spillway to safely convey water from large storms. Where thermal pollution is a concern, designers should provide shade around the channel at the wetland outlet.

Maintenance

One potential maintenance concern in wetlands is clogging of the outlet. A wetland should have a non-clogging outlet such as a reverse-slope pipe or a weir outlet with a trash rack. A reverse-slope pipe draws from below the permanent pool, extending in a reverse angle up to the riser, and establishes the water elevation of the permanent pool. Because these outlets draw water from below the permanent pool, floating debris is less likely to clog them. In addition, no orifice should be narrower than 3 inches, smaller orifices are susceptible to clogging. Another feature that can help reduce the potential for clogging is a small pool, or “micropool,” at the outlet. (Note that these pools can become mosquito breeding grounds and nuisances if in populated areas such as neighborhoods or community parks.)

Designers should also incorporate features that ease maintenance of both the forebay and the main treatment area of the wetland. Wetlands should have maintenance access to the forebay, and the treatment area should have a drain to draw down the water for the more infrequent dredging or vegetation harvesting.

Landscaping

Landscaping is an integral part of wetland design—of beautifying wetlands, making them an asset to a community, and enhancing their pollutant removal. To ensure the establishment and survival of wetland plants, a landscaping plan should provide detailed information about the selected plants, a timeline of when they will be planted, and a strategy for maintaining them. The landscape plan should also detail all plants used from within the water all the way up to the upland area.

Establishing plants in the stormwater wetland is key. The most effective techniques include using nursery stock as dormant rhizomes, live potted plants and bare rootstock. Designers can use a "wetland mulch" soil from a natural wetland or a designed "wetland mix" to supplement wetland plantings or establish wetland vegetation. Wetland mulch carries the seed bank from the original wetland and can help enhance diversity. The least expensive option is to allow the wetland to colonize itself, but this takes time and creates the potential for invasive species colonization.

When developing a plan for wetland planting, designers and construction staff need to take care to establish plants at the proper depth and during the planting season. The planting season varies regionally and is generally between 2 and 3 months long in the spring to early summer.

Plant lists are available for various regions of the United States through wetland nurseries, extension services and conservation districts. Designers should use native plants wherever possible.

Design Variations

Wetland designs can vary in terms of volume of the wetland in the deep pool, high marsh and low marsh, and in whether the design allows for detention of small storms above the wetland surface. Other design variations help to make wetland designs practical in cold climates.

Shallow Wetland

In the shallow wetland design, most of the volume is in the relatively shallow high marsh or low marsh depths. The only deep portions of the shallow wetland design are the forebay and micropool. This design generally requires less excavation and lower costs, and it is very effective at maximizing vegetation cover. Because the pool is very shallow, though, this design typically needs a large amount of land to store the water quality volume (i.e., the volume of stormwater the wetland will treat). Also, this system type may not be suitable where thermal impacts to cold water streams are a concern.

Extended Detention Wetland

The extended detention wetland design is the same as the shallow wetland, with additional storage above the marsh surface. Stormwater stays in this extended detention zone for between 12 and 24 hours. This design can treat a greater volume of stormwater in a smaller space than the shallow wetland design. When choosing it, designers should select plants that can tolerate wet and dry periods for the extended detention zone.

Pond/Wetland System

The pond/wetland system combines the wet pond (see Wet Ponds fact sheet) design with a shallow marsh. Stormwater flows through the wet pond and into the shallow marsh. Like the extended detention wetland, this design needs less surface area than the shallow marsh because it stores some water in the relatively deep (i.e., 6 to 8 feet) pond.

Pocket Wetland

In this design, the bottom of the wetland intersects with the groundwater, which helps to maintain the permanent pool. This option is helpful when the drainage area is not large enough to maintain a permanent pool.

Subsurface Flow Wetlands

In the subsurface flow wetland design, stormwater flows through a rock or gravel filter (also known as the medium) with wetland plants at the surface. Biological activity and pollutant uptake by plants removes the pollutants. This practice is fundamentally different from other wetland designs because subsurface wetlands are more similar to filtering systems, while most wetland designs behave like wet ponds with differences in grading and landscaping. With a surface layer of mulch for insulation, sub-surface wetlands are also better suited to cold climates where freezing is a concern.

Water Reuse Wetland

Stormwater can be a valuable water resource, helping to offset the use of potable water in water-scarce regions (NASEM, 2016; Wanielista, 2007). Stormwater wetlands can harvest and partially treat stormwater for non-potable uses such as irrigation. In this case, designers should perform a water balance analysis to account for the water that users will take from the wetland and make sure the wetland will not dry out. When done correctly, this planned withdrawal can even improve wetland inundation characteristics and vegetation survival (Jenkins et al., 2012).

Regional Variations

Cold Climates

Cold climates present many challenges to wetland designers. Spring snowmelt quickly generates a large volume of water with a relatively high pollutant load. Cold winters may also cause the permanent pool or the inlet and outlet areas to freeze. In addition, high salt concentrations and sediment loads from road salting and road sanding may affect wetland vegetation. When wetlands drain water from salted or sanded paved surfaces, designers should use salt-tolerant native vegetation.

One of the greatest challenges of stormwater wetlands, particularly shallow marshes, the potential for freezing. Although biological activity is reduced in all vegetated practices when temperatures are low, freezing can reduce the physical function of a wetland as well. Freezing reduces the wetland's treatment volume and can cause stormwater to flow on the top of the wetland. This inhibits physical treatment processes, including the detention of peak flows and physical filtration, letting sediment and pollutants travel through the wetland untreated. Several design features can help minimize this problem, including the following:

- "Online" designs that allow continuous flow and help prevent outlets from freezing.
- Designs with multiple cells, each separated by a berm or weir. This modification helps retain storage for treatment above the ice layer during the winter season.
- Outlets that are resistant to freezing. Examples include weirs or pipes with large diameters.
- Subsurface flow wetlands that can stay functional when insulated with mulch on the surface.

Karst Topography

In karst topography, a wetland should have an impermeable liner to prevent groundwater contamination or sinkhole formation and to help maintain the permanent pool.

Limitations

Features of stormwater wetlands that may make designs challenging and limit their usage include the following:

- Stormwater wetlands consume a relatively large amount of space.
- Stormwater wetlands can become a breeding area for mosquitoes without proper design and maintenance.
- Stormwater wetlands need careful design and planning to ensure that its vegetation survives.
- Stormwater wetlands may release nutrients during the non-growing season when plants break down.
- Designers need to ensure that wetlands do not harm natural wetlands or forested areas during the design phase.

Maintenance Considerations

Though design features can minimize their maintenance needs, wetlands still need regular maintenance and inspection. Table 1 outlines these practices.

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Table 1. Regular maintenance activities for wetlands.

Activity	Schedule
Inspect vegetation during establishment or restoration.	Biweekly until vegetation is established
Inspect all components for cracking, subsidence, spalling, erosion and sedimentation and repair as necessary.	Annually
Inspect components that receive or trap debris, and clean/remove debris.	Semiannually
Inspect vegetated areas for erosion, scour and unwanted growth.	Annually
Replace wetland vegetation to maintain at least 50% surface area coverage in wetland plants after the second growing season.	As needed

Activity	Schedule
Inspect wetland for invasive vegetation and remove where possible.	Semiannually
Mow side slopes.	3 to 4 times/year
Harvest wetland plants that sediment buildup has “choked out.”	Annually (as needed)
Remove sediment from the forebay when the wetland has lost 50% of its total forebay capacity.	As needed
Monitor sediment accumulations and remove sediment when it has reduced the pool volume by 50%, when it has “choked” the plants, or when the wetland has become eutrophic.	As needed

Source: Adapted from NJDEP, 2018

Effectiveness

Structural stormwater management, in general, is a way to pursue four broad resource protection goals: flood control, channel protection, groundwater recharge and pollutant removal. Stormwater wetlands can meet all four of these goals, as described below.

Flood Control

One objective of stormwater controls can be to reduce the flood hazard associated with large storms by reducing peak flow from these storms. Designers can easily design a wetland for flood control by providing flood storage above the level of the permanent pool.

Channel Protection

One result of urbanization is the landscape/geomorphic changes—such as eroded stream channels—that occur in response to modified hydrology. Traditionally, stormwater wetlands have provided control of the 2-year storm for channel protection. However, it appears that this control has been relatively ineffective for channel protection, and research suggests that control of a smaller storm, such as the 1-year storm, might be more appropriate (MacRae, 1996; Tillinghast et al., 2011). Most current regulations therefore require that channel protection features provide control of the 1-year storm event (e.g., MDE, 2009).

Groundwater Recharge

Stormwater wetlands can only provide groundwater recharge in limited cases, and in soils with high infiltration rates. Generally, the buildup of debris at the bottom of the wetland limits infiltration rates.

Pollutant Removal

Stormwater wetlands are among the most effective stormwater controls for pollutant removal. Table 2 summarizes pollutant removal data from a database of stormwater practice performance (Clary et al., 2017). Designers can also reasonably predict a stormwater wetland’s pollutant removal performance using standard design details. One widely used method, based on an analysis of hundreds of operational stormwater wetlands, is Kadlec and Wallace’s (2009) *P-k-C* model.

Q22

Table 2. Typical pollutant removal rates of stormwater wetlands.

Pollutant	Influent Concentration (Median)	Effluent Concentration (Median)
Total copper (µg/L)	4.51	3.20
Total zinc (µg/L)	22.6	12.00
Total suspended solids (mg/L)	38.9	12.0

Pollutant	Influent Concentration (Median)	Effluent Concentration (Median)
Total nitrogen (mg/L)	1.50	1.31
Nitrate (mg/L)	0.45	0.22
Total phosphorus (mg/L)	0.18	0.10
E. coli (most probable number/100 mL)	780	170

Source: Adapted from Clary et al. (2017).

Cost Considerations[1]

Wetlands are a relatively inexpensive stormwater control. Although total costs depend on several factors, including engineering, permitting, construction and maintenance, general equations exist to provide rough estimates. Using construction costs from 84 wetlands ranging from 0.1 to 25,000 acres, Kadlec and Wallace (2009) developed the following equation:

$$C = 479A^{0.69}$$

where:

C = cost (in thousands of dollars)

a = wetland area (acres)

Using this equation, construction costs (in 2019 dollars) for a 1-acre facility would be $600,000, while a 10-acre facility would cost $3 million.

King and Hagan (2011) suggest that total initial costs (including pre-construction costs of siting, design, permitting, etc.) per acre of treated impervious surface are $27,000 for new construction and $71,000 for retrofit projects, with pre-construction costs representing 30 to 50 percent of construction costs.

Wetland design should also consider land acquisition and maintenance costs. Stormwater wetlands consume about 3 to 5 percent of the land that drains to them, which is relatively high compared to other stormwater controls. The cost of land is therefore an important consideration.

Maintenance costs for wetlands are similar to those for wet ponds, though they can be slightly higher due to routine maintenance associated with greater vegetation cover or piping infrastructure. Kadlec and Wallace (2009) estimated the annual cost of routine maintenance to be roughly $1,000 per acre per year for surface flow wetlands and $1,500 per acre per year for subsurface wetlands. These estimates may show bias toward larger systems. However, King and Hagan (2011) suggest annual maintenance to be around $500 per acre of impervious surface treated. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section.

Stormwater wetlands typically last longer than 20 years: a community can consider its initial investment in light of this long life span.

Additional Information

Additional information on related practices and the Phase II MS4 program can be found at EPA's National Menu of Best Management Practices (BMPs) for Stormwater website

[1] Prices updated to 2019 dollars. Inflation rates obtained from the Bureau of Labor Statistics CPI Inflation Calculator website https://data.bls.gov/cgi-bin/cpicalc.pl.

References

Clary, J., Jones, J., Leisenring, M. Hobson, P., & Strecker. E. (2017). *International stormwater BMP database: 2016 summary statistics*. Water Environment & Reuse Foundation.

Jenkins, G. A., Greenway, M., & Polson, C. (2012). The impact of water reuse on the hydrology and ecology of a constructed stormwater wetland and its catchment. *Ecological Engineering*, *47*, 308–315.

Kadlec, R. H., & Wallace, S. D. (2009). *Treatment wetlands*. Boca Raton, FL: CRC Press.

Kill, K., Pärn, J., Lust, R., Mander, Ü., & Kasak, K. (2018). Treatment efficiency of diffuse agricultural pollution in a constructed wetland impacted by groundwater seepage. *Water*, *10*(11), 1601–1611.

King, H., & Hagan, P. (2011). *Costs of stormwater management practices in Maryland counties*. University of Maryland Center for Environmental Science.

MacRae, C. (1996). Experience from morphological research on Canadian streams: Is control of the two-year frequency runoff event the best basis for stream channel protection? In L. Roesner (Ed.), *Effects of watershed development and management on aquatic ecosystems* (pp. 144–162). Snowbird, UT: American Society of Civil Engineers.

Maryland Department of the Environment (MDE). (2009). *2000 Maryland stormwater design manual Volumes I & II*.

National Academies of Sciences, Engineering, and Medicine (NASEM). (2016). *Using graywater and stormwater to enhance local water supplies: An assessment of risks, costs, and benefits*. Washington, DC: National Academies Press.

New Jersey Department of Environmental Protection (NJDEP). (2018). *New Jersey stormwater best management practices manual*.

Tillinghast, E. D., Hunt, W. F., & Jennings, G. D. (2011). Stormwater control measure (SCM) design standards to limit stream erosion for Piedmont North Carolina. *Journal of Hydrology*, *411*(3-4), 185–196.

Walton, W. E. (2012). Design and management of free water surface constructed wetlands to minimize mosquito production. *Wetlands ecology and management*, *20*(3), 173-195.

Wanielista, M. P. (2007). Stormwater—an alternative water supply. In K. C. Kebbes (Ed.), *World Environmental and Water Resources Congress 2007: Restoring our natural habitat* (pp. 1–14). Tampa, FL: American Society of Civil Engineers.

Stormwater Best Management Practice

Wet Ponds

Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment
Subcategory: Retention/Detention

Description

Wet ponds (also referred to as stormwater ponds, wet retention ponds, or wet extended detention ponds) are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season). The primary pollutant removal mechanisms are sediment settling and pollutant uptake, particularly of nutrients, through biological activity in the pond. Traditionally, wet ponds have been a common stormwater control, especially for larger development projects.

Applicability

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Wet ponds are widely applicable. Although they have limited applicability in highly urbanized settings and in arid climates, they have few other restrictions.

Regional Applicability

Wet ponds are suitable for most regions of the United States—except arid climates, where water scarcity makes it difficult to justify the use of supplemental water to maintain a permanent pool. Cold climates and karst topography may also call for modifications and design variations (see the “Regional Adaptations” section).

Urban Areas

Wet ponds may not be ideal for urban areas with little pervious area, due to the large continuous land area they need. They can, however, treat stormwater from an urban environment if located just outside a densely developed area.

Stormwater Hot Spots

Stormwater hot spots are areas where certain land uses or related activities generate highly contaminated stormwater. Typical examples include gas stations and industrial areas. Wet ponds can accept stormwater from hot spots—but, if they do, they need significant separation from groundwater.

Wet ponds have traditionally been used for stormwater control in larger development projects such as residential neighborhoods.
Credit: Photo by Aaron Volkening on Flickr (Creative Commons license)

Stormwater Retrofit

A stormwater retrofit is a stormwater control (usually structural) that a community puts into place after development to improve water quality, protect downstream channels, reduce flooding or meet other specific objectives. In the past, many communities constructed detention ponds for only flood control. With a permanent wet pool and an outlet structure modified for channel protection, though, a detention pond can provide water quality control (see “Treatment” under “Design Considerations”).

Cold Water (Trout) Streams

Wet ponds pose a risk to cold water systems because of their potential to increase water temperatures. A number of factors affect pond temperature, including shading, depth, and the temperature of the surrounding air. In a study of several urban post-construction stormwater controls near trout habitat in North Carolina, Jones (2008) examined the way a wet pond affected the temperature of stormwater from an urban parking lot and found that the effluent from the wet ponds was significantly warmer than the influent water—meaning that wet ponds can raise surface water temperatures.

Siting and Design Considerations

Siting Considerations

Drainage Area

A wet pond needs enough drainage area to maintain its permanent pool. In humid regions, recommended drainage areas are generally 10–20 acres (NJDEP, 2014), though areas down to 5 acres are permissible in some locations (MDE, 2009). Wet ponds in an arid region may need larger drainage areas. When only small drainage areas are available, design engineers should consider practices that are more suitable for source control, such as bioretention.

Slope

Wet ponds can work at sites with an upstream slope up to about 15 percent. However, the local slope should be relatively shallow. Although there is no minimum slope requirement, there needs to be enough elevation drop from the pond inlet to the pond outlet to ensure that water can flow through the system.

Soils/Topography

Wet ponds can work in almost all soils and geology, with minor design adjustments for regions of karst (i.e., limestone) topography. Designers can include liners for soils with high infiltration rates if water loss is a concern.

Groundwater

Unless stormwater hot spots are a concern, ponds can intersect the groundwater table. This contact generally minimizes infiltration losses and maintains saturation during periods of low rainfall. In extreme cases where groundwater inflow is large relative to surface water inflow, the shorter detention time can reduce pollutant removal. However, groundwater flows are typically small and the benefit to pond hydrology is far greater than any reductions in pollutant removal efficiency.

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. Most wet ponds, though, should have certain design features. These fall into five basic categories: pretreatment, treatment, conveyance, maintenance reduction and landscaping.

Pretreatment

Pretreatment features remove coarse sediment by settling before it reaches the large permanent pool. This reduces the maintenance burden of the pond. Pretreatment typically involves a sediment forebay, a small pool typically about 10 percent of the volume of the permanent pool. Coarse particles stay trapped in the forebay so maintenance staff can primarily clean out the forebay, eliminating the need to dredge the entire pond.

Treatment

The treatment area, or permanent pool, helps a stormwater control remove pollutants. The purpose of most treatment design features is to increase the amount of time that stormwater remains in the pond.

One technique to increase pollutant removal in a pond is to increase the volume of the permanent pool. Typically, designers size ponds to equal the water quality volume (i.e., the volume of water treated for pollutant removal). They may consider using a larger volume to meet specific watershed objectives, such as phosphorus removal in a lake system. Regardless of the pool size, designers need to conduct a water balance analysis to ensure that enough inflow is available to maintain the permanent pool.

Another technique to increase pollutant removal is to increase the amount of time stormwater remains in the practice. To do this—and to eliminate short-circuiting—designers can create ponds with a minimum length-to-width ratio of 1.5:1 and add features (such as underwater berms) that lengthen the flow path through the pond. Similarly, a “treatment train” of several ponds in a series can slow the flow rate as well as providing redundancy.

Enhanced vegetation areas can also increase the effectiveness of wet ponds. Vegetated littoral zones (i.e., nearshore and shallow environments that receive enough sunlight to support vegetative growth) can increase vegetation uptake of pollutants and generate greater aesthetic appeal. The submerged and root zones of vegetation increase microbial activity, which can further enhance pollutant cycling and uptake. Where thermal impacts are a concern, vegetated buffers with shrubs or trees can shade (and thus cool) the pond water.

Stratification (i.e., the formation of distinct water layers) in wet ponds inhibits the mixing of water, which can create anaerobic conditions (i.e., no oxygen) near the pond bottom. This can cause sediment to release compounds such as phosphorus (Song et al., 2013). If pond stratification or phosphorus loading is a concern, designers can install a fountain or other mixing mechanism to mix the full water column and keep it aerobic.

Conveyance

A pond system should convey stormwater safely and in a manner that minimizes erosion potential. Designers should always stabilize the system's outfall to prevent scour, as well as providing an emergency spillway to safely convey water from large floods. Where thermal pollution is a concern, designers should provide shade around the channel at the pond outlet.

Maintenance

One potential maintenance concern in wet ponds is clogging of the outlet. A pond should have a non-clogging outlet such as a reverse-slope pipe or a weir outlet with a trash rack. A reverse-slope pipe draws from below the permanent pool, extending in a reverse angle up to the riser, and establishes the water elevation of the permanent pool. Because these outlets draw water from below the level of the permanent pool, floating debris is less likely to clog them. In addition, orifices should be wider than 3 inches: smaller orifices are susceptible to clogging.

Designers should incorporate features that ease maintenance of both the forebay and the main pool. A pond should have maintenance access to the forebay and a drain to draw down the pond for the more infrequent dredging of the main pond.

Landscaping

Landscaping can make a wet pond an asset to a community and can also improve its ability to remove pollutants. A vegetated buffer around the pond will protect the banks from erosion and remove some pollutants before stormwater enters the pond by overland flow. In addition, a planted littoral zone or an aquatic bench (i.e., a shallow shelf with wetland plants) around the edge can help stabilize the soil at the edge of the pond, enhances habitat and aesthetic value, and possibly provide some pollutant uptake. In all cases, designers should avoid fertilization of plants or turfgrass adjacent to the pond to limit nutrient discharge into the practice.

Design Variations

Design alternatives adapt wet ponds to various sites and account for regional constraints and opportunities.

Wet Extended Detention Pond

In concept, a wet extended detention pond combines wet ponds and dry extended detention ponds. It splits water between a permanent pool and detention storage above that pool. During storms, it detains water above the permanent pool and releases it over 12 to 48 hours. This design consumes less space but provides similar pollutant removal to a traditional wet pond.

Wet extended detention pond designs should maintain at least half the treatment volume in the permanent pool. In addition, designers need to carefully select vegetation for the extended detention zone to ensure that it can withstand both wet and dry periods.

Water Reuse Pond

Stormwater can be a valuable water resource, helping to offset the use of potable water in water-scarce regions (NASEM, 2016; Wanielista, 2007). Some designers have used wet ponds as a water source, usually for irrigation. In this case, a water balance analysis should account for the water that users will take from the pond.

Regional Adaptations

Semiarid Climates

Wet ponds are not feasible in arid climates, but may work in semiarid climates if designers give the permanent pool a supplemental water source or design the pool to vary seasonally. However, they should consider how much water the pool needs to stay permanent. For example, Saunders and Gilroy (1997) reported that a permanent pool of only 0.29 acre-feet in Austin, Texas, needed 2.6 acre-feet per year of supplemental water.

Cold Climates

Cold climates present many challenges to wet pond designers. Spring snowmelt quickly generates a large volume of water with a relatively high pollutant load. Cold winters may also cause the permanent pool or the inlet and outlet areas to freeze. In addition, high salt concentrations and sediment loads from road salting and road sanding may affect pond vegetation. If the facility receives water from roads, designers should consider planting the pond with salt-tolerant vegetation.

One option to address high pollutant loads and water volumes during spring snowmelt is the use of a seasonally operated pond to capture snowmelt during the winter and keep the permanent pool during warmer seasons. In this option, the pond has two water quality outlets, both with gate valves (Oberts, 1994; MPCA, 2019). The property owner or maintenance staff close the lower outlet during the summer and open it during the fall, and throughout the winter, to draw down the permanent pool. As the spring melt begins, they close the lower outlet again to provide extra detention volume. This method can act as a substitute for using a minimum extended detention storage volume. When wetlands preservation is a downstream objective, seasonal manipulation of pond levels may not be appropriate. Designers should analyze the effects on downstream hydrology before considering this option. In addition, the manipulation of this system requires some labor and vigilance—calling for a thorough maintenance agreement.

Several other modifications can improve the performance of ponds in cold climates, including:

- “Online” designs that allow continuous flow, which help prevent outlets from freezing.
- Outlets that are resistant to freezing. Examples include weirs or pipes with large diameters.
- Extended detention to retain usable treatment area above the permanent pool when it freezes.

Karst Topography

In karst topography, a wet pond needs an impermeable liner to prevent groundwater contamination or sinkhole formation and to help maintain the permanent pool.

Limitations

Limitations of wet ponds include the following:

- Wet pond construction can cause loss of wetlands or forest if planners choose the wrong location.
- Wet ponds are often inappropriate in dense urban areas because each pond generally needs a large continuous area.
  - The need to supplement the permanent pool restricts wet ponds’ use in arid and semiarid regions.
  - In cold water streams, wet ponds are not feasible due to the potential for stream warming.
  - Wet ponds may pose safety hazards.
- If ponds are too deep and they stratify, they risk mobilizing and exporting dissolved phosphorus.

Maintenance Considerations

Though design features can minimize their maintenance needs, wet ponds still need regular maintenance and inspection. Table 1 outlines these practices. (Note that designers may need to adjust the listed frequencies based on local climate, activities in the drainage area, and community.)

Table 1. Typical maintenance activities for wet ponds. Q24

Frequency	Inspection Items	Maintenance Actions
Once, after the first year	▪ Check for 50% plant survival in the littoral zone ▪ Check for invasive plants	▪ Replant vegetation as necessary ▪ Remove invasive plants
Monthly to quarterly, or after major storms	▪ Inspect orifices and pipes for clogging ▪ Check shoreline, inflows and discharges for erosion ▪ Check for floating debris	▪ Mow ▪ Remove debris ▪ Repair eroded areas, replant bare soil

Frequency	Inspection Items	Maintenance Actions
Semiannual to annual	■ Monitor wetland plant composition and health ■ Ensure mechanical components are functional	■ Clean up trash and debris ■ Remove invasive plants ■ Harvest wetland plants that are overgrown ■ Repair broken mechanical components
Every 1–3 years	■ Inspect all mechanical components, including pipes and risers ■ Monitor sediment deposition in facility and forebay	■ Repair broken mechanical components ■ Remove sediment from facility and forebay if needed

Source: Adapted from U.S. EPA, 2009

Effectiveness

Structural stormwater management, in general, is a way to pursue four broad resource protection goals: flood control, channel protection, groundwater recharge and pollutant removal. Wet ponds can provide flood control, channel protection and pollutant removal.

Flood Control

One objective of stormwater controls can be to reduce the flood hazard associated with large storms by reducing peak flow from these storms. Designers can easily customize a wet pond for flood control by providing flood storage above the level of the permanent pool.

Channel Protection

One result of urbanization is the landscape/geomorphic changes—such as eroded stream channels—that occur in response to modified hydrology. Traditionally, wet pond basins have provided control of the 2-year storm for channel protection. However, it appears that this control has been relatively ineffective for channel protection, and research suggests that control of a smaller storm, such as the 1-year storm, might be more appropriate (MacRae, 1996; Tillinghast et al., 2011). Most current regulations therefore require that channel protection features provide control of the 1-year storm event (e.g., MDE, 2009).

Groundwater Recharge

Wet ponds can only provide groundwater recharge in limited cases, and in soils with high infiltration rates. Generally, the buildup of debris at the bottom of the pond limits infiltration rates.

Pollutant Removal

Wet ponds can be very effective at removing stormwater pollutants, particularly those associated with settleable solids. A wide range of research is available to estimate the effectiveness of wet ponds. Table 2 summarizes pollutant removal data from a database of stormwater control performance (Clary et al., 2017).

Table 2. Typical pollutant removal rates of wet ponds.

Pollutant	Influent Concentration (Median)	Effluent Concentration (Median)
Total copper (µg/L)	8.24	4.00
Total zinc (µg/L)	22.60	12.00
Total suspended solids (mg/l)	38.9	12.0
Total nitrogen (mg/L)	1.50	1.31
Nitrate (mg/L)	0.45	0.22
Total phosphorus (mg/L)	0.18	0.10
E. coli (most probable number/100 mL)	780	180

Source: Adapted from Clary et al., 2017

Cost Considerations[1]

The construction costs associated with wet ponds can vary considerably. King and Hagan (2011) estimate that the construction cost of a wet pond can range from $35,000 to $75,000 per acre of impervious surface treated.

Ponds do not take up a large area relative to the drainage size of the watershed: typically 1–3 percent of the contributing drainage area (MPCA, 2019). They are still large, though, and they need a relatively large contiguous area. Other practices, such as filters or swales, may be better suited for small areas.

King and Hagan (2011) estimates the typical annual cost of routine maintenance for wet ponds at about 3 percent of the construction cost. Alternatively, a community can estimate the cost of the maintenance activities outlined in the "Maintenance Considerations" section. Ponds are long-lived (typically lasting longer than 20 years): a community can consider its initial investment in light of this long life span.

Additional Information

Additional information on related practices and the Phase II MS4 program can be found at EPA's National Menu of Best Management Practices (BMPs) for Stormwater website

References

Clary, J., Jones, J., Leisenring, M. Hobson, P., & Strecker. E. (2017). *International Stormwater BMP Database: 2016 summary statistics*. Alexandria, VA: Water Environment & Reuse Foundation.

Jones, M. P. (2008). *Effect of urban stormwater BMPs on runoff temperature in trout sensitive regions* (Doctoral thesis, North Carolina State University).

King, H., & Hagan, P. (2011). *Costs of stormwater management practices in Maryland counties*. University of Maryland Center for Environmental Science.

MacRae, C. (1996). Experience from morphological research on Canadian streams: Is control of the two-year frequency runoff event the best basis for stream channel protection? In L. Roesner (Ed.), *Effects of watershed development and management on aquatic ecosystems* (pp. 144–162). Snowbird, UT: American Society of Civil Engineers.

Maryland Department of the Environment (MDE). (2009). *2000 Maryland stormwater design manual Volumes I & II*.

Minnesota Pollution Control Agency (MPCA). (2019). Design criteria for stormwater ponds. In *Minnesota stormwater manual*.

National Academies of Sciences, Engineering, and Medicine (NASEM). (2016). *Using graywater and stormwater to enhance local water supplies: An assessment of risks, costs, and benefits*. Washington, DC: National Academies Press.

[1] Prices updated to 2019 dollars. Inflation data obtained from the Bureau of Labor Statistics CPI Inflation Calculator website: https://data.bls.gov/cgi-bin/cpicalc.pl.

New Jersey Department of Environmental Protection (NJDEP). (2014). *New Jersey stormwater best management practices manual*.

Oberts, G. L. (1994). Performance of stormwater ponds and wetlands in winter. *Watershed Protection Techniques, 1*(2), 64–68.

Saunders, G., & Gilroy, M. (1997). Treatment of nonpoint source pollution with wetland/aquatic ecosystem best management practices. Austin, TX: Texas Water Development Board.

Song, K., Xenopoulos, M. A., Buttle, J. M., Marsalek, J., Wagner, N. D., Pick, F. R., & Frost, P. C. (2013). Thermal stratification patterns in urban ponds and their relationships with vertical nutrient gradients. *Journal of Environmental Management, 127*, 317–323.

Tillinghast, E. D., Hunt, W. F., & Jennings, G. D. (2011). Stormwater control measure (SCM) design standards to limit stream erosion for Piedmont North Carolina. *Journal of Hydrology*, *411*(3–4), 185–196.

U.S. Environmental Protection Agency (EPA). (2009). *Stormwater wet pond and wetland management guidebook*.

Wanielista, M. P. (2007). Stormwater—an alternative water supply. In K. C. Kebbes (Ed.), *World Environmental and Water Resources Congress 2007: Restoring our natural habitat* (pp. 1–14). Tampa, FL: American Society of Civil Engineers.